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| **Transport investment and housing development: Modelling and valuing impacts**  Final report  **Prepared for:** Engineering New Zealand – Transportation Group  **Prepared by:** Peter Nunns |

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# Executive summary

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.

This paper therefore outlines an 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. Model parameters are estimated using data for the Wellington region.

Application of the proposed model to a simple hypothetical case study suggests that housing development benefits could be significant in magnitude – potentially comparable in magnitude to existing wider economic benefits that arise in labour markets, such as agglomeration benefits.

This research suggests that transport investment can help to overcome housing supply and affordability issues. Improving accessibility between areas tends to increase the competitive pressure facing landowners by making it easier to buy or rent in more locations. This principle applies throughout urban areas. A new rapid transit route or walking and cycling link that improves access to the city centre will allow medium- and high-density development to occur in more places, just as a new link road allows subdivision to extend into greenfield areas.

To achieve optimal results, land use policies must change in line with transport investment. Improved transport access tends to increase local housing demand. If land use policies do not allow or enable more homes to be built in the area, the result will be rising housing prices that benefit existing landowners at the expense of people who may want to move into the area. If land use policies are changed to allow more housing development, then rising demand will flow through into more new homes, more new residents, and lower price increases.

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# 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.

In this research paper, I examine how to model and value the impacts of transport investment on housing development. I argue that:

* Housing development markets are characterised by imperfect competition due to various factors that constrain the supply of new housing to meet demand (Section 3)
* 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 4)
* As a result, major transport investments can generate wider economic benefits in housing development (Section 5)
* 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 6).

To conclude the research, I:

* Describe a modelling approach that could be used to capture and value the wider benefits of transport investment for housing development and estimate the key parameters of this model for the Wellington urban area (Section 7).
* Apply this model to a hypothetical case study to understand its properties (Section 8).
* Discuss policy implications and areas for further research (Section 9).

# Characteristics of housing development markets

To begin, I discuss some important characteristics of housing development markets. I argue that housing development in New Zealand is characterised by market imperfections that make it difficult to supply new homes to meet demand. This results in scarcity-driven price increases that push the price of housing above the underlying cost to supply it.

Market imperfections in housing development play an important role in understanding how transport investment can affect housing markets and how wider economic benefits may arise as a result.

## 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). There is also significant evidence that the impact of these restrictions varies between locations, including in New Zealand (Glaeser, Gyourko and Saks, 2005; Nunns, 2020). |

## 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, 2020). Table 2 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 2: 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.

# Transport and housing markets

I now consider how transport improvements, such as new infrastructure or services, policy changes, or technology, changes can affect housing markets. I argue that it is necessary to distinguish between demand-side effects (such as more people wanting to live in newly accessible locations) and supply-side effects (such as land prices being competed down due to the fact that alternative sites are more substitutable). Complementary policy changes, such as rezoning to increase housing development capacity in areas served by new transport infrastructure or services, can also have supply-side effects.

## Local housing supply and demand dynamics

Transport investments can have two different effects on housing and land markets.

First, 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).

Second, 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 and causing land prices to be competed down (Homans and Marshall, 2008).

As a hypothetical example, consider a case where there are only a handful of vacant/redevelopable sites in an existing city centre. Owners of these sites would be able to name their price. A transport project that significantly reduced travel times to a nearby transitioning industrial area with many redevelopable sites would increase competition in the local land market and reduce prices in the city centre.

The impact of supply-side effects 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.

In Panel A, transport improvements can only reduce 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.

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. Supply-side effects are represented as an outward shift or flattening of the housing supply curve.

In Panel B, an increase in local housing demand can be satisfied without increasing prices as much. Furthermore, 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. 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.

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

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| --- | --- |
| *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* |

### Potential mechanisms for supply-side effects

There are two potential mechanisms for supply-side effects.

First, as noted above, improved transport access may make alternative sites more substitutable, reducing the market power enjoyed by landowners in desirable locations. In a multi-location model, as opposed to the simple single-location example above, this effect might be partly or fully captured by shifts in relative demand to previously inaccessible locations.

Second, transport projects might be bundled with rezoning or land amalgamation projects that increase housing development capacity in newly accessible areas. These could include:

* Upzoning of existing urbanised areas to allow redevelopment of existing sites to provide more dwellings
* Greenfield rezoning to allow new subdivision in non-urban areas
* Projects to amalgamate small sites to create development-ready parcels or to remediate environmental hazards on brownfield sites that were previously used for industrial purposes.

In some cases, transport projects can be a necessary condition for rezoning. For example, existing transport infrastructure may not be perceived to be sufficient to accommodate new development without undesirable congestion issues. In other cases, transport projects may not be a necessary condition for rezoning, but the two projects may be bundled together for institutional or political reasons. Regardless of why they are bundled together, if they coincide it would be desirable to assess them jointly.

## Transport access is necessary but not sufficient for new development

While transport access is important for housing development, 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 pre-existing constraints to housing development. The market imperfections identified in the previous section may slow new development.[[7]](#footnote-7) If these constraints are totally binding, transport improvements may have little impact on housing development as no further development *can* occur.

## 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 (2020) recently undertook a similar exercise for New Zealand regions.

The general finding from this literature is that increasing housing supply in highly-productive cities with high house prices will increase national 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.[[8]](#footnote-8)

If transport investments result in large reductions in citywide housing prices, they may in turn attract additional residents to those cities. This may have additional economic impacts, depending upon where additional people are moving from.

# Housing development impacts as a wider economic benefit

In this section, I argue that transport projects can generate wider economic benefits (WEBs) in housing development markets. These benefits are additional to conventional transport benefits, such as benefits from faster or more comfortable journeys, and to agglomeration benefits and other WEBs that principally arise in labour markets.

## Theory of WEBs

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.[[9]](#footnote-9)

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.[[10]](#footnote-10) Following UK WebTAG guidance, Kernohan and Rognlien (2011) describe the theory and evidence underpinning these benefits. They also note 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 disregard the potential for increased competition benefits due to the fact that most New Zealand industries have low price-cost markups, indicating a reasonable level of competition (Stevens, 2011). However, their conclusion does *not* apply in housing development markets, as:

1. We observe large price-cost markups for urban land and housing that indicate the presence of various barriers to development and redevelopment of land
2. Transport projects and complementary rezoning projects can affect the level of competition in housing development markets by strengthening competition between landowners in different locations and unlocking additional development opportunities.

## Valuing increased competition WEBs

Kernohan and Rognlien (2011) outline a conceptual approach for valuing increased competition WEBs. The basis for this approach is the observation that price-cost margins result in deadweight losses for society, because some people avoid consuming goods produced in uncompetitive markets. In highly distorted urban housing markets, some people may choose to live in overcrowded or substandard accommodation, or simply move to another location with cheaper housing. Reducing PCMs can therefore generate WEBs by reducing deadweight losses.

***Figure 2*** illustrates how to value increased competition benefits based on changes in PCMs in the affected market. Prior to an investment or policy change, low levels of competition produce a price-cost margin of A (ie prices Pa are higher than marginal costs of production MC). After the investment, increased competition reduces the PCM to B (prices drop from Pa to Pb while marginal costs are unchanged).

As a result of lower prices, more buyers enter the market, and the quantity of goods produced increases from Qa to Qb. The net social benefits of increased competition are given by the blue-shaded area, and the remaining unmitigated deadweight loss by the green-shaded area.[[11]](#footnote-11) Assuming that the demand curve is linear, increased competition WEBs can be calculated as:

Equation 1: Calculating the value of increased competition WEBs

***Figure 2: Conceptual approach for valuing increased competition benefits (Kernohan and Rognlien, 2011)***



Kernohan and Rognlien’s approach is to value additional benefits in imperfectly-functioning secondary markets as an adjustment to benefits that accrue directly in transport markets. This approach is common due to the fact that transport models that are used to value many project benefits are incomplete – that is, they model equilibrium outcomes in transport markets but do not model firm and worker relocation and other land use responses. However, as Martinez and Araya (2000) observe, a more theoretically sound approach would be to value benefits using a general equilibrium model of transport and land use outcomes that directly accounts for the imperfect functioning of land and labour markets. This research paper focuses on Kernohan and Rognlien’s approach, but the models outlined in it could also be applied to a general equilibrium approach.

### Implementing this calculation

Implementing this calculation requires three pieces of information:

* First, an estimate or forecast of existing housing (or land) prices (or price-cost markups) in affected locations.
* Second, a prediction of how a transport project (or a joint transport and rezoning project) will affect housing prices in affected locations and other competing locations.
* Third, an estimate or forecast of the degree to which reduced housing prices will attract more residents to a given location, relative to alternative competing locations.

***Figure 3*** illustrates how this calculation could be undertaken if a project affects both local housing supply and demand. The red-shaded area illustrates the magnitude of housing development WEBs that might arise as a result. In effect, this compares the predicted outcome of a local housing demand shift with and without a simultaneous shift in housing supply.

***Figure 3: Valuation of housing development WEBs***



## Wider economic benefits of changes to inter-regional population distribution

A significant reduction in citywide housing prices may also generate additional wider economic benefits in urban labour markets. These arise when lower prices enable more people to move to relatively productive locations. The benefits that arise as a result may include:

* Dynamic agglomeration benefits that arise as a result of increased economic mass that enables sharing, matching, and learning effects (Duranton and Puga, 2004)
* Economic benefits from reallocation of workers to cities where they can earn higher incomes and be more productive, which are often called ‘move to more productive jobs’ effects in transport appraisal guidance (NZTA, 2019).

While increased competition WEBs in housing development are universally positive, the above economic impacts can be either positive or negative. If a drop in housing prices in low-productivity cities attracts people from high-productivity cities, then it may *reduce* overall economic productivity and hence offset increased competition WEBs.

An implication of this is that the benefits of transport projects that enable housing development are likely to be larger in cities (or locations within cities) that are more productive than the national average, relative to less productive cities.

Improved competition benefits in housing development are likely to be positive in most growing cities in New Zealand due to economically significant PCMs in housing and land markets. However, M2MPJ WEBs are only likely to be positive in Auckland and Wellington, as these cities have higher productivity and wage levels than the national average (Maré, 2016; Nunns, 2020).

# Review of existing land use-transport interaction models

In this section, I review a range of existing land use-transport interaction models. This review focuses on how they address competitive dynamics in housing development and land markets and how they address redistribution of growth between cities/regions as well as within them. I consider 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.

## 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.

## 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, the model does not analyse the nature of housing supply constraints, model the impact of relaxing these constraints, or allow transport improvements to affect the dynamics of housing supply.

## Land use-transport interaction models

Land use-transport interaction (LUTI) models 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.[[12]](#footnote-12) 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.

## 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 aggregated to the city level: 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.

## How these models address competition in housing development

When these models address housing development, they typically 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.

## 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.

# Proposed modelling approach

In this section, I propose an approach to modelling the impacts of transport investments on:

* People’s choice of residential and work location – which in turn provides information about changes to the distribution of population and employment within a city
* Equilibrium outcomes for local housing markets, ie the quantity of housing that is supplied and the price at which it is supplied.

I also present estimates of the key parameters of this model for the Wellington urban area – full details of parameter estimation are provided in appendices.

The proposed model is related to several existing spatial equilibrium models of the land use impacts of transport investments (Mulalic, Pilegaard and Rouwendal, 2015; Teulings, Ossokina and de Groot, 2018; Severen, 2019). The household location choice element of this model builds upon my previous work (Nunns, 2019) as well as the wider literature. Modelling of local housing supply dynamics is related to Severen’s (2019) model of the impacts of the Los Angeles Metro. However, I extend the housing supply model to better capture the dynamics explored in Sections 3 and 4.

In an Appendix, I discuss several alternative modelling approaches that I considered but ultimately rejected for a variety of reasons.

## Model setup

The model includes two key actors:

* Households, which are assumed to be represented by individuals that choose where to live and where to work in order to maximise their utility
* Housing developers, who purchase land and develop housing that is then sold to households

Firms, which hire workers to maximise profits, are implicit in the model but not formally modelled. It is assumed that firms are ‘labour takers’ – that is, they congregate in places that are accessible to workers, rather than choosing locations that workers must then travel to. In principle, the model could be extended to formally capture the role of firms and agglomeration economies that encourage firm clustering.

### 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 2: 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 3: 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 4: Number of people travelling between origin and destination***

***Equation 4*** 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.

### 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 5: 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 5*** can be substituted back into ***Equation 4*** 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 6: Expanded household location choice function***

Summing up ***Equation 6*** 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 7: Elasticity of local housing demand with respect to house prices***

***Equation 8: Semi-elasticity of local housing demand with respect to a one-minute change in travel times***

### Local housing supply

I build upon the housing supply model described by Severn (2019) to consider how transport and land use policy may affect competitive dynamics in development markets. In doing so, I assume 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).

I consider two permutations of this model: First, a baseline model that extends Severn’s model to incorporate the impact of land use regulations that affect housing development capacity; and second, an extended model that addresses the potential for improved transport access between development sites to reduce land prices in both locations.

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 9: 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 10: 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.[[13]](#footnote-13) Details of this derivation are given in Severn (2019).

***Equation 11: Housing developer cost function***

***Equation 11*** 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. As noted above, I consider two alternative land pricing functions that result in the baseline housing supply model and the extended model.

***Baseline housing supply model***

***Equation 12*** outlines the baseline land pricing function. 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 12: Land pricing function (baseline)***

The 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. is an elasticity that measures the impact of local density and access to nearby development opportunities on land prices.

***Equation 12*** is substituted into ***Equation 11*** to derive the baseline local housing supply function, shown in ***Equation 13***. This function allows zoning policies to affect local housing supply dynamics. Increases in Kj also place downward pressure on local prices, which I interpret as an increase in the availability of development sites increasing the competitive pressure on landowners.

***Equation 13: Local housing supply function (baseline)***

***Extended housing supply model***

***Equation 14*** outlines an extended land pricing function. 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 14: Land pricing function (extended)***

As above, the first term () is a ‘congestion factor’ that results in increased land prices in areas with higher local densities. 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.[[14]](#footnote-14)

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 14*** is substituted into ***Equation 11*** to derive the extended local housing supply function, shown in ***Equation 15***. 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 15: Local housing supply function (extended)***

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.

### Summary and model closure

***Equation 6*** and ***Equation 13*** / ***Equation 15*** 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 16***).[[15]](#footnote-15) Second, I assume that total city size is fixed (***Equation 17***). This is achieved by scaling up or down overall utility levels until city size returns to its fixed level.[[16]](#footnote-16)

***Equation 16: Local housing market clearance condition***

***Equation 17: 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 6*** and ***Equation 15*** 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.

## Estimated model parameters for Wellington

To conclude this section, I summarise estimated model parameters for the Wellington urban area. These parameters are estimated using data on the observed variables of the model (commuting flows, travel times, house prices, and development capacity). Details of the underlying data and econometric estimation are provided in the Appendix.

A key challenge to estimating model parameters is that several parameters are likely to be endogenous. There is a potential ‘chicken and egg’ relationship between commuting flows and travel costs, and between local density and house prices. I address this using an instrumental variables approach that employs 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. I define instruments based on geography (ie the role of hills and harbours in determining transport costs) and history (ie the role of pre-1890 port location in determining historical population density, which in turn influences present-day density). These instruments are plausibly exogenous and pass key statistical tests of instrument validity, but it is difficult to conclusively prove that they are truly exogenous.[[17]](#footnote-17)

The following table summarises estimates of key model parameters and provides notes on estimation and uncertainty. Some key findings from this initial analysis are as follows:

* First, reduced AM peak travel times (averaged across both car or public transport) between two locations leads to an increase in the number of people choosing to live in one location and work in the other.
* Second, higher house prices reduce the number of people choosing to live in a given home location. The elasticity of local housing demand with respect to housing demand is large – well above one in absolute value. This is consistent with the idea that people are mobile within cities in response to housing prices, even if they may be less mobile between cities.
* Third, the coefficient on dwelling density relative to plan-enabled development capacity in the housing supply function is positive but smaller than one. This indicates that increasing demand to live in a given location cannot be met without increases in prices, unless rezoning is pursued to increase the local supply of development opportunities.
* Fourth, the coefficient on nearby development capacity in the housing supply function generally has a positive sign rather than a negative sign as hypothesised, and is statistically insignificant in the preferred model. This suggests that the baseline housing supply model is the preferred specification, and that improved access to development capacity in other locations does not reduce land prices. This in turn suggests that transport projects are most likely to place downward pressure on land prices by shifting the location of housing demand.

***Table 3: Preferred estimates of model parameters***

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Estimate** | **Std err** | **Interpretation** |
| (location choice model coefficient on travel time) | -0.101\*\*\* | 0.004 | A one minute reduction in AM peak travel time between two locations will lead to a 10% increase in commuting flows. A one minute reduction in travel time from a home location to all other locations will lead to a 10% increase in local housing demand.  *Reference: IV Poisson model 1 in Table 5.* |
| (location choice model coefficient on house price) | -4.495\*\*\* | 0.369 | Holding transport access constant, a 10% increase in house prices in a single suburb will lead to a ~35% reduction in local housing demand.  *Reference: IV Poisson model 1 in Table 7* |
| (housing supply function coefficient on local dwelling density relative to development capacity) | 0.289\*\*\* | 0.083 | House prices must rise by roughly 2.9% in order to accommodate a 10% increase in dwelling density, unless zoning is relaxed to increase development capacity.  *Reference: IV model 1b in Table 9* |
| (housing supply function coefficient on inverse travel time-weighted development capacity in nearby zones) | Not estimated |  | Coefficient estimates did not have the hypothesised sign (positive rather than negative) and were statistically insignificant in the preferred specification of this model. As a result I conclude that the baseline housing supply model specification is preferred.  *Reference: IV models 2a/2b in Table 9* |

*Statistical significance indicators: . p<0.1 \* p<0.05; \*\* p<0.01; \*\*\* p<0.01*

### Commentary on price elasticity of local housing demand

The estimated price elasticity of local housing demand is very high (-4.495), implying that people are very sensitive to differences in house prices between suburbs with comparable levels of transport access.

By contrast, previous research suggests that city/regional population is less sensitive to variations in inter-regional house prices. Based on data from the 1986-2013 New Zealand Censuses, Hyslop et al (2019) estimate that the price elasticity of regional housing demand lies between -0.3 and -0.5. The calibrated spatial equilibrium model used by Nunns (2020) also implies a price elasticity of regional housing demand of around -0.35 to -0.5.[[18]](#footnote-18)

In short, people appear to be around ten times as sensitive to local house price variations as they are to inter-regional house price variations. This finding is consistent with evidence on mobility from the Census. Figure 4 shows that roughly one in three New Zealanders moved homes within the same region over the 2008-2013 period, while only one in twelve moved between regions.

Figure 4: Usual residence five years ago (2013 New Zealand Census)



### Commentary on housing supply parameter

As detailed in the appendix, the housing supply parameter proved to the most difficult parameter to estimate. My preferred estimate of the housing supply parameter is 0.289, which implies that local house prices must rise by roughly 2.9% in order to accommodate a 10% increase in dwelling density. Alternative model specifications result in different parameter estimates ranging from 0.1 to 1.0.

Outside information is therefore helpful to understand what this parameter ‘should’ be. This indicates that the housing supply parameter should be less than one but considerably higher than 0.1.

The following diagram illustrates the relationship between land prices (horizontal axis) and the cost to build a standard-sized dwelling (vertical axis). Different curves are plotted for standalone homes, terraced homes, and apartments. Terraced homes and apartments incur higher construction costs and planning and financing costs, but require less land per dwelling. As a result:

* When land prices are low, standalone homes are cheaper to build than terraced homes or apartments
* As land prices rise, eg due to increased density leading to more competition for development sites, the cost to build standalone homes escalates more rapidly than the cost to build terraced homes or apartment.
* When land prices reach a certain level, it becomes cheaper to build terraced homes than standalone homes, and then cheaper to build apartments than either.

The dashed line indicates the overall cost envelope for building additional dwellings. Provided that land use regulations allow the construction of terraced houses and apartments, this implies that there should be a less than one-to-one relationship between density and housing prices. However, if land use regulations are extremely restrictive, then we may expect a housing supply parameter greater than one. Severn (2019) estimates a housing supply parameter of around 1.4 for Los Angeles, which may be due to extremely restrictive land use regulation.

Figure 5: Cost to supply a standard-sized dwelling as a function of land prices



However, previous evidence on housing supply responsiveness in New Zealand, the United States, and other OECD countries suggests that the housing supply parameter should be significantly higher than 0.1 at the regional or national level (Saiz, 2010; Caldera and Johansson, 2013; Hyslop et al, 2019).[[19]](#footnote-19)

For purposes of comparing with previous research, I note that is an inverse housing supply elasticity, and hence can be interpreted as the elasticity of housing supply with respect to price. My estimate of 0.289 implies that Wellington has a housing supply elasticity of around 3.5.

By comparison, Hyslop et al (2019) estimate a housing supply parameter (comparable to ) in the range of 0.4 to 0.65 at the territorial authority / Auckland ward level. This is slightly higher than my parameter estimate and implies that housing supply is slightly less responsive than I have found.

Saiz (2010) estimates housing supply elasticities for US cities that generally fall within the range of 1.5 to 5. My estimate for Wellington (3.5) is within this range, albeit higher than we would expect for a comparably geographically constrained US city with around 0.5 million residents. By contrast, my lower-end estimate of 0.1 would imply a housing supply elasticity of 10, which would be roughly twice as responsive as lightly-regulated American cities with abundant flat land for subdivision.

In short, a higher estimate of the housing supply parameter is more consistent with previous research.

Lastly, I note that the housing supply parameter can be decomposed as follows: , where is the land share of expenditure in a Cobb-Douglas housing production function and is the elasticity of land prices with respect to the local density of dwellings relative to development capacity. Previous estimates of the Cobb-Douglas land share fall in the range of 0.2 to 0.3 (Combes, Duranton, and Gobillon, 2017; Albouy and Erhlich, 2018), and a ratio of 0.3 has been used in analysis of housing supply costs in New Zealand (Ministry of Business, Innovation, and Employment, 2017).

A Cobb-Douglas land share parameter of 0.3 implies that the elasticity of land prices with respect to density is near one. This is consistent with previous estimates from the literature. Ahlfeldt and McMillen (2014) estimate that the elasticity of land prices with respect to density is near one using data from Berlin, Chicago, and Pittsburgh. This provides further support for my preferred housing supply parameter estimate.

# Application to a case study

In this section, I apply the model developed in the previous section to a simple hypothetical case study. The aim of this analysis is to understand the qualitative and quantitative predictions arising from the model and to identify potential policy implications arising from the model. I also considered extension to a more complex case study but have left this as an area for further work.

## Description of simple case study

In this example, average travel times from one suburb to the rest of the city reduce by two minutes, while travel times between other locations remain unchanged. This could occur if, for instance, a dead-end road leading to a residential suburb at the edge of the city was straightened to reduce travel times from that suburb to all other locations. However, it is a somewhat unrealistic scenario as most transport projects typically affect travel times between many locations.

The following table summarises key characteristics of the modelled suburb. Model parameters summarised in ***Table 4*** are used in this analysis.

Table 4: Hypothetical suburb characteristics

|  |  |
| --- | --- |
| **Suburb characteristic** | **Value** |
| Reduction in average travel time to all other locations | -2 minutes / trip |
| Starting number of commuters / dwellings  *Note: for ease of exposition one commuter per dwelling is assumed* | 1000 |
| Average dwelling price | $400,000 |

I used the model to calculate the underlying increase in local housing demand, defined as the uplift in commuters / dwellings that would occur if local house prices remained constant, as well as the impact of three scenarios:

* A scenario in which local zoning did not change – ie no additional development capacity was provided to serve additional demand
* A scenario in which zoning was changed to allow a 10% increase in development capacity
* A scenario in which zoning was changed to allow a 20% increase in development capacity

### Key model results

Key outcomes from these scenarios are presented in the following table. This shows that:

* The transport improvement would lead to a 22% in underlying demand to live in this location
* Under fixed zoning, only 41% of this underlying increase in demand would flow through into increased construction, with the remainder flowing into higher house prices
* Under fixed zoning, local house prices would rise by 2.6%. Due to the fact that local housing demand is found to be very price-sensitive, this is sufficient to ration out the remaining increase in demand to other locations.
* If zoning capacity is increased, an increasing share of the demand uplift is captured as new construction, and house price increases are even smaller.

The predicted increases in house prices are small. Due to the way that the housing supply parameter is estimated, these increases should be interpreted as the increase in prices due to a shift along the housing supply curve. The positive slope of the supply curve in turn reflects the degree to which prices for development sites are bid up as an area becomes more densely developed.

This is because the housing supply regression model includes a control variable for access to jobs via the transport network. That term captures the capitalisation of travel time benefits into house prices, while the housing supply parameter identifies the underlying slope of the housing supply curve. The total impact in house prices, including capitalisation effects, may be higher than indicated in this table.

Table 5: Modelled outcomes of a two minute reduction in average travel times for a single zone

|  |  |  |  |
| --- | --- | --- | --- |
| **Scenario** | **Percentage increase in zone population** | **Percentage increase in house price (housing supply cost)** | **Share of underlying demand captured as increased construction** |
| Underlying increase in local housing demand | +22% | - |  |
| Outcomes with fixed zoning | +9% | +2.6% | 41% |
| Outcomes with a 10% increase in development capacity | +15% | +1.4% | 68% |
| Outcomes with a 20% increase in development capacity | +21% | +0.2% | 94% |

### Conventional transport benefits and housing development WEBs

I use the above results to calculate conventional transport benefits (ie travel time savings) and housing development WEBs. This is a partial equilibrium analysis – it focuses on outcomes for a single location, ignoring changes in housing demand in other locations.

The following table calculates conventional transport benefits from the hypothetical project. Based on an average two minute travel time saving and a value of travel time parameter of $12/hour (based on the value of travel time savings for commuting purposes in NZ Transport Agency’s 2020 *Monetised Benefits and Costs Manual*, updated to 2019 NZ dollars), this will lead to slightly over $400 in benefits per day. This translates to over $5 million in benefits in present value terms, based on a 4% discount rate (again, drawn from NZTA, 2020).

I benchmark outcomes against a scenario in which no land use change occurs and the number of commuters who experience travel time savings stays fixed. Transport user benefits are between 4.6% and 10.5% higher with land use change, depending upon the degree to which the suburb is rezoned to allow more people to move in.

Table 6: Conventional transport benefits of a simple example project

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Scenario** | **Base case commuters** | **Scenario commuters** | **Daily travel time savings benefits based on 2 minute time saving and $12/hr value of travel time (incl rule of half for induced commuters)** | **Present value travel time benefits (bidirectional commutes, 250 working days/year, 4% discount rate)** |
| Outcomes with no land use change | 1000 | 1000 | $400 | $5,000,000 |
| **Outcomes with land use change** |  |  |  |  |
| With fixed zoning | 1000 | 1092 | $418 | $5,230,000 (+4.6%) |
| With a 10% increase in development capacity | 1000 | 1152 | $430 | $5,381,000 (+7.6%) |
| With a 20% increase in development capacity | 1000 | 1210 | $442 | $5,526,000 (+10.5%) |

The following table summarises the additional increased competition WEBs that would arise in housing development markets under the second and third scenarios, which involve rezoning to increase development capacity. No increased competition WEBs are calculated for the first scenario, because the lack of rezoning under that scenario means that local housing supply dynamics do not change. These benefits are calculated using the procedure outlined in Section 5.2, and in particular Equation 1.

The third scenario (a 20% increase in development capacity) would result in housing development WEBs equal to over $0.5 million, or around 10% of the conventional transport benefits generated by the project. These benefits are similar in magnitude to WEBs that arise in labour markets, which typically range from 10 to 30% of conventional benefits (NZTA, 2019).

Table 7: Housing development WEBs of a simple example project

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Scenario** | **Additional dwellings relative to fixed zoning** | **Average house price reduction relative to fixed zoning** | **Housing development WEBs** | **As share of conventional benefits** |
| Outcomes with a 10% increase in development capacity | 60 | -$4,886 | $148,000 | 2.7% |
| Outcomes with a 20% increase in development capacity | 118 | -$9,296 | $551,000 | 10.0% |

The impacts of changes in housing demand in other modelled locations are not calculated and valued in this simple example. Assuming that regional population stays (approximately) fixed, then a shift of population growth towards this area will reduce housing demand pressures and hence moderate price increases in other areas. This will lead to wider housing price impacts and (provided that the region suffers from price-cost markups in housing) broader benefits from reduced price pressures.

### Sensitivity tests

Lastly, I sensitivity test alternative model parameters drawn from alternative model specifications. In addition to my preferred parameter estimates, I sensitivity test the lowest estimate of the transport cost parameter and housing price parameter (-0.083 and -3.237, respectively, based on Poisson model 3 results in Table 8 and Table 10), the lowest estimate of the housing supply parameter (0.103, based on OLS model 1b in Table 11), and the highest estimate of the housing supply parameter (1.096, based on IV model 1a in Table 12).

Sensitivity tests show that varying the transport cost and housing price parameters does not have a large impact on modelled outcomes. However, varying the housing supply parameter does have a large impact on modelled outcomes. My lowest estimate of the housing supply parameter implies that two-thirds of the underlying increase in local housing demand would be accommodated without rezoning. My highest estimate implies that only 14% of the increase in local housing demand could be accommodated without rezoning, which is closer to Severn’s (2019) findings for Los Angeles. In short, if housing supply is less responsive due to local constraints, fewer people will be able to change location to take advantage of transport improvements.

Table 8: Sensitivity tests on simple example

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **(transport cost param)** | **(housing price param)** | **(housing supply param)** | **Underlying increase in local housing demand** | **Increase in zone population under fixed zoning** |
| -0.101 | -4.495 | 0.289 | 22% | 9% |
| -0.083 | -3.237 | 0.289 | 18% | 9% |
| -0.101 | -4.495 | 0.103 | 22% | 15% |
| -0.101 | -4.495 | 1.096 | 22% | 3% |
| -0.083 | -3.237 | 0.103 | 18% | 13% |
| -0.083 | -3.237 | 1.096 | 18% | 4% |

# Conclusion

To conclude, I briefly discuss some key lessons from this research, and outline areas for further research.

## Lessons for transport modelling and project appraisal

The key finding from this research is that it is conceptually defensible and technically viable to assess housing development benefits as a wider economic benefit of transport projects and (especially) integrated transport and land use planning projects.

Application of the proposed model to a simple hypothetical case study suggests that these benefits could be significant in magnitude. In some cases, they are likely to be comparable in magnitude to existing WEBs that arise in labour markets, such as agglomeration benefits. Failing to account for these benefits could result in inefficient project selection or project planning and design that does not deliver the appropriate mix of benefits.

However, existing transport models available in New Zealand are not well suited to assessing these benefits. This is because they fail to account for land use changes in response to transport projects, and do not model housing supply and demand dynamics. One approach to addressing this issue is to loosely couple existing transport models with land use models that explicitly address the functioning of the housing market. This paper demonstrates how such a model could be specified and how its key parameters could be estimated.

## Lessons for policymakers

New Zealand is currently suffering from severe and rising levels of housing unaffordability. Rising house prices have a variety of causes but a long-run driver is a lack of housing supply. In light of this, policymakers are asking whether and how transport infrastructure investment can contribute to unlocking housing development.

This research offers three recommendations to policymakers seeking to leverage transport investment for housing development outcomes.

First, transport investment can help to overcome housing supply and affordability issues. Improving accessibility between areas tends to increase the competitive pressure facing landowners by making it easier to buy or rent in more locations. This principle applies throughout urban areas. A new rapid transit route or walking and cycling link that improves access to the city centre will allow medium- and high-density development to occur in more places, just as a new link road allows subdivision to extend into greenfield areas. There is some tentative evidence that public transport improvements may have a larger impact than road improvements, relative to their current share of travel demand.

Second, to achieve optimal results, land use policies must change in line with transport investment. Improved transport access tends to increase local housing demand. If land use policies do not allow or enable more homes to be built in the area, the result will be rising housing prices that benefit existing landowners at the expense of people who may want to move into the area. If land use policies are changed to allow more housing development, then rising demand will flow through into more new homes, more new residents, and lower price increases.

Third, these effects are not particularly controversial, in the empirical literature, and nor are they particularly challenging to model and value. However, they are seldom assessed for major projects. Given the urgency of New Zealand’s housing affordability challenges, policymakers should expect better analysis of these impacts from transport agencies.

## Areas for further work

This research project has opened up several areas for further work, which I briefly discuss here.

First, there is a need to complete implementation of the model and loose coupling with an existing transport model. This is conceptually straightforward, as the key elements of the model are specified and key parameters are estimated, but is likely to involve some technical challenges related to finding an equilibrium solution.

Second, the model could be extended to incorporate more detail about other aspects of location choice. This could include a more realistic model of the labour market that addresses issues like agglomeration economies and labour taxation, both of which give rise to WEBs, and further analysis and modelling of other drivers of home location amenity, such as local public goods and negative impacts of traffic noise and emissions. This would move in the direction of a full general equilibrium model that accounts for all aspects of location and transport mode choice.

As Martinez and Araya (2000) observe, directly incorporating these dynamics into the model would allow all welfare impacts to be calculated within the model rather than as an adjustment to transport user benefits.

Third, and following on the above point, if a full general equilibrium model of location and transport mode choice was available, it would be possible to calculate and compare different approaches to valuing the direct and wider benefits of transport projects. In particular, it would be useful to know whether partial equilibrium analysis of WEBs mis-estimates total benefits relative to a general equilibrium analysis.

# Appendix: Other modelling approaches that were considered

In the course of preparing this research report, I ended up going down a number of modelling dead ends. In this appendix I briefly summarise the approaches that I investigated and briefly explain why they did not work.

In summary, these modelling approaches fall down for one or more of the following reasons:

* It is not possible to link housing supply models with existing transport and land use models without considerable ad-hockery
* Models are tractable for a small number of housing zones but cannot easily be expanded to include many zones (a requirement for modelling complex urban areas)
* Models do not capture the key effect of interest, ie the role of transport access in shaping competition in housing development.

## Dead end 1: Alonso-Muth-Mills

First, I considered whether it would be possible to loosely couple the Alonso-Muth-Mills (AMM) model with a conventional strategic transport model to predict housing development impacts. The AMM model shows that the house price gradient can be described as a function of transport costs to jobs (and sometimes consumption amenities). As a result, changing transport costs can affect average housing costs and the distribution of households throughout the city.

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.

The AMM model can be used to simulate the impacts of zoning policies that constrain housing density (eg building height limits and minimum lot sizes) or limit the extent of housing development (eg urban growth boundaries). In the model, these policies shift growth between areas, driving up total housing plus transport costs for residents in the process. If an urban growth boundary is applied, then the model can also estimate price-cost markups between agricultural land and urban land at the edge of the city

I considered the following model process and tested a simple implementation of the model:

* Step 1: Run strategic transport model to estimate transport cost gradient with respect to the CBD.
* Step 2: Source estimates of price discontinuities between urban and agricultural land at the edge of the city.[[20]](#footnote-20)
* Step 3: Use estimated transport cost gradient, plus other economic inputs, to calibrate the AMM model. Use urban land price discontinuities, plus other information on zoning policies, to calibrate the restrictiveness of existing zoning policies.
* Step 4: Re-run transport model to estimate the impact of a transport improvement on the transport cost gradient.
* Step 5: Input the new transport cost gradient into the calibrated AMM model to estimate population redistribution and changes in average house prices.[[21]](#footnote-21)
* Step 6: If transport improvements are paired with relaxation of zoning policies, simulate the joint effect of both policies.

This approach has several fatal flaws.

First, loosely coupling the AMM model with a strategic transport model would require considerable – and probably excessive – simplification of urban space. Strategic transport models contain a large number of zones, with the potential for travel in many directions, while the AMM model assumes that all commuters travel to the CBD and that urban space outside the CBD is homogenous in all other respects.

Second, model testing indicates that housing price-cost markups only reduced in the case where transport improvements were paired with zoning relaxation. If transport access improves but existing building height limits and urban growth boundaries remain unchanged, population will disperse somewhat but land price differentials at the edge of the city will *rise*. This in turn suggests that this modelling approach is not capable of capturing the main effect of interest, ie the impact of transport improvements on housing supply competition.

## Dead end 2: Vertical differentiation models

Second, I considered models of imperfect competition drawn from the industrial organisation (IO) literature. Different IO models incorporate various barriers to competitive market functioning, such as limited numbers of firms (oligopoly), barriers to entry for new firms, or product differentiation that gives firms a degree of market power.

The vertical differentiation model of oligopolistic competition provides one seemingly promising approach. An extension to this model that also captures shifting demand over time and developers’ choice of development timing has been used for theoretical analysis of housing market dynamics (Guthrie, 2019).

To demonstrate the basic features of this model, I outline a simple example. Assume that a city has two residential locations separated by a harbour. Location 1 is on the same side of the harbour as the main business district, but there are also small-scale employment locations scattered around both locations. Residents of Location 2 must use a ferry to cross the harbour, which increases the amount of time they must spend commuting. This means that access to jobs via the transport network is higher in Location 1, ie a1 > a2.

Land in each location is owned by a single firm, which develops rental housing at per-unit cost c. There are N households in the city, who each earn the same average income Y but differ in terms of preference for better transport access. Preference for access is distributed continuously on the interval . For notational convenience, assume that . Households derive the following utility from choosing location i:

Households with high preference for transport access therefore sort themselves into Location 1, and households with low preference sort into Location 2. In equilibrium, the utility of choosing either location must be equalised for the marginal household, which is the household with :

We can rearrange this (and cancel out the Y’s) to show that the marginal household is located at:

Turning now to the land owners/developers, we can write the expected profits in each location as a function of market share, prices, and costs:

If we assume that firms are in Bertrand competition (ie competing on price, rather than quantity), then we can substitute the expression for into each profit function, calculating first order conditions for profit maximisation (ie ), and using the resulting system of equations to solve for equilibrium prices and market shares. This results in the following outcomes:

Aggregate profits (a measure of price-cost markups) are given by:

Rents in both locations are an increasing function of , which means that *reducing* differences in access to jobs between locations, eg by building a bridge across the harbour, will reduce overall housing prices. Intuitively, this reflects the fact that the land owner in the more accessible location is less able to charge a premium for better access. , which means that building a bridge is also expected to reduce price-cost markups (ie firms’ excess profits). This is a desirable feature of the model.

However, is *not* a function of in this model, which means that the share of households living in each location is not expected to change if a bridge is constructed. Moreover, because this model assumes that firms provide enough housing to serve all households, the total quantity of housing produced does not change. These are both unrealistic outcomes that highlight the limitations of this model.

This approach has several fatal flaws.

First, while many alternative housing locations can be differentiated based on a transport accessibility measure, it it is not straightforward to extend the vertical differentiation model to include many model zones. A brief review of the theoretical literature related to this model did not find any clear examples of how this could be done. Experimentation with discrete increases to the number of model zones (eg going from two to three zones) suggests that the computational complexity of the model would rapidly increase due to the need to solve for a large number of potential ‘corner solutions’ in which some zones experience no development.

Second, the treatment of housing demand in the vertical differentiation model is inconsistent with how strategic transport models (and other land use models) treat households. The vertical differentiation model assumes that households are homogenous in terms of income, household size, etc, but that they differ on preference for accessibility. Strategic transport models typically segment households based on observable characteristics and assume that households in each segment have the same preferences for travel. This would make it difficult to couple this model to a transport forecasting model.

## Dead end 3: Regional model of transport investment and house price distortions

Third, I investigated whether it was possible to estimate a simple regional model of the relationship between transport investment and house price distortions. This approach would build upon previous work by Nunns (2020) that (a) derived estimates of regional house price distortions using microdata on housing sales and (b) calibrated a spatial equilibrium model of inter-regional location choice that allowed people to relocate between cities in response to changes in house prices.

This model would ‘bypass’ detailed modelling of the impact of transport investments on land use and local housing supply dynamics. Instead of simulating changes that take place within cities, it would focus on estimating aggregate effects.

I therefore considered the following model process:

* Step 1: Source data on transport investment and house price distortions at the territorial authority level over a multi-year period.
* Step 2: Undertake an econometric analysis of the relationship between transport investment (ie spending on new / improved transport infrastructure) and land price distortions.
* Step 3: Using the coefficients from this econometric model, predict how much house prices would change in response to a given dollar amount of investment in new / improved transport infrastructure.
* Step 4: Plug in estimated changes to house prices Nunns’s (2020) inter-regional spatial equilibrium model to predict changes to regional population.
* Step 5: Use results from steps 3 and 4 to calculate increased competition WEBs for housing development, using the procedure set out in the scoping report.

I attempted to implement this approach using data on regional land price distortions from Nunns (2020) and territorial authority-level transport funding data for the 2008-2018 period. In previous research, I showed that three measurable constraints to housing supply have a positive impact on land price distortions.[[22]](#footnote-22) I hypothesised that greater per-capita transport investment would tend to reduce land price distortions by overcoming barriers to housing development and strengthening competition between landowners.

I therefore estimated the following equation, where pi = land price distortion in region i in the 2015-2017 period; ti = per-capita spending on new and improved transport infrastructure over the 2008-2018 period; Xi is a vector of other housing supply constraints measured in the early/mid 2000s; ei is a random error term; and Greek letters are coefficients to be estimated.

***Equation 18: Transport investment and regional land price distortions***

The problem with this approach is that ti is potentially endogenous. That is, if planners expect a region to grow strongly, they may choose to invest more in it. As faster growth tends to push up housing prices, especially in the presence of supply constraints, this can lead to bias in estimates of the impact of ti on pi. To correct for this, I searched for instrumental variables that could provide plausibly exogenous variation in ti. I posit that historical infrastructure provision (proxied by the existing stock of roads per capita) and political incentives (which I proxied by the National Party vote share in the 2008 General Election, which is in turn negatively correlated with votes for left-wing parties) may influence present-day infrastructure spending.

However, I found that historical infrastructure provision and voting patterns in general elections were not related to subsequent transport spending patterns, meaning that these measures are not valid instrumental variables. This meant that it was not possible to convincingly address the endogeneity issue described above.

Ordinary least squares estimation of the above equation, which does not control for endogeneity in transport spending patterns, suggests a positive but statistically insignificant relationship between transport spending and land price distortions. This is potentially consistent with several alternative hypotheses:

* Transport investment is endogenous to regional house prices, as both are affected by expected growth rates
* Recent transport investment has been poorly targeted to unlocking housing development, meaning that we can observe no average relationship between spending and house prices
* The sample size (75 territorial authorities) is is too small to precisely estimate the impacts of transport investment on land price distortions.

In short, at this stage it is not possible to estimate a parameter that summarises the relationship between transport investment and land price distortions at the regional level. This is a fatal flaw for this modelling approach.

## Dead end 4: Expanded model of the housing supply chains

Fourth, I considered a modelling approach outlined by Martinez and Roy (2004) and Martinez and Henriquez (2007). This model treats housing development as a ‘chain’ of markets, leading from landowners (who decide whether or not to release land for development) to land developers (who buy undeveloped land and choose how to subdivide it) to housing developers (who buy subdivided sites and choose what type of building to construct on them) to home-buyers or renters.

The following diagram summarises this chain of markets.

***Figure 6: Martinez and Roy’s model of housing development***



Martinez and Roy develop a system of equations to represent this process. At each stage, they implement a probabilistic model for development decisions. Developers are assumed to maximise profits, but a degree of heterogeneity between different developers (or model zones) means that different estimated profit rates will be accepted in different places. This results in a supply model that resembles a multinomial logit model – the share of total development that occurs in each zone is a function of prices and costs in that zone, relative to other zones.

Importantly, Martinez and Roy explicitly address the issue of whether development markets are perfectly competitive or whether they exhibit imperfect competition. They model imperfect competition by assuming that land owners and land developers are ‘price-setters’ rather than ‘price-takers’. That is, developers anticipate buyers’ willingness to pay for locations and choose a price and quantity combination that maximises their profit.

The exact behaviour of this housing supply model depends upon whether and how buyers are willing to substitute between living in different model zones. This substitutability in turn depends upon how households’ utility functions are defined.

Martinez and Henriquez (2007) provide further detail on the specification of the housing demand function and the housing supply function. They do not explicitly address substitution patterns in households’ utility function, but instead suggest that a development cost function could be specified to account for spillovers between alternative model zones, such as development in one zone driving up cost in another zone. However, the version of the model that they solve and apply to an example case does not include spillovers between zones.

This model outlines many of the conceptual issues that are important to this project and proposes a general approach that could be adapted to development of a specific model. However, there are two fatal flaws to this approach.

First, as Martinez and Roy note, it is not clear whether it is possible to calibrate an imperfect competition model of housing development to a real-world city. Nor is it clear that this model would arrive at a unique equilibrium.

Second, while the model can in theory capture spillover between alternative model zones, and hence the potential for investments that improve access to increase competition, there is no straightforward way to implement this. This makes it challenging to implement a realistic model that captures the effects of interest.

# Appendix: Data sources and data preparation

This appendix summarises the underlying data sources used in model estimation and describes how data was prepared, including data cleaning and matching.

For model estimation, all data was matched to 2013 Census area units. There are 203 Census area units in the Wellington region, most of which fall within the Wellington City, Lower Hutt City, Porirua City, Upper Hutt City, and Kapiti Coast District territorial authorities that include the bulk of urban Wellington.

## Observed commuting flows (Njk)

Observed commuting flows between 2013 Census area units were obtained from a custom data request to Statistics New Zealand. This data was used in previous research on transport improvements and land use change (Nunns, 2019). Because there are 203 Census area units in the Wellington region, this results in 41,209 origin-destination pairs.

Statistics NZ confidentialises data like commuting flows by randomly rounding to multiples of three. This results in some inaccuracy for small commuting flows, but previous analysis has showed that this is not material for coefficient estimation.

## Average travel times (GCjk)

Average travel times by car and public transport were estimated using outputs from the Wellington Transport Strategy Model (WTSM), which is a four-step transport forecasting model used for transport forecasting and project analysis.[[23]](#footnote-23) Outputs from the 2013 base year of the model were used.

WTSM models travel flows and travel times between 225 model zones. These zones do not exactly align with 2013 Census area units and as a result it was necessary to resample them to Census area units based on the share of land area in each model zone that falls within each Census area unit. For instance, if a WTSM zone overlapped two area units, travel demands would be proportionately allocated to the area units.

As a measure of travel cost, I used demand-weighted average travel time across both car and public transport modes. If car users accounted for 80% of total people travelling between two locations, car travel times would be assigned an 80% weight and public transport travel times a 20% weight.

Generalised cost is a potential alternative measure of travel cost. This includes both travel time and the financial cost of travel, weighted according to the estimated value of travel time.

## House prices (Pj)

I undertook an econometric analysis of residential property sales microdata to construct quality-adjusted house price estimates for each suburb. The derivation of these values is explained in the following appendix.

House sale data was sourced from Wellington region territorial authorities, who gather this data as an input to three-yearly rating revaluations. This data is coded to Census area units.

House price data was cleaned according to the following rules:

* Only sales within the Wellington region were included, and sales that could not be matched to a Census area unit were excluded
* Non-residential property sales, sales of vacant lots, and sales of residential lots with extremely small (<30m2) or large (>500m2) buildings were excluded
* Residential sales with large (>1ha) sections were excluded as these are lifestyle blocks or farm properties rather than urban residential properties
* Sales with missing data on key variables (land area, floor area, etc) were excluded, as were sites with zero or negative sale prices
* Sales of dwellings with land (ie not apartments) were excluded if the dwelling site coverage exceeded total site area
* The top and bottom 0.5% of the house price / capital value distribution were excluded
* Indicator variables were constructed to identify sales with missing data on building / roof construction or condition or views
* Sale prices were adjusted to 2017Q1 prices using Statistics New Zealand’s Consumer Price Index.

## Number of dwellings (Hj)

The total number of occupied and unoccupied dwellings in each Census area unit was obtained from published Census tables.[[24]](#footnote-24)

## Development capacity (Kj)

Wellington’s five urban territorial authorities recently undertook a major planning exercise that included an assessment of how much capacity for new dwellings is enabled by existing district plans. This assessment included both greenfield housing capacity (ie new subdivisions) and capacity for infill and redevelopment in existing urbanised areas. Wellington City Council’s (2019) *Wellington Housing and Business Assessment* report published estimates of housing development capacity at a suburb level for these five councils, based on 2018 data on property boundaries, location of existing buildings, and zoning codes.[[25]](#footnote-25)

The following table summarises total dwelling capacity by council area, broken down between infill/redevelopment capacity and greenfield subdivision capacity. Note that the measure used here is plan-enabled capacity – ie what district plans allow to be built – rather than commercially feasible or realisable capacity – ie what developers may currently see as profitable to build.

Table 9: Plan-enabled capacity for additional dwellings in Wellington urban area

|  |  |  |  |
| --- | --- | --- | --- |
| **Council area** | **Infill / redevelopment capacity** | **Greenfield subdivision capacity** | **Total plan-enabled capacity** |
| Wellington City | 103,783 | 2,628 | 106,411 |
| Lower Hutt City | 39030 | 2,210 | 41,240 |
| Upper Hutt City | 15,488 | 2,818 | 18,306 |
| Kapiti Coast District | 19,785 | 3,350 | 23,135 |
| Porirua City | 36,084 | 6,629 | 42,713 |
| **Total urban area** | **214,170** | **17,635** | **231,805** |

*Source: Table 1.9 in Wellington Housing and Business Assessment (2019)*

For several councils, the suburb definitions used in the report differed from 2013 Census area units. As a result, it was necessary to resample capacity data to Census area units based on the share of land area in each council-defined suburb that falls within each area unit. For instance, if a suburb overlapped two area units, capacity would be proportionately allocated to the area units.

Dwelling capacity estimates were available for 176 Census area units. Capacity data was not available for all Census area units within the region, as the focus of the assessment was on urban and future urban areas. Rural areas typically have some dwelling development capacity, eg from large-lot subdivisions that are allowed by rural zoning, but this was not assessed in the report. If proportional allocation rules only allocated a small amount of development capacity to a given area unit (<10 dwellings), then that area unit was discarded.

To obtain an estimate of total development capacity in each area unit, including both existing and new dwellings, I added together capacity for new dwellings with Census data on the number of total dwellings in 2013.

# Appendix: Model estimation and robustness checks

This section provides further detail on model estimation, including statistical methods and robustness checks. All model estimation has been conducted in R, an open-source statistics package. The following packages were used for econometric analysis and model estimation: ‘AER’, ‘car’, ‘fixest’, and ‘lmtest’.

## Estimating location choice model

I estimate the household location choice model in two stages. First, I estimate the commuting flow model described in ***Equation 4***. Second, I estimate a supplementary model of the impact of higher quality-adjusted house prices on the underlying attractiveness of home locations, as described in ***Equation 5***. Finally, I combine the results from these models into a single location choice model.

Extensions to this basic model are possible. This could include:

* Extending the model of home location attractiveness to include other amenities, such as parks, schools, or other local public goods
* Estimating a model of work location attractiveness that accounts for the impact of wages and other amenities and/or incorporates an agglomeration function.

### Commuting flow model

I begin by estimating a Poisson regression model that corresponds to ***Equation 4***. I use a Poisson regression model due to the fact that the dependent variable, the number of people observed to commute between home location j and work location k (Njk), is a ‘count’ variable that is not normally distributed.[[26]](#footnote-26)

This regression model includes fixed effects for both home and work locations. These fixed effects capture the underlying desirability of living or working in a given place, controlling for transport access to that place. For instance, people may have a preference for living by the beach or living in ‘desirable’ school zones, or a preference for working in places that offer high wages or diversity of economic opportunities. These factors will be reflected in more positive fixed effects for those locations. Due to the large number of fixed effects in this model, I estimate it using the ‘fixest’ package in R.

The major challenge in credibly estimating the coefficient on the travel time variable is that average travel times are endogenous to commuting flows. This can happen through several mechanisms. On the one hand, larger car commuting flows result in traffic congestion, which may cause downward bias in the coefficient estimate. On the other hand, transport agencies may respond to high demand for commuting between locations by improving transport infrastructure or services to reduce travel times, which may cause upward bias in the coefficient estimate.

To address this issue, I estimate this model using a control function approach with instruments for the endogenous variable (Train, 2009). This entails estimating the following first stage regression via ordinary least squares, saving the fitted residuals (), and including these residuals as control variables in the second stage equation. The idea behind this approach is that, provided that the instruments are exogenous, the fitted residuals will account for the endogenous component of .

Equation 19: First stage regression for control function estimation of commuting flow model

***Equation 20: Control function estimation of commuting flow equation***

I use three instruments based on physical geography. These are: Straight-line distance between origin and destination, average slope along that straight line, and share of that straight line that falls over water rather than land. Geographic barriers have a plausibly exogenous impact on travel times between locations as they pre-exist travel demands and drive up the cost to supply transport infrastructure. (Bridges and tunnels tend to be more expensive than roads through flat terrain.) These instruments are strongly positively correlated with travel times (indicating that they are relevant instruments). Fitted residuals from the first stage model are statistically significant in the second-stage model, indicating that endogeneity is likely to be present.

Table 5 summarises results from five alternative specifications for the commuting flow regressions. The first three columns report results from Poisson regressions that do not control for potential endogeneity between travel time and commuting flows. The last two columns report Poisson regression models that use instrumental variables to control for endogeneity. These alternative specifications show that:

* Across all specifications, longer travel times have a negative impact on commuting flows after home and work location fixed effects are included.
* Poisson model 1 shows that longer car travel times and longer PT travel times have a negative effect on commuting flows. The coefficient on car travel times is around 50% higher, but this highlights the fact that both modes can affect location choices.
* Controlling for endogeneity results in a small increase in the coefficient on travel time (eg -0.10 in IV Poisson model 1 vs -0.095 in Poisson model 1).
* First stage residuals are strongly statistically significant, which highlights the likely presence of endogeneity.

The preferred model is IV Poisson model 1, which has a coefficient of -0.10 on average AM peak travel times, excluding PT boarding time.

Note that standard errors have not been corrected to account for the two-stage estimation approach. This can be done by bootstrapping standard errors.

Table 10: Commuting flow regressions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Explanatory variable** | **Poisson model 1** | **Poisson model 2** | **Poisson model 3** | **IV Poisson model 1** | **IV Poisson model 2** |
| Car travel time (AM peak) | -0.0492\*\*\* |  |  |  |  |
|  | (0.0099) |  |  |  |  |
| PT travel time (ex boarding time, AM peak) | -0.0332\*\*\* |  |  |  |  |
|  | (0.0069) |  |  |  |  |
| Average travel time (ex boarding time, AM peak) |  | -0.0949\*\*\* |  | -0.1008\*\*\* |  |
|  |  | (0.0036) |  | (0.0036) |  |
| Average travel time (incl boarding time, AM peak) |  |  | -0.0829\*\*\* |  | -0.0887\*\*\* |
|  |  |  | (0.0036) |  | (0.0035) |
| First stage residuals (control function) |  |  |  | 0.054\*\*\* | 0.0566\*\*\* |
|  |  |  |  | (0.0042) | (0.0043) |
| Origin area unit fixed effects | Yes | Yes | Yes | Yes | Yes |
| Destination area unit fixed effects | Yes | Yes | Yes | Yes | Yes |
| Observations | 41,209 | 41,209 | 41,209 | 41,209 | 41,209 |
| SE type: Two-way | by: AU20. & AU20. | by: AU20. & AU20. | by: AU20. & AU20. | by: AU20. & AU20. | by: AU20. & AU20. |
| Pseudo R2 | 0.86332 | 0.84886 | 0.8435 | 0.86747 | 0.86379 |
| BIC | 167,495 | 184,283 | 190,505 | 162,671 | 166,950 |

*Statistical significance indicators: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1*

Table 6 reports first stage regression results. Residuals from these models were used as the control function for IV Poisson models above. First-stage models are highly statistically significant (as shown by the F-stat for the entire model and the highly statistically significant coefficients on each of the three instrumental variables.

Table 11: First stage regressions for control function Poisson models

|  |  |  |
| --- | --- | --- |
| **Outcome variable** | **Average travel time (ex boarding time, AM peak)** | **Average travel time (incl boarding time, AM peak)** |
| **Corresponding commuting flow model** | **IV Poisson model 1** | **IV Poisson model 2** |
| Average slope between origin and destination (%) | 169.4476\*\*\* | 167.9611\*\*\* |
|  | (17.6182) | (18.3113) |
| Share of straight line that falls over water (%) | 27.6643\*\*\* | 26.8099\*\*\* |
|  | (2.4986) | (2.6477) |
| Straight line distance (km) | 1.1786\*\*\* | 1.3382\*\*\* |
|  | (0.0423) | (0.0489) |
| Origin area unit fixed effects | Yes | Yes |
| Destination area unit fixed effects | Yes | Yes |
| Observations | 41,209 | 41,209 |
| SE type: Two-way | by: AU20. & AU20. | by: AU20. & AU20. |
| R2 | 0.91526 | 0.90884 |
| F-stat (df=407; 40801) | 1083\*\*\* | 999.5\*\*\* |

*Statistical significance indicators: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1*

### Home location attractiveness

After estimating the above model, I estimate a model of home location attractiveness as a function of local housing prices. This model is as described in ***Equation 5***. Home location fixed effects from the commuting flow model (Uj) are used as the dependent variable. The explanatory variable of interest is the natural log of quality-adjusted house prices (Pj), the derivation of which is explained below.

All else equal, I would expect a negative relationship between local house prices and home location attractiveness, as higher house prices tend to discourage people from choosing a given location. However, the impact of transport accessibility or other localised amenities such as schools, parks, or beaches is typically capitalised into house prices. This introduces the potential for upward bias into my estimate of the impact of local housing prices on home location attractiveness.

However, home location fixed effects exclude the impact of transport accessibility as this is separately measured in the commuting flow model. This eliminates the primary source of upward bias in coefficient estimates. Estimating the model using ordinary least squares results in a large and negative coefficient estimate, which suggests that this strategy is effective. Including controls for other measurable amenities may further increase the magnitude of this coefficient.

Table 7 summarises results from home location attractiveness regression models. Five models are estimated, using fixed effects from each of the five commuting flow models estimated above. The explanatory variable in each model is the average quality-adjusted house price in each area unit. (This measure is explained below.)

Higher house prices are strongly negatively correlated with home location fixed effects from all five commuting flow model specifications. This suggests that, controlling for transport access, higher house prices have a negative impact on local housing demand. Coefficients are larger (more negative) in the IV Poisson model specifications.

As the preferred commuting flow model is IV Poisson model 1, the preferred coefficient on housing demand in the home location attractiveness model is -4.50.

Lastly, note that these models are parsimonious and do not include variables for other amenities or disamenities. They could be extended to include further variables, such as school zones, beaches, parks, etc.

Table 12: Home location attractiveness regression models

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Outcome variable** | **Home location fixed effects** | **Home location fixed effects** | **Home location fixed effects** | **Home location fixed effects** | **Home location fixed effects** |
| **Corresponding commuting flow model** | **Poisson model 1** | **Poisson model 2** | **Poisson model 3** | **IV Poisson model 1** | **IV Poisson model 2** |
| Quality-adjusted house prices (demeaned, natural log) | -2.512\*\*\* | -3.481\*\*\* | -3.237\*\*\* | -4.495\*\*\* | -4.287\*\*\* |
|  | (0.277) | (0.311) | (0.295) | (0.369) | (0.354) |
| Constant | 5.289\*\*\* | 4.986\*\*\* | 5.003\*\*\* | 5.084\*\*\* | 5.124\*\*\* |
|  | (0.132) | (0.148) | (0.140) | (0.176) | (0.168) |
| Observations | 195 | 195 | 195 | 195 | 195 |
| R2 | 0.298 | 0.394 | 0.383 | 0.434 | 0.432 |
| F Statistic (df = 1; 193) | 82.023\*\*\* | 125.491\*\*\* | 120.055\*\*\* | 148.039\*\*\* | 146.986\*\*\* |

*Statistical significance indicators: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01*

## Local housing supply model

I estimate several versions of the housing supply model described in ***Equation 13*** / ***Equation 15***. To enable estimation via ordinary least squares or two-stage least squares regression, I log-transform this equation to obtain the following econometric model specification. This specification estimates log-transformed quality-adjusted house prices in home location j as a function of dwelling density relative to development capacity in the area (Hj/Kj) and available development capacity in nearby locations (the second term, which is included only in the extended model specification.) A vector of other location-specific controls is also included if needed to ensure unbiased estimation of key model parameters. Location-specific cost shifters (Cj) are subsumed into the error term ().

I estimate several variants of this model with different specifications of the dwelling density variable and including and excluding the variable for available development capacity in nearby locations.

***Equation 21: Local housing supply regression model***

The primary challenge to estimating this model is that dwelling density and house prices are endogenous. This is illustrated in the following diagram. Higher dwelling density (relative to development capacity) is expected to increase local housing prices due to increased competition for a limited quantity of development sites. However, if some areas are attractive for other, underlying reasons, this may increase both house prices (due to capitalisation effects) and density (due to the fact that more people want to be there). This may bias coefficient estimates.

Figure 7: Endogeneity in housing supply equation



There are several strategies for addressing this issue. The first is to include additional variables that control for underlying attractiveness. I use the following variables:

* Indicator variables for territorial local authorities (TLAs): These control for differences in underlying attractiveness at a relatively ‘coarse’ level as there are five TLAs in the Wellington urban area.
* An effective job density (EJD) variable: This measures travel-time weighted access to employment from home locations. It controls for attractiveness due to better access to economic opportunities. The calculation of this measure is defined in the section on calculation of agglomeration benefits in NZ Transport Agency’s (2020) *Monetised Benefits and Costs Manual*.
* Average income in the home suburb: Higher-income people tend to ‘sort’ into areas with good access to jobs or high levels of amenity, and therefore average incomes may serve as a control for underlying attractiveness. Lagged incomes from the 2001 Census are used to reduce endogeneity issues.

The second strategy to use instrumental variables for the dwelling density and development capacity variables to control for endogeneity. The literature suggests several potential instrumental variables. Severn (2019) calculates a Bartik-style shift-share instrument for changes in local density in a housing supply regression. Hyslop et al (2019) tests lagged population density and lagged immigrant share as instruments in a similar regression, but finds that they are weak instruments. Grimes et al (2016) find that the proximity to historical infrastructure have a long-run impact on urban population growth in New Zealand.

After some investigation, I use instruments based on Grimes et al (2016). These are straight-line distance to the nearest pre-1890 port (Wellington Port, which was located in the Lambton area unit prior to its expansion and relocation to a slightly more northerly location in the mid-20th century) and indicators for the second-, third- and fourth-closest pre-1890 ports.[[27]](#footnote-27) The argument for using these instruments is that locations that were close to historical ports were developed earlier, which has a positive impact on dwelling density (as older suburbs tend to have smaller residential lots than newer suburbs) and a negative impact on development capacity (as smaller lots are harder to redevelop, and district plans often limit demolition and redevelopment of pre-1930 buildings).

A threat to instrument exogeneity is that port proximity may have a positive impact on present-day economic outcomes. However, this threat is mitigated by the fact that (a) improvements to land transport have reduced the economic importance of close proximity to ports and (b) several of the historical ports used as instruments have closed down. Remaining issues can be addressed by including controls for present-day access to economic opportunities (ie the effective job density measure mentioned above).

The F-stat from the first-stage regression suggests that these instruments are relevant, while a Sargan Chi overidentification test fails to reject the null hypothesis that the instruments are exogenous.[[28]](#footnote-28) This suggests that these instruments are likely to be valid.

I estimate twelve permutations of this basic model, including both instrumented and non-instrumented models and including different permutations of dependent variables and control variables. OLS models are reported in Table 8, while IV models are reported in Table 9.

The preferred model (IV 1b) is highlighted in grey. This model is preferred as it best corresponds to the underlying economic model outlined above, incorporates the full set of control variables, and controls for endogeneity using an instrumental variables approach.

The key findings from this analysis are as follows.

First, area units that are more built out (defined either by dwellings/development capacity or dwellings/land area) have higher house prices even after including controls for access to jobs and the presence of amenities. This finding is qualitatively consistent across both OLS and IV models, indicating that density does increase the cost of housing supply as expected.

Second, my chosen instruments (proximity to pre-1890 ports) appear to be valid. In four out of six IV models, I reject the null hypothesis of weak instruments at the 1% level. (In models 1a and 3a, the weak instruments test has a p-value of just over 10%.) In five of six models, I fail to reject the null hypothesis of instrument exogeneity on the Sargan Chi test at the 10% level. (In model 1a, the Sargan Chi test has a p-value of 9.4%.)

Third, IV models result in higher estimates of the housing supply parameter. For instance, IV model 1b (the preferred model) provides a parameter estimate of 0.289, while the corresponding OLS model (1b) provides a parameter estimate of 0.103. This suggests that endogeneity between density and house prices leads to *downward* bias in parameter estimates. This is consistent with the idea that residents are mobile within cities and highly sensitive to local house prices – developers who build in high-cost locations without attractive amenities may find that they are unable to sell at a price that fully covers their costs and expected profits.

Fourth, models 3a and 3b include a variable for access to development capacity in other zones. This is intended to capture the impact of competition from landowners in nearby areas on local land prices. However, the sign on this variable is positive, rather than negative, in most specifications, and it is not statistically significant in IV model 3b, which includes other controls. As a result, I conclude that there is no strong case to include a competition term in the model.[[29]](#footnote-29)

Finally, as a specification test, I estimated variants of OLS and IV models 1b that include separate variables for dwellings and development capacity. The underlying economic model implies that the coefficients on these variables should sum to zero. (IE coefficient on dwellings = and coefficient on development capacity = .) Table 10 summarises the results of this specification test. Coefficients on these two variables are similar in magnitude. A linear restrictions test fails to reject the null hypothesis that they sum to zero in either OLS or IV models (at the 10% significance level). This suggests that the model specification is appropriate.

Table 13: Housing supply regression models (OLS)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Model specification** | **OLS 1a** | **OLS 1b** | **OLS 2a** | **OLS 2b** | **OLS 3a** | **OLS 3b** |
| **Outcome variable** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** |
| ln(dwellings/development capacity) | 0.078\*\* | 0.103\*\*\* |  |  | 0.137\*\*\* | 0.068\*\*\* |
|  | (0.039) | (0.025) |  |  | (0.040) | (0.024) |
| ln(dwellings/land area) |  |  | 0.106\*\*\* | 0.048\*\*\* |  |  |
|  |  |  | (0.025) | (0.014) |  |  |
| ln(inverse transport cost-weighted development capacity in other zones) |  |  |  |  | 0.373\*\*\* | -0.471\*\*\* |
|  |  |  |  |  | (0.057) | (0.083) |
| ln(effective job density) |  | 0.389\*\*\* |  | 0.291\*\*\* |  | 0.555\*\*\* |
|  |  | (0.064) |  | (0.064) |  | (0.068) |
| ln(median personal income, 2001) |  | 0.280\*\*\* |  | 0.317\*\*\* |  | 0.322\*\*\* |
|  |  | (0.050) |  | (0.056) |  | (0.044) |
| TLA fixed effects |  | Yes |  | Yes |  | Yes |
| Constant | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 165 | 164 | 165 | 164 | 165 | 164 |
| R2 | 0.023 | 0.715 | 0.184 | 0.711 | 0.168 | 0.781 |
| F Statistic | 3.784\* (df = 1; 163) | 55.932\*\*\* (df = 7; 156) | 36.705\*\*\* (df = 1; 163) | 54.742\*\*\* (df = 7; 156) | 16.338\*\*\* (df = 2; 162) | 68.923\*\*\* (df = 8; 155) |

Table 14: Housing supply regression models (IV)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Model specification** | **IV 1a** | **IV 1b** | **IV 2a** | **IV 2b** | **IV 3a** | **IV 3b** |
| **Outcome variable** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** |
| ln(dwellings/development capacity) | 1.096\*\*\* | 0.289\*\*\* |  |  | 1.160\*\*\* | 0.585 |
|  | (0.423) | (0.083) |  |  | (0.395) | (0.694) |
| ln(dwellings/land area) |  |  | 0.370\*\*\* | 0.182\*\*\* |  |  |
|  |  |  | (0.060) | (0.070) |  |  |
| ln(inverse transport cost-weighted development capacity in other zones) |  |  |  |  | 0.681\*\*\* | 1.095 |
|  |  |  |  |  | (0.158) | (2.546) |
| ln(effective job density) |  | 0.442\*\*\* |  | 0.098 |  | 0.118 |
|  |  | (0.065) |  | (0.118) |  | (0.813) |
| ln(median personal income, 2001) |  | 0.303\*\*\* |  | 0.454\*\*\* |  | 0.233 |
|  |  | (0.084) |  | (0.103) |  | (0.244) |
| TLA fixed effects |  | Yes |  | Yes |  | Yes |
| Constant | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 165 | 164 | 165 | 164 | 165 | 164 |
| Weak instruments p-value (ln(dwellings/dev capacity) or ln(dwellings/land area)) | 0.102 | 0.000\*\*\* | 0.000\*\*\* | 0.003\*\*\* | 0.102 | 0.000\*\*\* |
| Weak instruments p-value (ln(dev capacity in other zones)) |  |  |  |  | 0.000\*\*\* | 0.000\*\*\* |
| Sargan Chi (p-value) | 0.094\* | 0.981 | 0.647 | 0.818 | 0.838 | 0.999 |

Table 15: Housing supply model specification test

|  |  |  |
| --- | --- | --- |
| **Model specification** | **OLS 1c** | **IV 1c** |
| **Outcome variable** | **ln(quality-adjusted house prices)** | **ln(quality-adjusted house prices)** |
| ln(dwellings) | 0.069\*\*\* | 0.306\*\* |
|  | (0.020) | (0.155) |
| ln(development capacity) | -0.066\*\*\* | -0.139\*\*\* |
|  | (0.021) | (0.052) |
| ln(effective job density) | 0.388\*\*\* | 0.371\*\*\* |
|  | (0.065) | (0.098) |
| ln(median personal income, 2001) | 0.265\*\*\* | 0.351\*\*\* |
|  | (0.048) | (0.122) |
| TLA fixed effects | Yes | Yes |
| Constant | Yes | Yes |
| Observations | 164 | 164 |
| Linear hypothesis test p-value. H0: ln(dwellings) coeff- ln(development capacity) coeff = 0 | 0.902 | 0.249 |

## Quality-adjusted house price estimates

Dwelling characteristics vary significantly between suburbs. Dwellings in the city centre tend to be apartments with fewer bedrooms and no garden space, while dwellings in outer suburbs tend to be larger houses with gardens. In general, developers and residents respond to higher land prices by building smaller, denser units to economise on land.

Using average house prices (or average rents) as the dependent variable in the housing supply equation will therefore cause downward bias in coefficient estimates. This is because the size and/or quality of housing will tend to be lower in denser areas.

To address this issue, I construct quality-adjusted house price estimates for each suburb by estimating a hedonic regression on residential property sales microdata. I estimate this model using My basic approach is summarised in the following equation. I regress log-transformed sale prices (pi,j) for property sale i in suburb j on a vector of dwelling and site characteristic variables (xi), plus a set of suburb fixed effects (dj).[[30]](#footnote-30) No location-related variables, such as distance to the city centre or coastlines, are included, as suburb fixed effects capture these impacts.

Equation 22: Hedonic regression for dwelling sale prices

Differences in observable dwelling and site characteristics between suburbs are captured in the coefficient on the vector of dwelling and site characteristics. Suburb fixed effects therefore provide (de-meaned) quality-adjusted house price estimates for each suburb. Positive fixed effects indicate that a suburb has higher housing prices than the reference suburb, and vice versa.

The following table summarises some key coefficient estimates from this model, as well as model statistics. The overall model is highly statistically significant (as indicated by the F-statistic) and it fits the data well (as indicated by the R2).

Table 16: Hedonic regression for dwelling sale prices

|  |  |  |
| --- | --- | --- |
| **Outcome variable** | **ln(sale price)** | |
| **Explanatory variables** | **Coeff** | **Std err** |
| ln(land area) | 0.058\*\*\* | 0.003 |
| Zero land area indicator | 0.304\*\*\* | 0.019 |
| ln(dwelling floor area) | 0.547\*\*\* | 0.004 |
| Apartment indicator | (base level) | |
| Standalone dwelling indicator | 0.242\*\*\* | 0.012 |
| Residential flat indicator | 0.119\*\*\* | 0.012 |
| Decade of construction | Y |  |
| Number of garages | Y |  |
| Building and roof construction and condition indicators | Y |  |
| View indicators | Y |  |
| Intensity ratio (improvement value / rateable value) | Y |  |
| Sale year / quarter indicators | Y |  |
| Suburb fixed effects | Y |  |
| Observations | 24,649 | |
| R2 | 0.865 | |
| F-statistic | 587.434\*\*\* (df = 265; 24383) | |

*Statistical significance indicators: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01*

The following table summarises quality-adjusted house price estimates for each suburb, the standard error for each value, and the number of dwelling sales recorded in each suburb. It also reports the natural logarithm of mean house prices in each suburb. As shown in the following chart, quality-adjusted house prices are strongly positively correlated with average house prices, but there are many outliers. For instance, the Lambton area unit (in the Wellington city centre) has a lower average sale price than the regional average, but after adjusting for the fact that most dwellings in this area are small apartments, it has a higher quality-adjusted house price.

Figure 8: Correlation between mean house prices and quality-adjusted house price estimates for Wellington suburbs



Table 17: Quality-adjusted house price estimates for Wellington suburbs

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Area unit** | **Number of sales** | **ln(mean sale price)** | **Suburb fixed effect** | **Std error** | **Area unit** | **Number of sales** | **ln(mean sale price)** | **Suburb fixed effect** | **Std error** | **Area unit** | **Number of sales** | **ln(mean sale price)** | **Suburb fixed effect** | **Std error** |
| Adelaide | 65 | 12.958 | 0.000 | NA | Karori Park | 265 | 13.006 | -0.189 | 0.024 | Paraparaumu Central | 566 | 12.776 | -0.574 | 0.023 |
| Adventure | 85 | 12.911 | -0.450 | 0.028 | Karori South | 262 | 13.169 | -0.139 | 0.024 | Paremata-Postgate | 155 | 13.150 | -0.324 | 0.025 |
| Akatarawa | 28 | 12.509 | -0.604 | 0.038 | Kelburn | 150 | 13.620 | 0.127 | 0.025 | Parkway | 170 | 12.507 | -0.668 | 0.025 |
| Alicetown | 122 | 12.928 | -0.295 | 0.026 | Kelson | 171 | 12.854 | -0.392 | 0.025 | Pauatahanui | 10 | 13.527 | -0.105 | 0.057 |
| Arakura | 99 | 12.299 | -0.809 | 0.027 | Khandallah Park-Broadmeadows | 193 | 13.312 | -0.158 | 0.025 | Peka Peka | 8 | 13.096 | -0.451 | 0.062 |
| Aro Street-Nairn Street | 84 | 13.143 | -0.025 | 0.028 | Kilbirnie East | 123 | 13.076 | -0.085 | 0.026 | Petone Central | 43 | 12.950 | -0.224 | 0.033 |
| Ascot Park | 129 | 12.745 | -0.555 | 0.026 | Kilbirnie West-Hataitai South | 127 | 13.230 | -0.053 | 0.026 | Pinehaven | 184 | 12.830 | -0.496 | 0.025 |
| Avalon East | 132 | 12.755 | -0.356 | 0.026 | Kingston-Mornington | 102 | 13.065 | -0.144 | 0.027 | Plimmerton | 102 | 13.196 | -0.207 | 0.027 |
| Avalon West | 127 | 12.927 | -0.279 | 0.026 | Kopuaranga | 9 | 12.466 | -0.979 | 0.059 | Poets Block | 139 | 12.778 | -0.466 | 0.026 |
| Awarua | 212 | 13.202 | -0.135 | 0.024 | Korokoro | 73 | 13.086 | -0.349 | 0.029 | Porirua East | 52 | 12.440 | -0.702 | 0.032 |
| Belmont | 142 | 13.111 | -0.364 | 0.026 | Lambton | 245 | 12.913 | -0.002 | 0.025 | Pukerua Bay | 126 | 12.965 | -0.410 | 0.026 |
| Berhampore East | 49 | 12.991 | -0.081 | 0.032 | Lansdowne | 258 | 12.466 | -0.887 | 0.024 | Rangoon Heights | 175 | 13.345 | -0.078 | 0.025 |
| Berhampore West | 113 | 12.999 | -0.113 | 0.026 | Linden | 207 | 12.832 | -0.424 | 0.024 | Ranui Heights | 61 | 12.655 | -0.531 | 0.030 |
| Boulcott | 143 | 13.073 | -0.220 | 0.026 | Lyall Bay-Airport-Moa Point | 159 | 13.109 | -0.045 | 0.025 | Raroa | 235 | 12.965 | -0.268 | 0.024 |
| Brentwood | 102 | 12.675 | -0.537 | 0.027 | Maidstone | 4 | 12.527 | -0.594 | 0.085 | Raumati Beach | 339 | 12.943 | -0.426 | 0.023 |
| Brooklyn | 161 | 13.270 | -0.046 | 0.025 | Makara-Ohariu | 12 | 13.104 | -0.224 | 0.052 | Raumati South | 226 | 12.922 | -0.406 | 0.024 |
| Brooklyn South | 57 | 13.087 | -0.121 | 0.031 | Mana-Camborne | 146 | 13.070 | -0.374 | 0.026 | Resolution | 17 | 13.470 | -0.341 | 0.045 |
| Cannons Creek East | 46 | 12.317 | -0.782 | 0.033 | Mangaroa | 16 | 12.836 | -0.518 | 0.047 | Riverstone Terraces | 145 | 13.158 | -0.507 | 0.026 |
| Cannons Creek North | 42 | 12.219 | -0.879 | 0.033 | Manuka | 79 | 12.747 | -0.558 | 0.028 | Roseneath | 91 | 13.702 | 0.198 | 0.028 |
| Cannons Creek South | 40 | 12.302 | -0.823 | 0.034 | Maoribank | 190 | 12.806 | -0.613 | 0.025 | Seatoun | 126 | 13.746 | 0.254 | 0.026 |
| Carterton | 403 | 12.490 | -0.868 | 0.023 | Martinborough | 173 | 12.706 | -0.629 | 0.025 | Seatoun Tunnel West | 43 | 13.362 | -0.030 | 0.033 |
| Churton Park North | 188 | 13.348 | -0.291 | 0.025 | Masterton Central | 26 | 12.417 | -0.923 | 0.039 | Solway North | 166 | 12.399 | -0.878 | 0.025 |
| Churton Park South | 227 | 13.112 | -0.232 | 0.024 | Masterton East | 163 | 12.221 | -1.056 | 0.025 | Solway South | 192 | 12.374 | -0.926 | 0.025 |
| Clouston Park | 202 | 12.746 | -0.559 | 0.024 | Masterton Railway | 15 | 12.070 | -1.120 | 0.048 | Strathmore Park | 126 | 13.239 | -0.082 | 0.026 |
| Cloustonville | 2 | 12.387 | -0.603 | 0.118 | Masterton West | 160 | 12.514 | -0.884 | 0.025 | Taita North | 129 | 12.608 | -0.658 | 0.026 |
| Crofton Downs | 112 | 13.103 | -0.173 | 0.026 | Maungakotukutuku | 1 | 13.002 | -0.469 | 0.166 | Taita South | 98 | 12.561 | -0.594 | 0.027 |
| Delaney | 121 | 12.556 | -0.700 | 0.026 | Maungaraki | 205 | 12.940 | -0.369 | 0.025 | Taitville | 19 | 13.148 | -0.077 | 0.043 |
| Discovery | 162 | 12.978 | -0.439 | 0.025 | Maupuia | 57 | 13.210 | -0.026 | 0.031 | Takapu | 4 | 13.428 | -0.368 | 0.085 |
| Eastbourne | 302 | 13.465 | 0.034 | 0.024 | Melling | 19 | 12.674 | -0.390 | 0.043 | Tawa Central | 231 | 12.877 | -0.391 | 0.024 |
| Ebdentown | 161 | 12.673 | -0.476 | 0.025 | Melrose-Houghton Bay-Southgate | 178 | 13.226 | -0.076 | 0.025 | Tawa South | 181 | 13.007 | -0.354 | 0.025 |
| Elderslea | 170 | 12.707 | -0.466 | 0.025 | Miramar | 113 | 13.112 | -0.048 | 0.026 | Tawhai | 186 | 12.612 | -0.613 | 0.025 |
| Elsdon-Takapuwahia | 52 | 12.507 | -0.692 | 0.031 | Miramar North | 108 | 13.189 | -0.023 | 0.027 | Te Horo | 31 | 12.850 | -0.579 | 0.037 |
| Emerald Hill | 164 | 12.775 | -0.528 | 0.025 | Miramar South | 178 | 13.197 | -0.067 | 0.025 | Te Kainga | 244 | 13.565 | 0.044 | 0.024 |
| Endeavour | 253 | 13.197 | -0.423 | 0.024 | Miramar West | 22 | 13.125 | -0.136 | 0.043 | Te Marua | 41 | 12.809 | -0.592 | 0.034 |
| Epuni East | 150 | 12.920 | -0.328 | 0.025 | Mitchelltown | 24 | 13.197 | -0.105 | 0.040 | Te Wharau | 17 | 12.703 | -0.761 | 0.046 |
| Epuni West | 136 | 12.960 | -0.294 | 0.026 | Moera | 51 | 12.477 | -0.574 | 0.031 | Thorndon-Tinakori Road | 248 | 13.222 | 0.095 | 0.024 |
| Esplanade | 122 | 13.021 | -0.146 | 0.026 | Mt Cook-Wallace Street | 226 | 13.073 | 0.067 | 0.024 | Tirohanga | 79 | 13.161 | -0.401 | 0.029 |
| Featherston | 169 | 12.216 | -1.058 | 0.025 | Mt Holdsworth | 18 | 12.808 | -0.766 | 0.045 | Titahi Bay North | 122 | 12.688 | -0.495 | 0.026 |
| Fernlea | 83 | 12.450 | -0.755 | 0.028 | Mt Victoria West | 206 | 13.419 | 0.243 | 0.025 | Titahi Bay South | 150 | 12.665 | -0.531 | 0.025 |
| Glendale | 151 | 12.384 | -0.792 | 0.025 | Naenae North | 159 | 12.479 | -0.620 | 0.025 | Totara Park | 188 | 12.638 | -0.493 | 0.025 |
| Glenside North | 27 | 12.718 | -0.382 | 0.038 | Naenae South | 160 | 12.534 | -0.605 | 0.025 | Trentham North | 150 | 12.548 | -0.523 | 0.025 |
| Greenacres | 71 | 13.041 | -0.431 | 0.029 | Newlands East | 44 | 13.084 | -0.309 | 0.033 | Trentham South | 18 | 12.984 | -0.484 | 0.045 |
| Grenada North | 33 | 13.067 | -0.426 | 0.036 | Newlands North | 155 | 12.834 | -0.285 | 0.025 | Tuturumuri | 12 | 12.560 | -0.803 | 0.052 |
| Grenada Village | 121 | 13.126 | -0.299 | 0.026 | Newlands South | 204 | 12.896 | -0.310 | 0.024 | Upper Hutt Central | 12 | 12.664 | -0.411 | 0.054 |
| Greytown | 194 | 12.897 | -0.515 | 0.025 | Newtown East | 144 | 13.150 | -0.027 | 0.025 | Vogeltown | 49 | 13.162 | -0.102 | 0.032 |
| Happy Valley-Owhiro Bay | 65 | 13.123 | -0.159 | 0.030 | Newtown West | 121 | 13.110 | -0.050 | 0.026 | Vogeltown West | 61 | 13.202 | -0.077 | 0.030 |
| Hataitai North | 192 | 13.367 | -0.007 | 0.025 | Ngaio South | 174 | 13.279 | -0.012 | 0.025 | Wadestown | 196 | 13.593 | 0.078 | 0.025 |
| Haywards-Manor Park | 17 | 12.979 | -0.500 | 0.045 | Ngaumutawa | 76 | 12.486 | -0.827 | 0.029 | Waikanae Beach | 285 | 12.944 | -0.484 | 0.024 |
| Heretaunga | 69 | 13.230 | -0.228 | 0.029 | Ngauranga East | 1 | 12.967 | -0.339 | 0.166 | Waikanae East | 190 | 12.859 | -0.562 | 0.025 |
| Heretaunga-Silverstream | 193 | 12.987 | -0.387 | 0.025 | Normandale | 110 | 12.971 | -0.384 | 0.027 | Waikanae Park | 140 | 12.929 | -0.489 | 0.026 |
| Holborn | 87 | 12.583 | -0.634 | 0.028 | Northland | 132 | 13.300 | -0.020 | 0.026 | Waikanae West | 409 | 12.855 | -0.452 | 0.023 |
| Homebush-Te Ore Ore | 3 | 12.577 | -0.723 | 0.098 | Northland North | 50 | 13.076 | -0.069 | 0.032 | Waingawa | 2 | 12.585 | -0.833 | 0.118 |
| Homedale East | 152 | 12.369 | -0.807 | 0.025 | Onepoto | 90 | 12.727 | -0.504 | 0.028 | Waitangirua | 57 | 12.312 | -0.800 | 0.031 |
| Homedale West | 105 | 12.355 | -0.779 | 0.027 | Opaki-Fernridge | 6 | 13.004 | -0.639 | 0.071 | Waiwhetu North | 61 | 12.840 | -0.311 | 0.030 |
| Hutt Central | 159 | 13.427 | -0.022 | 0.025 | Oriental Bay | 25 | 14.328 | 0.835 | 0.040 | Waiwhetu South | 172 | 12.744 | -0.430 | 0.025 |
| Island Bay East | 128 | 13.339 | -0.011 | 0.026 | Otaihanga | 70 | 13.020 | -0.502 | 0.029 | Wallaceville | 144 | 12.602 | -0.481 | 0.025 |
| Island Bay West | 156 | 13.297 | -0.036 | 0.025 | Otaki | 426 | 12.461 | -0.838 | 0.023 | Waterloo East | 211 | 13.057 | -0.230 | 0.024 |
| Johnsonville Central | 218 | 12.983 | -0.275 | 0.024 | Otaki Forks | 4 | 12.802 | -0.687 | 0.098 | Waterloo West | 50 | 13.199 | -0.127 | 0.032 |
| Johnsonville East | 77 | 13.030 | -0.317 | 0.028 | Paekakariki | 77 | 13.037 | -0.242 | 0.029 | Whareama | 26 | 12.890 | -0.615 | 0.039 |
| Johnsonville North | 98 | 12.983 | -0.283 | 0.027 | Papakowhai North | 108 | 13.018 | -0.409 | 0.027 | Wilford | 182 | 13.031 | -0.177 | 0.025 |
| Kahutara | 33 | 13.069 | -0.632 | 0.036 | Papakowhai South | 222 | 13.300 | -0.395 | 0.024 | Willis Street-Cambridge Terrace | 407 | 13.002 | 0.154 | 0.024 |
| Kaiwharawhara | 10 | 13.684 | 0.006 | 0.056 | Paparangi | 104 | 12.933 | -0.249 | 0.027 | Wilton | 102 | 13.120 | -0.089 | 0.027 |
| Karaka Bay-Worser Bay | 83 | 13.670 | 0.169 | 0.028 | Paparangi West | 70 | 12.936 | -0.214 | 0.029 | Woburn North | 81 | 13.487 | -0.026 | 0.028 |
| Karori East | 167 | 13.574 | 0.079 | 0.025 | Paraparaumu Beach North | 281 | 12.912 | -0.510 | 0.024 | Woburn South | 17 | 12.937 | -0.267 | 0.045 |
| Karori North | 146 | 13.470 | 0.043 | 0.025 | Paraparaumu Beach South | 424 | 12.921 | -0.454 | 0.023 | Woodridge | 120 | 13.188 | -0.269 | 0.026 |
| **Regional total / average** | **24702** | **12.998** | **-0.352** | **NA** |  |  |  |  |  |  |  |  |  |  |

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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. 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-7)
8. 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; Ahlfeldt and Pietrostefani, 2019). [↑](#footnote-ref-8)
9. 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-9)
10. These are agglomeration benefits, imperfect competition benefits, and labour supply benefits. [↑](#footnote-ref-10)
11. There is also a transfer of wealth between existing buyers and sellers. For instance, a general reduction in housing prices will benefit existing renters, who can pay less for their accommodation, while reducing the income of their landlords. This transfer has important distributional consequences but does not affect the net social benefits of a scheme. [↑](#footnote-ref-11)
12. See also Wegener (2004) for an earlier review. [↑](#footnote-ref-12)
13. , which means that costs are higher in zones with lower construction productivity. [↑](#footnote-ref-13)
14. This term is similar to the effective job density measure that is commonly used to calculate agglomeration potential. [↑](#footnote-ref-14)
15. This entails normalising housing supply to a per-worker basis. This normalisation has no impact on the interpretation of the model. [↑](#footnote-ref-15)
16. 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-16)
17. While instruments based on the location of historical infrastructure or historical infrastructure plans are widely used in the empirical literature (eg Duranton and Turner, 2012; Dalgaard et al, 2018), they are subject to theoretical and practical critique. For instance, Kelly (2019) argues that the presence of spatial autocorrelation – when outcomes in one place are correlated with outcomes in other nearby places – can invalidate these types of instruments. [↑](#footnote-ref-17)
18. This estimate assumes the presence of idiosyncratic preferences for specific locations or frictions to inter-regional mobility. If idiosyncratic preferences / frictions are disregarded, the model implies a higher demand elasticity in the range of -0.85 to -1.2. [↑](#footnote-ref-18)
19. We would expect supply constraints to be more binding at the local level than at the regional level, due to the fact that there are fewer alternative development opportunities at a local level. [↑](#footnote-ref-19)
20. See MBIE estimates published online at <https://mbienz.shinyapps.io/urban-development-capacity/>. [↑](#footnote-ref-20)
21. The ‘open city’ version of the model can be used to estimate changes in city size. Under this case, average housing plus transport costs return to their original level as the city ‘fills up’ again. [↑](#footnote-ref-21)
22. These factors were: a smaller supply of developable land that has not yet been built on, larger delays in processing resource consents, and higher development contributions, which indicate greater challenges funding development infrastructure. [↑](#footnote-ref-22)
23. Model documentation available online at <https://www.gw.govt.nz/wellington-transport-models-technical-reports/>. [↑](#footnote-ref-23)
24. Available online at <http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE8080> [↑](#footnote-ref-24)
25. There were not any major changes to district plans between 2013 and 2017/18, and thus these figures are unlikely to materially under- or over-state development capacity in 2013. They are less valid for earlier Census years as there were several significant district plan changes in the 2000s. [↑](#footnote-ref-25)
26. Alternatively, both sides of this equation could be log-transformed and the model could be estimated using linear regression. This is not possible due to the fact that zero commuters are observed for some origin-destination pairs, as the logarithm of zero is undefined. [↑](#footnote-ref-26)
27. After Wellington Port, the nearest ports were located at Castlepoint (Wairarapa), Wanganui, Picton, and Blenheim. Castlepoint and Blenheim are now defunct, and Wanganui only serves a small amount of shipping. [↑](#footnote-ref-27)
28. Sargan Chi tests whether coefficient estimates are stable when different instruments are included or excluded. Rejection of the null hypothesis indicates that at least one instrument is endogenous. Failure to reject the null hypothesis provides suggestive, but not conclusive, evidence that the instruments are exogenous. In principle, if all of the proposed instruments were endogenous, Sargan Chi would also fail to reject the null hypothesis. [↑](#footnote-ref-28)
29. I experimented with a number of different specifications for this variable, including different decay parameters on transport cost and specifications with hard cutoff thresholds. No alternative specification delivered fundamentally different results. [↑](#footnote-ref-29)
30. Dwelling and site characteristics include: log(land area), an indicator for sites with zero land area, dwelling floor area, dwelling type (standalone house, flat, multi-storey apartment), decade of construction, number of garagers / carports, sale quarter, building and roof condition and construction, views of land or water, and the ratio of improvement value to total rateable value (a measure of development potential – higher intensity ratios indicate sites with relatively more valuable buildings). These coefficients generally had the expected sign and relative impact. [↑](#footnote-ref-30)