**Transport investment and housing development**

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**ABSTRACT**

Transport policy and investments shape how cities and regions grow. Major projects like the London Underground, the US interstate highway system, and, locally, the Auckland Harbour Bridge have shaped urban growth.

Transport improvements also influence opportunities for housing development and, in doing so, can influence the price and availability of housing in growing cities. These effects are widely discussed but they are seldom fully considered when developing projects and programmes.

This paper investigates how to analyse and value the impact of transport investment on housing development, taking into account the price and quantity of housing that is supplied.

Housing and land markets are characterised by various constraints that make it difficult to supply new housing in response to increased demand, such as the differentiated nature of land, persistence in development patterns, and barriers arising from land use regulations and a lack of infrastructure servicing. This drives up prices for housing and urban land above the ‘fundamentals’.

Transport investments (or technology changes) that reduce transport costs can improve the functioning of housing development markets by increasing the substitutability between different sites and thus increasing the competitive pressure that landowners experience. Transport improvements can therefore indirectly affect housing prices as well as the shape and size of cities.

Although this creates the potential for wider benefits related to unlocking housing development, existing land use-transport interaction models are poorly suited to capturing these effects. A survey of these models reveals that they typically neglect competitive dynamics in housing development.

To conclude, this paper outlines a potential approach for modelling and valuing the impacts of transport investment on housing development. This approach builds upon a well-understood conceptual framework and can be applied in conjunction with existing strategic transport models. Requirements for estimating and implementing this model are discussed.

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1. **Introduction**

Transport policy and investments shape how cities and regions grow. Major projects like the London Underground, the US interstate highway system, and, locally, the Auckland Harbour Bridge have shaped urban growth (Heblich, Redding, and Sturm, 2018; Duranton and Turner, 2012; Grimes, 2011). The effects can last decades or even millennia, as shown by the impact of Roman roads on present-day regional development in Europe (Dalgaard et al, 2018).

Today, policymakers are increasingly concerned about New Zealand’s challenges with housing affordability and looking for evidence on how transport investment can help to address this problem. However, we lack methods for predicting impacts on housing development or valuing the resulting benefits (or disbenefits).[[1]](#footnote-1)

There are several reasons why it is desirable to assess these impacts. First, doing so may help inform strategic planning and investment prioritisation. For instance, a project that is expected to have large benefits for housing development may be preferred over a similar project that does not deliver those benefits. Second, assessing these impacts may assist in designing complementary land use policies, such as rezoning of areas to enable housing development.

This research paper therefore examines how to model and value the impacts of transport investment on housing development. It argues that:

* Housing development markets are characterised by imperfect competition due to various factors that constrain the supply of new housing to meet demand (Section 2)
* Transport investments can affect local housing demand, as increased accessibility makes areas more attractive for residents, and local supply dynamics, as increased accessibility can place landowners under greater competitive pressure (Section 3)
* As a result, major transport investments can generate wider economic benefits in housing development (Section 4)
* Existing land use-transport interaction models are ill-suited to capture these benefits, as they typically assume that housing development is perfectly competitive or that transport improvements cannot affect housing supply dynamics (Section 5).

To conclude, this paper sketches out a modelling approach that could be used to capture and value the wider benefits of transport investment for housing development (Section 6).

1. **Characteristics of housing development markets**
   1. ***Market imperfections in housing development***

‘Housing development’ is the process of constructing new residential buildings, either by infilling or redeveloping existing sites or by building on new sites created by subdivision of large greenfield or brownfield sites.[[2]](#footnote-2) In New Zealand, most new housing is developed by private companies and sold to individual buyers or rental property investors.

Housing developers use a mix of inputs, including land, infrastructure services (eg water, wastewater, and roads), construction materials and services, and financing. They also must interact with land use and building regulations, which are governed by national legislation (the Resource Management Act and Building Act) and implemented by local governments.

Housing development is characterised by a number of market imperfections that constrain the supply of new homes to meet demand and in doing so drive up the price of housing. The following table summarises five underlying reasons why housing development markets are not perfectly competitive.[[3]](#footnote-3) These exacerbate the impact of demand ‘shocks’ such as rapid migration inflows.[[4]](#footnote-4)

**Table 1: Reasons why housing development markets are imperfectly competitive**

|  |  |
| --- | --- |
| **Cause** | **Explanation** |
| Market power in land markets | Land in each location is only available in a fixed quantity and different locations are imperfect substitutes for each other.[[5]](#footnote-5) Different sites have different underlying geology and different levels of access to amenities, employment opportunities, and so on and so forth.  Landowners in any given location can exercise market power over people seeking to buy and use land. Land prices tend to be higher near localised amenities like beaches and closer to employment opportunities. |
| Persistence in subdivision patterns | After land is initially subdivided for urban use, it tends to be very costly and difficult to amalgamate or re-subdivide it to serve changing demands. Subdivision is a ‘putty-clay’ problem – lot sizes and shapes are highly malleable at the outset, but rigid and hard to change at later dates.  Amalgamating or re-subdividing sites is difficult due to the costs associated with negotiating with multiple neighbouring landowners and the risk of hold-ups if some neighbours are unwilling to sell. As a result, it is rare in practice, even after major disasters that clear away existing buildings (Fredrickson, Fergusson and Wildish, 2016; Hornbeck and Keniston, 2017). |
| Durable housing | Buildings are durable. While different parts of buildings wear out at different rates, the underlying structures may have a usable life of decades or even centuries if they are well maintained (Brand, 1995). This can slow redevelopment of sites, as landowners may be reluctant to scrap existing assets with remaining value. However, existing buildings can also serve changing demands through renovation or redesign.  The durable nature of buildings affects the functioning of declining housing markets (Glaeser and Gyourko, 2018). A city with a falling population does not experience an immediate drop in its stock of housing, leading to high vacancy rates and prices that fall significantly below replacement costs. |
| Monopoly provision of development infrastructure | Housing development must be served by infrastructure, including water, wastewater, road access, and electricity and power. While developers provide on-site infrastructure, they depend on network infrastructure providers for connections. Monopolistic behaviour or inefficient pricing of infrastructure services can therefore constrain housing development or push up its cost.  Effective competition regulation can prevent monopoly infrastructure providers from charging prices significantly higher than the cost of providing services or restricting access to networks. |
| Land use regulations | Housing development is regulated by local and central government through building codes (which set standards for new construction), zoning codes / district plans (which define what land can be used for and how intensely it can be developed), and environmental regulations (such as restrictions on wastewater outflows into sensitive marine areas).  In New Zealand, district plans commonly limit how intensively sites can be developed or redeveloped, via building height limits, minimum lot sizes, and requirements to provide land-intensive features like carparking. They also limit the extent of new subdivision, often to manage the costs that councils bear to provide new development infrastructure.  There is evidence that the costs of some rules outweigh the benefits they provide (Nunns and Denne, 2016) and that overly restrictive land use regulations can reduce the responsiveness of new housing development to increased demand (Gyourko and Molloy, 2015). |

* 1. ***Empirical estimates of housing development market imperfections***

Economists commonly use price-cost margins (PCMs) to measure the degree of imperfect competition in markets (Stevens, 2011). The intuition behind this measure is that businesses should not be able to charge prices that are significantly higher than their underlying costs of production unless they benefit from market power or barriers to competitors entering the market (Cheshire and Hilber, 2008). PCMs can reflect the aggregate impact of multiple constraints and hence may not provide specific evidence on what specific features of markets limit competition.

A number of recent studies have measured PCMs in housing and land markets in New Zealand (Grimes and Liang, 2009; MBIE, 2017; Lees, 2019; Nunns, 2018). Table 1 summarises price-cost margins for urban residential land in New Zealand cities, based on measured discontinuities in land values at rural-urban zoning boundaries (MBIE, 2017). These reflect the aggregate impact of regulatory and non-regulatory constraints to infill and redevelopment of existing sites and to new subdivision at the edge of cities.

PCMs in residential land markets are large relative to PCMs observed in other areas of the New Zealand economy. Residential land prices at the edge of Auckland and Queenstown appear to be roughly three times as high as the underlying cost to develop new land. In other cities markups range from 30% to 140%.[[6]](#footnote-6)

By comparison, Stevens (2011) uses firm-level data for 2000-2007 to estimate that PCMs in most ANZSIC industries are less than 15%. PCMs only rise above 30% in capital-intensive sectors like water transport and air transport. This indicates that urban housing development is much less competitive than the rest of the New Zealand economy.

**Table 1: Land value discontinuities at selected rural-urban zoning boundaries (2017)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Urban area** | **Price-cost margin** | **Difference ($/m2)** | **Difference ($/600m2 section)** |
| Auckland | 215% | $345 | $206,700 |
| Christchurch | 123% | $150 | $90,100 |
| Dunedin | 29% | $38 | $22,500 |
| Hamilton | 142% | $227 | $136,200 |
| New Plymouth | 61% | $92 | $55,100 |
| Palmerston North | 57% | $73 | $43,900 |
| Queenstown | 212% | $337 | $202,500 |
| Tauranga | 102% | $232 | $139,100 |
| Wellington | 130% | $201 | $120,400 |
| Whangarei | 100% | $80 | $48,100 |

*Source:* [*http://urban-development-capacity.mbie.govt.nz/*](http://urban-development-capacity.mbie.govt.nz/)*. Price-cost margins calculated as the ratio of land prices inside and outside boundaries, minus 1.*

PCMs in urban housing markets can reduce overall wellbeing. Because housing prices are high, some people consume less housing than would be optimal for them or live in less desirable places. This in turn leads to various other social and economic costs, such as the health impacts of living in overcrowded or substandard housing, the economic costs of discouraging people from living in productive cities with high housing costs, and traffic congestion caused by excess urban sprawl.

1. **Transport and housing markets**
   1. ***Supply and demand dynamics***

Transport investments can have two different effects on housing and land markets. They can affect *demand* for housing in particular places. This can be due to improved transport access that makes areas more attractive (Heblich, Redding, and Sturm, 2018; Garcia-López, 2012; Baum-Snow, 2007, 2010; Duranton and Turner, 2012; Grimes, 2011), or noise and severance that makes them less attractive (Brinkman and Lin, 2017). In New Zealand cities, better transport access by both car and public transport increases the density of development and the volume of commuting flows between locations (Nunns, 2019).

Transport investments can also affect the conditions under which housing is *supplied* in different places. Improving access can increase the substitutability between alternative sites, thereby reducing the market power held by landowners in a particular location (Homans and Marshall, 2008). For instance, a project that increases the speed of public transport to the city centre might make further-out locations a better substitute for inner-city areas. The impact of this will generally be to *flatten* the land-price gradient around desirable amenities.

The following supply and demand diagrams show the impact of considering one or both of these dynamics. Panel A shows the impact of transport improvements that shift local demand for housing by making some places relatively more accessible and hence desirable. In the context of an upwards-sloping local supply curve for housing, an increase in local housing demand translates into higher house prices as well as greater density.[[7]](#footnote-7)

Panel B illustrates a case in which transport improvements simultaneously shift local demand for housing, by making some places relatively more accessible, and shift local housing supply dynamics, by making alternative development locations more substitutable and hence increasing competition between them. In this context, an increase in local housing demand can be satisfied without increasing prices as much.[[8]](#footnote-8)

***Figure 1: A simple model of local housing supply and demand dynamics***

|  |  |
| --- | --- |
| *Panel A: Transport improvements that only shift local demand for housing* | *Panel B: Transport improvements that shift local demand for housing and shift local housing supply dynamics* |

* 1. ***Transport access is necessary but not sufficient***

While transport access is important, other factors also influence whether housing will actually be developed.

First, there must be some underlying, unmet demand for new housing, either overall or in a specific sub-market. Building new transport infrastructure in cities (or neighbourhoods) that are declining economically or losing population is unlikely to encourage more housing development, as these housing markets are already ‘slack’.

Second, the rate of new housing development in a newly accessible area will also depend upon constraints to housing development. The market imperfections identified above – landowners’ market power, persistence in subdivision patterns, durable housing, monopoly provision of development infrastructure, and land use regulations – may slow new development.[[9]](#footnote-9) If these constraints are totally binding, transport improvements will have no impact on housing development as no further development *can* occur. Happily, this is not generally the case.

Transport improvements may be coupled with land use policies that ease constraints to developing new housing in newly accessible areas, such as rezoning of newly accessible areas for subdivision or higher-density redevelopment. These decisions may be so closely linked that it is difficult to assess them separately. However, where they are not tightly linked impacts on housing development cannot be fully attributed to the transport improvements.

* 1. ***City size may change as a result of improvements to housing supply***

All else equal, increasing the supply of housing and reducing its price will affect the spatial equilibrium of population distribution between urban and rural areas, between different cities, and potentially between New Zealand and other countries (Glaeser, 2008).

A number of recent papers use spatial equilibrium models to simulate the impact of loosening restrictions on development, mainly in the US (Hsieh and Moretti, 2019; Glaeser and Gyourko, 2018; Ganong and Shoag, 2017; de Groot, Marlet, Teulings, and Vermuelen, 2015). Nunns (2018) recently undertook a similar exercise for New Zealand regions.

The general finding from this literature is that increasing housing supply will increase economic output and increase aggregate wellbeing. This reflects the fact that more people can access and take advantage of larger labour markets, which tend to be more productive and thus support higher incomes.[[10]](#footnote-10)

1. **Housing development impacts as a WEB?**

Conventional transport appraisal focuses on assessing the impact of transport improvements on the user costs of transport, meaning the time, money, and inconvenience that people must incur to travel. Reducing transport user costs increases the consumer surplus that people enjoy from travelling, as they are able to achieve the benefit of reaching their destination at a lower cost.[[11]](#footnote-11)

If all related markets, such as labour markets that people access by commuting, are functioning efficiently, then transport user cost savings are equivalent to total social benefits (Boardman et al, 2011). However, transport markets and related markets are rife with externalities and other market imperfections, ranging from unpriced traffic congestion impacts to air quality impacts to taxes on labour income to agglomeration externalities in production. This creates the potential for additional (positive or negative) effects to arise from changes in transport behaviours. In transport appraisal, these impacts are described as wider economic benefits, or WEBs.

New Zealand’s transport appraisal procedures address three WEBs that arise in the labour market.[[12]](#footnote-12) Following UK WebTAG guidance, Kernohan and Rognlien (2011) describe the theory and evidence underpinning these benefits. They also identify the potential for WEBs resulting from transport improvements that increase the level of competition in the economy:

*Increasing the levels of competition in an economy therefore produces an additional economic benefit by pushing the economy toward its optimum position and reducing the overall deadweight loss to society by increasing output and reducing price, and eroding market power from monopoly, oligopoly and other forms of market failure.*

*If a price cost margin exists […] there is also potential for a project to improve the level of competition in the economy by reducing the magnitude of the price cost margin and directly increase welfare.*

Kernohan and Rognlien do not recommend valuing increased competition benefits due to the fact that price-cost markups are low in New Zealand industries, indicating a reasonable level of competition (Stevens, 2011). However, previous sections outline a case for valuing increased competition benefits in housing development markets. This is because:

1. Housing development markets are imperfectly competitive, as shown by large price-cost markups for urban land and housing that indicate the presence of various barriers to development and redevelopment of land.
2. Major transport investments can increase the substitutability between different locations. This can increase the competitive pressure facing individual landowners and help overcome localised constraints to developing more housing, ranging from existing subdivision patterns to restrictive land use regulations.

To value these impacts it is necessary to model the relationship between transport investment and housing development. The next section therefore reviews existing modelling practice.

1. **Review of existing land use-transport interaction models**

This review focuses on how these models address competitive dynamics in housing development and land markets, and how they address redistribution of growth between cities/regions as well as within them. It considers four broad categories of models: urban economics models, spatial equilibrium models, LUTI models built on four-step transport models, and spatial computable general equilibrium models.

* 1. ***Urban economics models***

The Alonso-Muth-Mills (AMM) model is a standard urban economics model that describes equilibrium location of households within a city. It shows that the house price gradient can be described as a function of transport costs to jobs (and/or consumption amenities). Reduced transport costs therefore affect average housing costs and the location of residents.

Glaeser (2008) describes the basic AMM model and several permutations. In its simplest version, the city is assumed to consist of a population of homogenous workers that all commute to a single central business district (CBD) and earn wage W. Commuting costs t(d) are an increasing function of distance d to the CBD (ie ). Workers rent L units of land from an absentee landlord, paying rents r(d) that vary by distance to the CBD. Workers choose a location d that maximises the utility that they derive from consuming land L and other consumption goods, ie U(W-t(d)-r(d)L, L).



In equilibrium, all workers must be indifferent between staying in their current location and moving to another location instead. Rents adjust to satisfy this condition. The first order condition for utility maximisation is therefore that the rent gradient is a function of the transport cost gradient, ie . This implies in turn that rents fall with distance to the CBD. A corollary is that a reduction in transport costs will reduce the rate at which rents fall with distance. The spatial extent of the city is determined by the point at which r(d) is equal to agricultural land rents ra. This also means that a reduction in transport costs will increase the spatial extent of the city.



Two variants of this model address interactions with the rest of the world differently. In the ‘closed city’ variant, city size is fixed, meaning that reduced transport costs flow through into lower housing costs and higher levels of utility for city population. In the ‘open city’ variant, city size is not fixed, and reduced transport costs attract more people to live in the city, which in turn increases rents and leaves utility levels unchanged.

The basic AMM model can be extended in various ways. Glaeser (2008) includes a housing development sector into the model, which allows population density to vary between locations. Kulish, Richards, and Gillitzer (2011) and Lees (2014) use this model to assess the impact of different planning policies, such as restrictions on building height or urban growth boundaries that limit city size. Venables (2017) expands the AMM model to account for trade between multiple cities and local production sectors that enjoy local agglomeration economies and which can specialise in specific tasks. He uses this model to understand potential wider economic benefits of transport improvements that reduce commuting costs within cities or reduce transport costs between cities. Hazledine, Donovan and Mak (2017) use a variant of Venables’ approach to analyse wider economic benefits from reductions in commuting costs to central business districts.

Anas and Xu (1999) and Lucas and Rossi-Hansberg (2002) generalise the AMM model to account for the fact that jobs can locate outside of the CBD. They make different assumptions about the production sector and household utility. Anas and Xu assume that firms located in different places each produce a unique good, and that consumers live in one location and travel to all other locations a non-zero number of times to sample the goods in all locations. Consumers have idiosyncratic tastes, meaning that different people will exhibit different travel patterns. By contrast, Lucas and Rossi-Hansberg model a production sector that produces a single undifferentiated product but which enjoys agglomeration economies, ie firms are more productive when they locate near larger concentrations of other firms.

* 1. ***Spatial equilibrium models***

Spatial equilibrium models are calibrated off observed data on people’s choice of home and work location, in particular commuting flow data. People are assumed to choose home and work locations to maximise their utility, taking into account job opportunities (and other amenities) available at destinations, housing options (and other amenities) at home locations, and the cost of travelling between these locations. Observed commuting flows are assumed to represent a spatial equilibrium outcome, in which everybody has chosen the location that works best for them.

These models can be used to analyse how changes to transport costs or the availability of transport infrastructure can affect the equilibrium distribution of population and employment. They can also be used to estimate the net welfare impacts of transport improvements, taking into account the potential for land use changes. However, it is necessary to run them iteratively with transport models to capture feedback between increased commuting flows and traffic congestion.

Several recent papers illustrate the estimation and application of spatial equilibrium models. Mulalic, Pilegaard and Rouwendal (2015) estimate a discrete choice model of working households’ choice of residential location and car ownership using Danish administrative data. This model accounts for the impact of access to jobs by car and public transport on households’ choice of residential location and car ownership. They use it to estimate the impact of the Copenhagen metro expansion on land use and car ownership outcomes.

Mulalic et al observe that the net outcomes for residential population changes depend upon the elasticity of housing supply, and model two alternative scenarios. In the first, an arbitrarily large quantity of new housing can be supplied at the same cost as existing housing, and hence everyone can relocate freely. In the second, housing supply is totally inelastic, and hence relative house prices must adjust to fully offset any increases in the attractiveness of some areas. They find that welfare gains tend to be lower in the latter scenario.

Brinkman (2016) calibrates a spatial equilibrium model of Columbus, Ohio using land price data and Census employment, population and commuting data. This model is closely related to Lucas and Rossi-Hansberg (2002), but includes both congestion and agglomeration externalities. Brinkman simulates the impact of a congestion toll on equilibrium land use, land prices, and net economic outcomes, finding that foregone agglomeration benefits offsets decongestion benefits.

Donovan (2017) estimates a spatial equilibrium model using commuting flow data between suburbs in Brisbane, Australia, focusing on the impact of walking and cycling time on people’s location choices. He finds that a one-minute saving on a 15-minute journey causes a 3-6 percent increase in commuting flows between affected locations. Nunns (2019) undertakes a similar analysis using commuting flow data for Auckland and Wellington, focusing on the impact of public transport journey times. Both papers account for amenities at home and work locations using suburb- or area-specific fixed effects that capture the impact of local amenities, wages, and house prices and which do not change if people’s location choices change. This is equivalent to the assumption, stated explicitly by Mulalic et al (2015), that housing supply is infinitely elastic.

Teulings, Ossokina and de Groot (2018) estimate a system of equations that defines equilibrium outcomes residential and work location and commuting mode, using household travel survey data, worker microdata, and house sales data for Amsterdam, Netherlands. They use the model to estimate the impact of rail tunnels that connect Amsterdam and its northern suburbs on location choices and welfare for workers with different education levels. They find that the rail tunnels have the largest benefits for high skilled individuals, as they have the highest preference for commuting by train and the most to gain from being able to commute to jobs in central Amsterdam.

Land rents and housing supply also adjust. There is a fixed supply of land in each location, but it can be (re)developed flexibly at any density to meet demand. Housing developers are perfectly competitive and can build additional housing under constant returns to scale, while competition among landowners results in a price that equates demand for land in each location with the available supply. The result is that the price of housing is equal to the cost of production.

Severn (2019) estimates a spatial equilibrium model of residential and employment location using 1990 and 2000 commuting flow data between Census tracts for Los Angeles, California. He then calculates the annual consumer welfare benefits of the Los Angeles Metro, taking into account changes in location choices. He estimates welfare impacts under either a ‘closed city’ or ‘open city’ assumption, as in the Alonso-Muth-Mills model. In the former scenario, Los Angeles residents’ welfare increases, and in the latter, utility levels are equalised but city population increases.

In Severn’s model, housing developers are perfectly competitive, ie selling new housing at marginal cost, but the price of land at each location is affected by frictions due to topography and regulation that push up costs. This results in increased prices in response to increased demand, which in turn dissuades some people from moving into those areas. However, transport improvements do not influence local housing supply conditions.

* 1. ***Land use-transport interaction models***

Land use-transport interaction (LUTI) models typically extend existing strategic transport forecasting models. Strategic transport models involve four iterative steps (trip generation, distribution, mode choice, route choice) that sequentially converge to equilibrium. The future location of residential population and employment within the city is treated as exogenous. LUTI models extend this by iteratively allowing population and employment to respond to changing transport access and then re-running the transport model (Department for Transport, 2014).

Lopes et al (2018) review the workings of eight LUTI models.[[13]](#footnote-13) They observe that although models often represent land use as one single system, land use actually covers two distinct aspects: location choices of households, firms, and other actors (ie how local housing demand is affected by improved access) and changing intensity of development in different places (ie housing supply).

Some models do not explicitly address housing development, but others formally model housing development and may capture constraints arising from durable buildings or land use regulations. Where land use regulations are addressed, they are typically treated as exogenous constraints that limit the amount of housing that can be supplied in a given location by perfectly competitive developers. In this setting, changing transport access therefore affects demand for housing in different locations, but not developers’ ability to respond to demand.

LUTI models often to make simplifying assumptions about housing development and land markets. For instance, Safirova et al (2006) develop a LUTI model to simulate the impacts of congestion pricing in Washington DC, including impacts on the location of population and employment growth and rents in different locations. Safirova et al’s model treats housing development similarly to Anas and Xu (1999). Developers choose whether or not to build new housing based on expected future rents relative to costs. They are assumed to operate under perfect competition, without barriers to redeveloping sites, and hence there is no potential for price-cost markups.

Kim (2019) outlines a LUTI model that was developed for Munich, Germany. This is based on a modelling process developed by Moeckel (2011) in which households balance expenditures on housing and transport against a fixed budget, and also balance travel time. Housing developers respond to the resulting demands. Kim describes the application of this model to new housing development and transport infrastructure to the north of Munich, which is intended to help alleviate a housing shortage. However, the outcomes described by the model appear to largely focus on the location of households, rather than the price of housing.

* 1. ***Spatial computable general equilibrium models***

Spatial computable general equilibrium (SCGE) models simulate the economic impacts of transport improvements. To do so, they extend economic models of interactions between different industries, the household sector (which supplies labour and consumes goods), and international trade, adding a spatial dimension to firm activity and incorporating transport costs for freight and commuting.

SCGE models allow economic activity to redistribute throughout space and allow the overall size of the economy to increase. Depending upon the model, this may reflect agglomeration benefits that arise in larger, denser cities or the impacts of changes to firms’ investment decisions. These models focus on predicting overall impacts for economic output (Simmonds and Feldman, 2013).

Byett et al (2017) develop an SCGE model for New Zealand and apply it to a hypothetical case study of a major transport improvement in the Auckland-Hamilton-Tauranga area. This model is reasonably aggregated: it includes four large residential and work zones (Auckland, Hamilton, Tauranga and the rest of Waikato) and four port zones (Auckland Airport, Port of Auckland, Port of Tauranga and Other New Zealand). Firms and households can relocate between zones, but the total regional population is fixed. The overall quantity of land within each zone is fixed, and land and housing prices within each zone can adjust in response to changing demands. Like other economic sectors, housing development is assumed to function competitively.

* 1. ***How these models address competition in housing development***

When these models address housing development, they assume that development markets are perfectly competitive, meaning that housing is sold or rented at a price equal to the marginal cost of production. Similarly, landowners are modelled as price-takers – they accept whatever rents are on offer, as long as they are above some ‘reservation’ level set by agricultural land rents.

As a result, these models do not address the possibility for PCMs for housing or urban land. Land prices are higher in some locations, but this simply reflects the capitalised value of better transport access, or other localised factors that affect prices such as local geography and climate.

Market imperfections arising from land use regulation can be incorporated as an exogenous ‘cap’ on development (Kulish, Richards and Gillitzer, 2011; Lees, 2014), or as land costs or development costs that rise with density of development (Severn, 2019). These reflect ad hoc treatments of market imperfections, rather than formal modelling of deviations from perfect competition. These models may not be able to capture the impact of transport investment on PCMs for housing or land without additional exogenous adjustments, such as relaxing land use policies.

* 1. ***How these models address inter-regional redistribution of population***

Some models can account for inter-regional impacts of local transport improvements. For instance, the ‘open city’ variant of the AMM model allows city size to increase in response to a transport improvement. Severn (2019) builds upon the same approach, considering an ‘open city’ scenario following the AMM spatial equilibrium concept. The same approach could be implemented in the context of other spatial equilibrium models or LUTI models, with some adjustment.

A limitation of the AMM ‘open city’ approach is that city residents’ utility is equalised relative to an outside ‘reservation’ location. In the model, transport improvements or reduced house prices can increase city size but only if they do not affect overall levels of wellbeing. For major projects in large cities, this is likely to be unrealistic. It could be addressed by modelling a full system of cities, as in Hsieh and Moretti (2019) or related models, and allowing average utility levels across all cities to change in response to changes in a single location.

SCGE models adopt a different approach. In this model, the size of cities’ population and economic output changes in response to better inter-regional or within-city connectivity as well as flow-on impacts on business investment decisions.

1. **Proposal for a new modelling approach**

A well-known Irish joke involves a lost traveller asking a farmer for directions to a certain village. The farmer thinks for a moment and then says “If you want to get there, I wouldn't start here.”

Modelling the wider economic benefits that transport investment generates in housing development markets appears to be a similar case. Attempts to investigate this question typically start with land use-transport interaction models that are ill-suited for the task of predicting changes to the competitive dynamics of housing development and urban land markets, as they generally assume that these markets are perfectly competitive.

This paper therefore proposes an approach to modelling land use-transport interactions that is capable of addressing the potential for improved competition in housing development markets. This approach builds upon the spatial equilibrium models discussed in the literature review, as well as a separate review of industrial organisation models of imperfect competition.

The proposed model starts with a reasonably well-established approach for estimating how household location choice responds to changes in transport costs between origin and destination locations. It then extends this model to capture local housing supply and demand dynamics. The household location choice element of this model builds upon Nunns (2019) as well as the wider literature. Modelling of local housing supply dynamics is related to Severn’s (2019) model of the impacts of the Los Angeles Metro, with extensions to capture the potential for increased competition between developers in alternative locations.

* 1. ***Household location choice***

Each individual *i* is assumed to choose home location *j* and work location *k* to maximise their utility, as in the following equation. *Uj* and *Wk* denote the utility derived from living in location *j* and working in location *k*, respectively, and *GCjk* represents the average generalised cost (ie time, money, and perceived inconvenience) of commuting from *j* to *k*, summing across all transport modes. is an error term. is a coefficient to be estimated that reflects the disutility associated with increased commuting costs.



***Equation 1: Utility maximisation via location and transport mode choice***



Assuming that is independent and identically distributed and that it follows an extreme value distribution, the probability that individual i chooses locations j and k can be written as follows.



***Equation 2: Probability of travelling between origin and destination by a given mode***



By extension, the following formula estimates the number of people who are travelling between home location j and work location k (Njk).

***Equation 3: Number of people travelling between origin and destination***



***Equation 3*** can be estimated using a Poisson regression model. An important note is that *Uj* and *Wk*, which measure the utility that people derive from given home and work locations, are treated as fixed effects in this equation – that is, a series of home and work location constants are estimated. Explaining why some locations deliver higher (or lower) levels of utility can be addressed through extensions to this model.

* 1. ***Local housing demand***

Local housing demand is a function of local house prices (or rents) as well as transport accessibility. It is also likely to reflect the availability of other localised amenities, such as parks, schools, or beaches. To capture this effect, *Uj* is parameterised as a function of local house prices (Pj) and a vector of other measurable amenities (Xj). and are coefficients to be estimated, and ej is an error term.



***Equation 4: Modelling the utility of living in zone j***



For current purposes, the Xj term can be disregarded as including it does not influence the main model results. While it is possible to measure Pj using data on average rents or average house prices, it is preferable to construct a quality-adjusted measure of house prices in each zone to avoid the need to include controls for housing quality. This can be done using results from a hedonic model of house prices.

***Equation 4*** can be substituted back into ***Equation 3*** to obtain a household location choice function that depends upon both local house prices and transport access. This serves as a model of local housing demand.

***Equation 5: Expanded household location choice function***



Summing up ***Equation 5*** across all work destinations (ie ) and partially differentiating with respect to house prices and transport costs gives the following elasticities of housing demand. As coefficients and are both expected to be negative, this implies that higher prices or higher transport costs reduce the number of people who would choose to live in a given location.



***Equation 6: Elasticities of local housing demand***



* 1. ***Local housing supply***

The housing supply model described by Severn (2019) can be adapted to address the potential for transport investments to increase competition in development markets. This assumes that housing supply involves both housing developers, who face a perfectly competitive environment, and landowners, who operate in an imperfectly competitive environment that enables them to set prices (Martinez and Roy, 2004).

Housing developers produce housing in model zone j (quantity of housing produced = Hj) using land (Lj) and construction inputs (M) according to a Cobb-Douglas production technology, where is the land share in housing production and is a zone-specific productivity factor.



***Equation 7: Housing production function***



Developers sell housing at price Pj to maximise profit , taking into account the zone-specific price of land () and the price of construction inputs (PM), which is assumed to be equal across locations. Due to competition in housing development, economic profits for developers are driven down to zero.



***Equation 8: Housing developer profit / zero profit condition***



It is possible to use the zero profit condition and the first order condition for profit maximisation with respect to construction inputs () to simplify the above formulae to the following expression for housing prices as a function of local land prices.[[14]](#footnote-14) Details of this derivation are given in Severn (2019).



***Equation 9: Housing developer cost function***



***Equation 9*** relates prices for housing supplied by developers to local land prices. To close the model, it is necessary to specify competitive dynamics in land markets. ***Equation 10*** outlines a proposed approach. Kj is the quantity of development capacity in zone j, ie the total amount of dwellings that are allowed to be constructed under zoning rules, and other variables are as previously defined.

***Equation 10: Land pricing function***



The first term () is a ‘congestion factor’ that results in increased land prices in areas with higher local densities. This reflects the fact that, as densities rise, landowners can command higher prices due to the scarcity of development sites.



The second term () is a ‘competition factor’ that results in lower land prices when there is a greater supply of development opportunities in nearby areas that are accessible via transport networks. This is defined as the sum of development capacity in other model zones, weighted according to the inverse of travel costs between zones.[[15]](#footnote-15)



and are elasticities that measure the impact of local density and access to nearby development opportunities on land prices, and is a distance decay parameter that defines how much weight is placed on near vs far model zones.



***Equation 10*** is substituted into ***Equation 9*** to derive the local housing supply function, shown in ***Equation 11***. This function is more complex than Severn (2019) but has several key advantages:

* First, it allows transport improvements to affect local housing supply dynamics by changing the degree of competitive pressure that local landowners operate under. Reductions in *GCjk* increase access to development opportunities in nearby zones, thereby placing downward pressure on local prices.
* Second, it allows zoning policies to affect local housing supply dynamics. Increases in Kj also place downward pressure on local prices.

***Equation 11: Local housing supply function***



Empirical research provides some support for this modelling approach. In an analysis of price and zoning data from Montgomery County, Maryland, Pollakowski and Wachter (1990)

show that more restrictive zoning raises land prices in adjacent parcels. Byun, Waldorf and Esparza (2005) show that development restrictions in California local governments increase home-building in adjacent areas. Turner, Haughwout, and van der Klaauw (2014) investigate various impacts of land use regulation differentials near municipal boundaries, finding evidence that tighter land use regulations raise land values and the share of land that is developed in neighbouring areas, relative to more restrictively regulated areas.

* 1. ***Summary and model closure***

***Equation 5*** and ***Equation 11*** constitute a system of equations that defines housing demand and housing supply as a function of transport costs (GCjk), fixed effects for the attractiveness of home and work locations (ej and Wk), development capacity in each model zone (), and model parameters , , , and , which can be estimated econometrically. The endogenous variables of this model are local housing prices (Pj), number of people commuting between each pair of home and work locations (Njk), and total quantity of housing supplied in each zone (Hj).



The following assumptions close the model First, local housing markets are assumed to clear, meaning that the quantity of housing supplied is equal to the number of people living in the zone (***Equation 14***).[[16]](#footnote-16) Second, I assume that total city size is fixed (***Equation 15***). This is achieved by scaling up or down overall utility levels until city size returns to its fixed level.[[17]](#footnote-17)

***Equation 14: Local housing market clearance condition***



***Equation 15: Fixed city size assumption***



Finally, numerical methods are needed to solve this model. This entails running a strategic transport model to predict the impact of a project on travel costs, and then updating ***Equation 5*** and ***Equation 11*** in iterative fashion until they converge on a single solution. Ideally, this would also involve iteration between the above land use change model and the strategic transport model.

* 1. ***Notes on model estimation***

The next step is to estimate the key parameters of this model and apply it to a case study project. The model can be estimated using the following key sources of data, which are either currently available or expected to be available upon request for the Wellington region.

***Table 3: Required data for model estimation***

|  |  |  |
| --- | --- | --- |
| **Variable** | **Source** | **Status** |
| Njk | 2013 Census (custom data request) | Available as this data was used in previous research (Nunns, 2019) |
| GCjk | Wellington Transport Strategy Model (WTSM) 2013 base year outputs | Available as this data was used in previous research (Nunns, 2019). Code to analyse WTSM model outputs is available but will need to be adapted. |
| Pj | Preferred source: Quality-adjusted house price estimates based on house sale microdata (Wellington City Council and other councils)  Alternative source: Mean dwelling rents from 2013 Census | House sale microdata potentially available from Wellington City Council; similar data previously analysed in Nunns (2018)  Census rent data is readily available |
| Kj | Preferred source: Wellington development capacity modelling (from 2019 NPS-UDC Housing and Business Assessment)  Alternative source: If development capacity / zoning data is not available, simply use land area | Development capacity data potentially available from Wellington City Council |

The parameters of ***Equation 5*** and ***Equation 11*** can be estimated on observed data using econometric techniques. The primary challenge is that several parameters are likely to be endogenous – that is, there is a potential ‘chicken and egg’ relationship between commuting flows and travel costs, and between local density and house prices.

This can be addressed using an instrumental variables approach. This entails identifying additional variables that are (a) correlated with the endogenous explanatory variable of interest but (b) not correlated with other unobserved factors that might influence the outcome variable.[[18]](#footnote-18) Nunns (2019) identifies several valid instruments for transport costs that are based on the presence of exogenous geographic constraints (hills and harbours, specifically), while Severn (2019) suggests using shift-share variables that predict local changes in housing demand based on pre-existing industry composition combined with national changes in employment. An alternative approach would be to rely upon the presence of historical infrastructure or public facilities that influence present-day density (MRCagney, 2019).

**REFERENCES**

Anas, A. and Xu, R., 1999. Congestion, land use, and job dispersion: a general equilibrium model. *Journal of Urban Economics*, *45*(3), pp.451-473.

Baum-Snow, N., 2007. Did highways cause suburbanization? *The Quarterly Journal of Economics*, *122*(2), pp.775-805.

Baum-Snow, N., 2010. Changes in transportation infrastructure and commuting patterns in US metropolitan areas, 1960-2000. *American Economic Review*, *100*(2), pp.378-82.

Boardman, A.E., Greenberg, D.H., Vining, A.R. and Weimer, D.L., 2011. *Cost-benefit analysis: concepts and practice*. Cambridge University Press.

Brand, S., 1995. *How buildings learn: What happens after they're built*. Penguin.

Brinkman, J., 2016. Congestion, agglomeration, and the structure of cities. *Journal of Urban Economics*, *94*, pp.13-31.

Brinkman, J. and Lin, J., 2017. *Freeway Revolts*. Working Paper.

Byett, A., Stroombergen, A., Laird, J. and Paling, R., 2017. *The economic impacts of connectivity*. NZ Transport Agency research report 608.

Byun, P., Waldorf, B.S. and Esparza, A.X., 2005. Spillovers and local growth controls: An alternative perspective on suburbanization. *Growth and Change*, *36*(2), pp.196-219.

Cheshire, P.C. and Hilber, C.A., 2008. Office space supply restrictions in Britain: the political economy of market revenge. *The Economic Journal*, *118*(529), pp.185-221.

Dalgaard, C. J., Kaarsen, N., Olsson, O., & Selaya, P. (2018). *Roman Roads to Prosperity: Persistence and Non-Persistence of Public Goods Provision*. University of Gothenburg Department of Economics Working Paper No 722.

de Groot, H.L., Marlet, G., Teulings, C. and Vermeulen, W., 2015. *Cities and the urban land premium*. Edward Elgar Publishing.

Department for Transport (UK), 2014. Supplementary Guidance: Land Use/Transport Interaction Models. Available online at <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/427140/webtag-tag-supplementary-luti-models.pdf>.

Donovan, S. 2017. *Going with the flow – Using commuting data to identify the effect of walking and cycling travel-time on location choice in Australian cities*. MPhil Thesis, Tinbergen Institute / Vrije Universiteit Amsterdam.

Duranton, G. and Turner, M.A. 2012. Urban growth and transportation. *Review of Economic Studies*, 79(4).

Fredrickson, C., Fergusson, E. and Wildish, B.R., 2016. *Residential Property Amalgamation and Aggregation in Auckland, 2004-2014*. Auckland Council technical report, TR2016/001.

Ganong, P. and Shoag, D., 2017. Why has regional income convergence in the US declined? *Journal of Urban Economics*, *102*, pp.76-90.

Garcia-López, M.A., 2012. Urban spatial structure, suburbanization and transportation in Barcelona. *Journal of Urban Economics*, 72(2-3), pp.176-190.

Glaeser, E.L., 2008. *Cities, agglomeration, and spatial equilibrium*. Oxford University Press.

Glaeser, E. and Gyourko, J., 2018. The economic implications of housing supply. *Journal of Economic Perspectives*, *32*(1), pp.3-30.

Grimes, A. and Liang, Y., 2009. Spatial determinants of land prices: Does Auckland’s metropolitan urban limit have an effect? *Applied Spatial Analysis and Policy*, *2*(1), pp.23-45.

Grimes, A. (2011). *Building Bridges: Treating a New Transport Link as a Real Option*, 51st Congress of the European Regional Science Association: "New Challengesfor European Regions and Urban Areas in a Globalised World", 30 August - 3 September 2011, Barcelona, Spain, European Regional Science Association (ERSA), Louvain-la-Neuve.

Gyourko, J. and Molloy, R., 2015. Regulation and housing supply. In *Handbook of regional and urban economics* (Vol. 5, pp. 1289-1337). Elsevier.

Hazledine, T., Donovan, S. and Mak, C., 2017. Urban agglomeration benefits from public transit improvements- Extending and implementing the Venables model. Research in Transportation Economics, 66, pp.36-45.

Heblich, S., Redding, S. J., & Sturm, D. M. (2018). *The Making of the Modern Metropolis: Evidence from London*. National Bureau of Economic Research working paper no. w25047.

Homans, F.R. and Marshall, E.P., 2008. Modeling Recreational Amenities in an Urban Setting: Location, Congestion, and Substitution Effects. *Agricultural and Resource Economics Review*, *37*(2), pp.257-272.

Hornbeck, R. and Keniston, D., 2017. Creative destruction: Barriers to urban growth and the Great Boston Fire of 1872. *American Economic Review*, *107*(6), pp.1365-98.

Hsieh, C.T. and Moretti, E., 2019. Housing constraints and spatial misallocation. *American Economic Journal: Macroeconomics*, *11*(2), pp.1-39.

Kernohan, D. and Rognlien, L., 2011. *Wider economic impacts of transport investments in New Zealand*. NZ Transport Agency Research Report 448.

Kim, R. 2019. *Applying German spatial planning in Auckland*. Paper presented at the 2019 Engineering New Zealand-Transportation Group conference.

Kulish, M., Richards, A. and Gillitzer, C., 2011. *Urban Structure and Housing Prices: Some Evidence from Australian Cities*. Reserve Bank of Australia Discussion Paper 2011-03.

Lees, K., 2014. *Big city life? Challenges and trade-offs for Auckland city*. New Zealand Institute of Economic Research working paper 2014/2.

Lees, K., 2019. Quantifying the costs of land use regulation: evidence from New Zealand. *New Zealand Economic Papers*, *53*(3), pp.245-269.

Lopes, A.S., Loureiro, C.F.G. and Van Wee, B., 2019. LUTI operational models review based on the proposition of an a priori ALUTI conceptual model. *Transport reviews*, *39*(2), pp.204-225.

Lucas, R.E. and Rossi–Hansberg, E., 2002. On the internal structure of cities. *Econometrica*, *70*(4), pp.1445-1476.

Martínez, F. and Roy, J., 2004. A model for residential supply. *The Annals of Regional Science*, *38*(3), pp.531-550.

Ministry of Building, Innovation, and Employment. 2017. *Price Efficiency Indicators*. Available online at <http://urban-development-capacity.mbie.govt.nz/>.

Moeckel, R., 2011. Simulating household budgets for housing and transport. Paper presented at *International Conference on Computers in Urban Planning and Urban Management*.

MRCagney, 2019. *The costs and benefits of urban development*. A report for the Ministry for the Environment. Available online at <https://www.mfe.govt.nz/publications/towns-and-cities/costs-and-benefits-of-urban-development>.

Mulalic, I., Pilegaard, N., and Rouwendal, J. 2015. Does improving public transport decrease car ownership? Evidence from the Copenhagen metropolitan area. *Tinbergen Institute Discussion Papers, (2015-139/VII)*.

New Zealand Transport Agency, 2019. *Transformative Transport Projects (Dynamic WEBs and Land Use Benefits and Costs*. Available online at <https://www.nzta.govt.nz/planning-and-investment/planning/investment-decision-making-framework-review/>.

Nunns, P. and Denne, T., 2016. *The costs and benefits of urban development: A theoretical and empirical synthesis*. Paper presented at the 2016 New Zealand Association of Economists Conference.

Nunns, P., 2018. *The causes and economic consequences of rising regional house prices in New Zealand*. University of Auckland Centre for Applied Research in Economics working paper 005.

Nunns, P., 2019. *Modelling and valuing land use change*. Paper presented at the 2019 Engineering New Zealand-Transportation Group conference.

Pollakowski, H.O. and Wachter, S.M., 1990. The effects of land-use constraints on housing prices. *Land economics*, *66*(3), pp.315-324.

Safirova, E., Houde, S., Lipman, D.A., Harrington, W. and Baglino, A., 2006. *Congestion pricing and land use change*. Working paper.

Severen, C., 2019. *Commuting, labor, and housing market effects of mass transportation: Welfare and identification*. Working paper.

Simmonds, D. and Feldman, O., 2013. Modelling the economic impacts of transport changes: experience and issues. In *Employment Location in Cities and Regions* (pp. 33-56). Springer, Berlin, Heidelberg.

Stevens, P. 2011. *Competition in New Zealand: An analysis using micro data*. Paper presented at the 2011 New Zealand Association of Economists conference.

Teulings, C.N., Ossokina, I.V. and de Groot, H.L., 2018. Land use, worker heterogeneity and welfare benefits of public goods. *Journal of Urban Economics*, *103*, pp.67-82.

Turner, M.A., Haughwout, A. and Van Der Klaauw, W., 2014. Land use regulation and welfare. *Econometrica*, 82(4), pp.1341-1403.

Venables, A.J., 2017. Expanding cities and connecting cities: the wider benefits of better communications. *Journal of Transport, Economics and Policy*, *51*(1).

Wegener, M., 2004. Overview of land-use transport models. In *Handbook of transport geography and spatial systems*, volume 5, pp.127-146.

1. These impacts are alluded to in the NZ Transport Agency’s interim guidance on valuing the dynamic / transformative benefits of transport investments (NZTA, 2019). [↑](#footnote-ref-1)
2. ‘Greenfield’ sites are large sites, often although not always in rural use, that must be serviced and subdivided before being urbanised. ‘Brownfield’ sites are large sites with previous uses, such as closed-down industries, that are being re-used for other urban uses. [↑](#footnote-ref-2)
3. A ‘perfectly competitive’ market is one that lacks any significant market imperfections, such as externalities, market power, or information problems (Boardman et al, 2011). In the absence of market imperfections, voluntary transactions between willing buyers and willing sellers will lead to an optimal outcome for society. However, if there are market imperfections, then this may not be the case. [↑](#footnote-ref-3)
4. For instance, Nunns (2018) finds that New Zealand regions with greater evidence of supply constraints experienced larger increases in house prices and rents than less-constrained regions in response to similarly-sized migration inflows. [↑](#footnote-ref-4)
5. It is possible to create new land by filling or draining water bodies, but this is costly and hence infrequent in New Zealand. [↑](#footnote-ref-5)
6. PCMs are slightly lower but still significant for house prices and apartment prices, as opposed to residential land prices. Nunns’ (2018) estimates of house price distortions imply a PCM of 93% for standalone homes in Auckland, 66% in Wellington, and 38% in Christchurch. PCMs are lower for house prices as they include the cost to physically build structures. [↑](#footnote-ref-6)
7. In this scenario, transport improvements can only affect regional average house prices by shifting housing demand away from densely-developed areas with high prices towards less dense areas with lower prices. This could mean shifting demand away from redevelopment areas into greenfield areas, or shifting demand away from dense city centre areas to less-developed areas around suburban train stations. [↑](#footnote-ref-7)
8. In this scenario, transport improvements can reduce regional average house prices by increasing competition between alternative locations. Complementary measures such as rezoning to enable greater density can strengthen this effect. Importantly, reductions in prices can coincide with a variety of different patterns of land use relocation. For instance, stronger competition in land / housing development could reduce inner-city housing prices and hence attract people to relocate to formerly-expensive neighbourhoods. [↑](#footnote-ref-8)
9. Poor geography can also play a role. For instance, holding all else equal a new train station next to the coast will do less to enable housing development than an inland train station, as half of the area around the station is underwater and hence undevelopable. [↑](#footnote-ref-9)
10. A potential objection to this is that these economic gains will be offset by other social and environmental costs, such as increased congestion, crowding, and environmental damage. The empirical evidence is mixed on the net direction of these effects but in general it does not seem to be the case that the ‘bads’ outweigh the ‘goods’ (Nunns and Denne, 2016; MRCagney, 2019). [↑](#footnote-ref-10)
11. Lower transport costs will cause some people to make additional trips. Conventional transport appraisal captures the benefits of these trips using a ‘rule of half’ calculation. [↑](#footnote-ref-11)
12. These are agglomeration benefits, imperfect competition benefits, and labour supply benefits. [↑](#footnote-ref-12)
13. See also Wegener (2004) for an earlier review. [↑](#footnote-ref-13)
14. , which means that costs are higher in zones with lower construction productivity.

    

    [↑](#footnote-ref-14)
15. This term is similar to the effective job density measure that is commonly used to calculate agglomeration potential. [↑](#footnote-ref-15)
16. This entails normalising housing supply to a per-worker basis. This normalisation has no impact on the interpretation of the model. [↑](#footnote-ref-16)
17. An alternative approach (drawing upon the open-city Alonso-Muth-Mills model) would be to hold utility levels fixed at their starting level and allow city size to adjust accordingly. [↑](#footnote-ref-17)
18. If it is not possible to apply an instrumental variables approach, then it may be possible to fall back on alternative techniques such as panel data regression. [↑](#footnote-ref-18)