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Measuring the Cost of Land inputs to Housing Construction

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Measuring the the Cost of Land Inputs to Housing Construction[*]

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Abstract

We propose a market indicator for tracking the cost of land inputs to housing production: Land cost per floor area (LCFA). LCFA is the ratio of land price to the maximum permissible floor area ratio (FAR) determined by local land use regulations (LURs). The salient feature of the indicator is that it captures the effects of policy changes on both the extensive (quantity) and intensive (price) margins of land costs. This makes it highly responsive to relaxations in LURs that enable intensification, such as upzoning, because these policies primarily act on the extensive margin by reducing the amount of land requied to build a dwelling. It also means that the indicator can be used used to assess the effects of policies that operate on the intensive margin, such as the relaxation of urban growth boundaries. In this briefing paper we provide the theoretical precepts of the LCFA indicator, describe its construction, and produce a prototype of the indicator based on changes in LURs under the Auckland Unitary Plan. The prototype suggests that upzoning under the AUP significantly reduced land input costs to construction.

Abbreviations:
AMM: Alonso-Muth-Mills
AUP: Auckland Unitary Plan
FAR: Floor Area Ratio
LCFA: Land Cost per Floor Area
LVCV: Land Value to Capital Value percentage
LUR: Land Use Regulation
MHS: Mixed Housing Suburban
MHU: Mixed Housing Urban
SH: Single House
THAB: Terraced Housing and Apartment Buildings
UGB: Urban Growth Boundary

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1 Introduction

Land is one of the most significant input costs to housing construction in New Zealand (Lees, 2019; Nunns 2021). The price of land is consequently a key focal point in the motivation and design of supply-side reforms to encourage housing construction and affordability. For example, the Randerson Report, which provides the framework for reforming the Resource Management Act, calls for "more use of land price data and analysis to inform regulatory decision-making" (p. 127) and states "[t]o assist analysis of regulatory stringency and its costs and benefits, aggregated land value data collected by local authorities could be made publicly available, so that informed and contestable cost-benefit analysis of local regulations can be undertaken" (Report of the Resource Management Review Panel, June 2020, p. 352–353).

However, policies to enable residential intensification act on the extensive margin of land costs (quantities), not the intensive margin (prices). For example, upzoning reduces the amount of land required to build a dwelling by relaxing height (and other) restrictions on residential structures. Regulatory reforms that are narrowly focused on reducing land prices therefore risk precluding policies that achieve housing affordability through intensification of existing residential areas.

Furthermore, both theory and evidence indicate that policies to encourage intensification can *increase* land prices. This further biases planning decisions against intensification when evaluated by their impact on land prices, rather than land costs. For example, under the canonical Alonso-Muth-Mills (AMM) model of urban development, the removal of restrictions on the capital intensity of dwellings increases land prices in areas of high demand, such as locations close to places of work (Bertaud and Brueckner, 2005, p.117–118). Empirically, Brueckner, Fu, Gu and Zhang (2017), Moon (2019) and Brueckner and Singh (2020) find that less stringent LURs are associated with higher land prices in US and Chinese cities, while Ihlanfeldt (2007) instruments for LURs and shows that towns in Florida with more stringent LURs have lower land prices.

The set of economic indicators that are currently mandated in planning decisions further work against intensification policies because they are primarily responsive to changes in land prices. For example, the National Policy Statement on Urban Development (2020) (NPS-UD) requires Housing and Business Development Capacity Assessments (HBAs) that include market and price efficiency indicators of housing affordability (NPS-UD, 2020, Section 3.23). These include land value as a percentage of capital value (LVCV) of developed parcels and urban-rural land price differentials.[1] LVCVs only decrease after teardown and replacement of existing land-intensive housing (e.g. detached single family dwellings) with capital-intensive housing (e.g. attached multi-family dwellings). The immediate impact of intensification policies on LVCVs will therefore operate via the intensive margin, meaning that LVCVs will *increase* in areas where intensification policies increase land prices. Price Cost Ratios, which compare land values of extant dwellings to current construction costs, suffer from the same problem. These indicators have been criticised for these and related reasons (Fairgray, 2021).[2]

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[1] These indicators are compiled by the Ministry of Housing and Urban Development (HUD).

[2] Canonical monocentric models of urban development (such as the AMM model) predict that cities with less

Local Councils require a measure of land input costs to construction that captures the impacts of planning decisions on both the intensive and extensive margins. This paper responds to this need by proposing Land Cost per Floor Area (LCFA) as an indicator of land costs. LCFA is the ratio of land prices (measured in dollars per area unit, such as square metres) to the maximum floor area ratio (FAR) effectively permitted in a residential zone.[3] The numerator is therefore increasing in the intensive margin of land costs, while the denominator is decreasing in the extensive margin. Because the denominator of the indicator is directly determined by LURs, the indicator immediately decreases in response to policies that increase (i.e. relax) effective FARs.

The indicator is also responsive to policies that act on the intensive margin of residential land costs, such as relaxations of the urban growth boundaries (UGBs) to enable increased supply of residential land. It can therefore also be used to assess the efficacy of planning decisions that lower land costs by targeting land prices.

Because it is responsive to both prices and quantities, LCFA offers policymakers with a single metric that can be applied to evaluate a variety of planning scenarios, thereby allowing them to compare and evaluate policies that operate on the intensive margin (relaxing an UGB) to policies that operate on the extensive margin (upzoning). The LCFA indicator can also be used as an event-based trigger for rezoning or expansion (see Productivity Commission, 2015).

The remainder of the paper is organized as follows. The following section presents the canonical AMM model and shows how upzoning decreases dwelling costs while increasing land prices in areas of high demand. This serves to underscore the need for land cost indicators that act on the extensive – not intensive – margin when evaluating intensification policies that enhance housing affordability. Section three then introduces the LCFA ratio and presents a simple prototype for Auckland over a period in which the AUP upzoned large areas of the city. The prototype illustrates the responsiveness of the ratio to a change in LURs – it immediately falls, reflecting the fact that upzoning reduces land input costs to housing production. We conclude with a brief discussion of how the prototype indicator can be further refined.

2 The Effects of Upzoning on Dwelling and Land Prices

In this section we use the AMM model to describe the anticipated impacts of upzoning on dwelling and land prices. We briefly overview the model before describing how it is used to model upzoning. We then calibrate the model to Auckland in order to demonstrate how upzoning increases land

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restrictive LURs will have higher land prices close to the CBD, and lower land prices far from the CBD, compared to a city with more restrictive LURs. Based on this, one might expect upzoning to eliminate urban-rural price differentials, since upzoning can be viewed as a transition from the former to the latter as the housing stock depreciates and housing is redeveloped to the capital intensity permitted by the less binding LURs. However, the ability of upzoning to eliminate urban-rural price differentials is impeded by a variety of factors, including downward stickiness in real estate prices (Greenaway-McGrevy and Haworth, 2020), durable housing, and in-migration in response to lower dwelling prices.

[3] The FAR is the ratio of floor area to land area. LURs can regulate this directly, or indirectly through restrictions on, for example, site coverage ratios and building height limits. Recession planes and setbacks interact with the geometry of individual parcels to further impact FARs on individual parcels.

prices in areas of high demand close to downtown. We extend the analysis to the case where households can in-migrate to the city to take advantage of lower dwelling prices, showing that land prices increase everywhere in the city.

2.1 The Alonso-Muth-Mills model

We provide a brief overview of a canonical AMM model. Households are located on a two-dimensional disk around a central business district. They commute to the CBD to work and earn a wage W. Households have Cobb-Douglas preferences described by

$$U\left(C, H\right) = C^{1-\alpha} H^{\alpha}$$

where C is the consumption numeraire (price set to unity) and H is housing floorspace. Their budget constraint is

$$C = W - tx - p\left(x\right) H$$

where x denotes the distance of their house to the CBD, t is the per distance cost of commuting, and $p\left(x\right)$ is dwelling rent at distance x.

Housing floorspace H is provided by developers using Cobb-Douglas production

$$H\left(K, L\right) = A K^{\gamma} L^{1-\gamma}$$

where L is land and K is capital K. Housing production exhibits diminishing marginal product of capital, reflecting the fact that 'building up' (i.e., adding more floorspace while holding land fixed) requires additional materials at lower levels to strengthen the building (Brueckner, 2011, p.35–36). Because production is constant returns to scale, we can define housing per unit of land as

$$h = \frac{H}{L} = A\left(\frac{K}{L}\right)^{\gamma} = A k^{\gamma}$$

where $k = K/L$ is the capital to land ratio. Developer profits per unit of land are then

$$p\left(x\right) h\left(k\right) - p_K k - r\left(x\right)$$

where $r\left(x\right)$ denotes per unit land rent at x. Developers profit-maximise and earn zero profits. Under these assumptions, h, H and k depend on distance to the city centre x, and are henceforth denoted as $h\left(x\right)$, $H\left(x\right)$ and $k\left(x\right)$.

Three equilibrium conditions then solve the model. First, utility is equalized at all locations x. Second, land rent at edge of the city $\bar{x}$ is equal to exogenous agricultural rents $\bar{r}$,

$$r\left(\bar{x}\right) = \bar{r}$$

Third, the population of the city must fit within the dwellings built. That is

$$\int_0^{\bar{x}} \theta x \frac{h(x)}{H(x)} dx = N$$

where N is the number of households and θ are the radians of the city disk.

2.2 Land Use Regulations and Upzoning

Following Bertaud and Brueckner (2005) we model LURs as a restriction on the capital-to-land ratio of a parcel. This is equivalent to imposing a restriction on the height of a building. Upzoning then corresponds to a relaxation (increase) in this restriction. That is, there is some $\hat{h}$ such that

$$h(x) \leq \hat{h}$$

for all $x > 0$. Given that there is greater demand to live close to the CBD, the restriction is binding within a given radius of downtown. That is there is some $\hat{x} > 0$ such that $h(x) = \hat{h}$ for $x \leq \hat{x}$ and $h(x) < \hat{h}$ for $x > \hat{x}$. As shown in the Appendix, the model can easily be solved under this restriction. To model upzoning, we examine what happens when $\hat{h}$ increases. Thus the height limit is relaxed to a more permissive (higher) level.

In order to illustrate the impacts of upzoning, we first calibrate the model using the parameter values described in Lees (2015). Specifically we use $W = 76500$, $t = 738$, $\alpha = 0.17$, $\beta = 0.675$ and $\theta = 2$. However, we use a population of $N = 1.5$ million (which is close to the population of 1.55 million in the Auckland region in 2015) and set agricultural rents to 55000, which is 22% higher than the rents used in Kulish et al (2011) for Sydney. This yields a city radius of approximately 49km in our baseline calibration (with the more restrictive FAR imposed), which means the city spans approximately Warkworth to Pokeno.

In contrast to Lees (2015) we impose the height limits of $\hat{h} = 1$ and $\hat{h} = 4$ and compare the outcomes. We use the model to examine what happens when the FAR restriction is increased from one to four, under two scenarios typically considered in the urban development literature: "Closed City" assumptions, under which population is held constant, and "open city" assumptions, under which population increases until utility is back to where it was prior to the policy change.

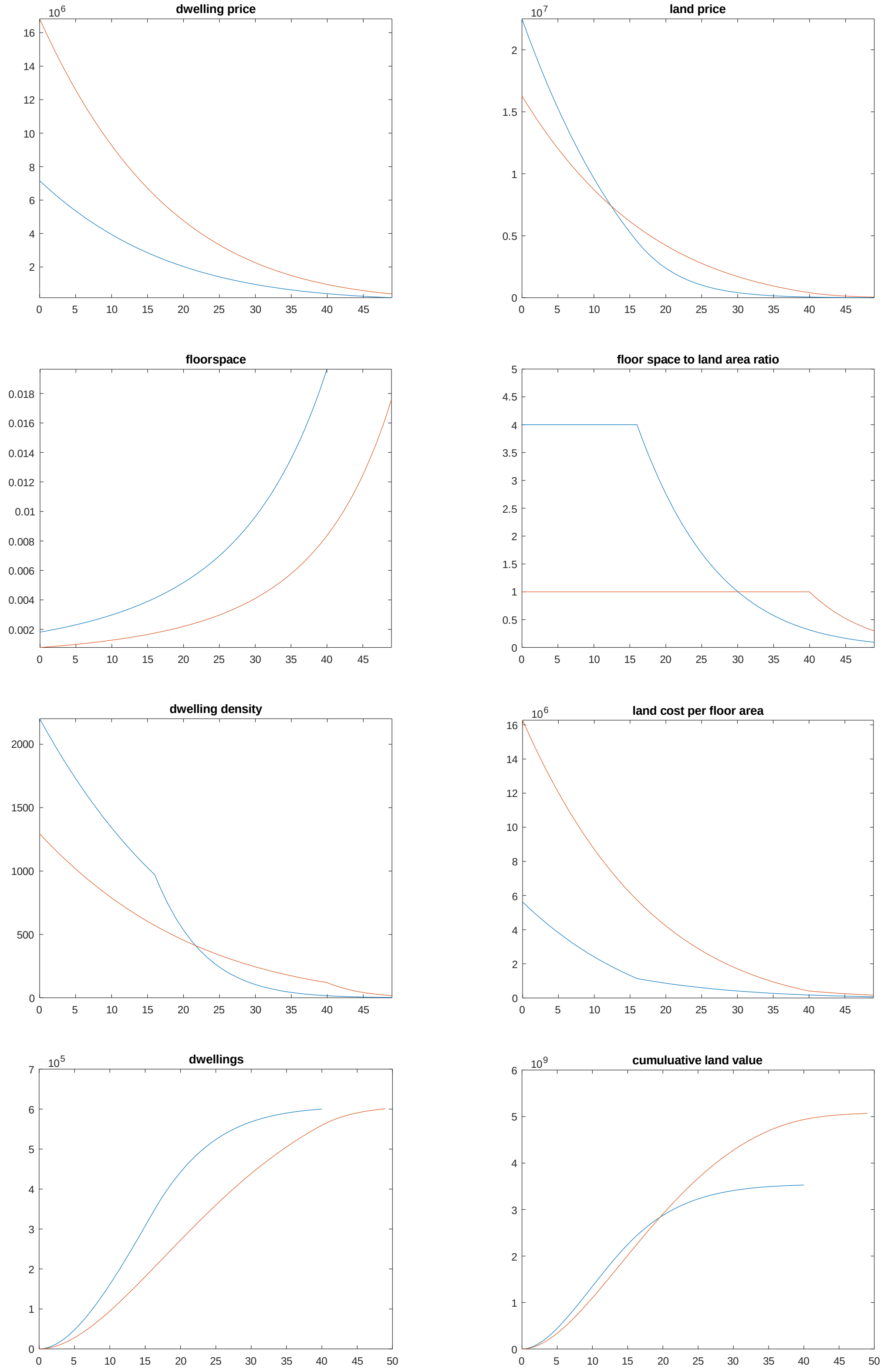
2.2.1 Closed City

Figure 1 presents land prices, dwelling prices, dwelling density, FARs (floor space to land area ratio), floorspace per dwelling, and the ratio of land cost to floor area (which is the proposed indicator of land costs; see (1) below) under the two different values of $\hat{h}$.

Notably upzoning reduces dwelling prices for all distances x. This represents an increase in housing affordability from upzoning. It also enables greater density closer to the CBD.

The impact of upzoning on land prices is depends on distance to the CBD. Land sufficiently close increases in value while distant land decreases in value. Land within approximately thirteen

Figure 1: The impact of upzoning under Alonso-Muth-Mills model with fixed population



Notes: Housing market outcomes when maximum FAR is set to one (red line) and four (blue line) with population held constant. x-axis is distance (km) from downtown.

kilometres of downtown increases in price (the blue line exceeds the red), while land beyond thirteen kilometres decreases. Thus upzoning increases the value of land in areas with sufficiently high demand (i.e., areas close to downtown in the AMM model) and decreases it in areas with low demand (far from downtown).

The final row of Figure 1 exhibits the cumulative number of dwellings and aggregate land values as the distance to the city centre increases. For example, we can see that under both equilibiria, the total number of dwellings is 600,000. However, the distance from the city centre at which this is reached is different. Under the less restrictive LURs, it occurs at a distance of 40km from the CBD, which is the radius of the city under this scenario. Turning to aggregate (or cumulative) land values as we move from the CBD, we can see that the total value of land is greater under the more restrictive LURs. This results from the fact that, for a given population, the LURs spreads residential development across a larger radius from the CBD. However, as we shall see, this result does not hold under open city assumptions, under which aggregate land values increase.

2.2.2 Open City

Next we consider what happens when in-migration is permitted in response to the reduction in dwelling prices. Inter-city equilibrium is achieved as households migrate to equate utility in all locations within a country or labour union. The conventional approach to modelling in-migration in response to a reduction in dwelling prices is to hold utility constant, under the assumption that the city-specific policies have a negligible impact on household utility at all locations in the country. If the city in question is sufficiently large to impact household utility at all locations (which is a possibility for Auckland), or if all cities in the country upzone, then we should not expect in-migration to occur up to the point where utility is back at its original, pre-reform level.

Notwithstanding these caveats, we model in-migration by holding initial (i.e. prior to FAR increase) utility constant. This implies that dwelling prices $p(x)$ are bid back up to their original levels as households move in (since wages W and transport costs t are unaffected).[4]

Figure 2 presents the outcome variables of interest. We note that land prices are now higher for all $x > 0$ after upzoning. The area under which the new FAR is binding extends out to about 28km from downtown. Note that the total number of dwellings has increased by 333%, and that aggregate land values have increased by a factor of three.

We present a sketch of proof for the result that (i) the city radius is unchanged and (ii) that aggregate land values increase under open city model assumptions. First, there is a one-to-one mapping of city radius to utility, all else equal: This follows since price of agricultural land and transport costs are fixed at the boundary. So if utility is constant, as assumed under open city assumptions, then city radius is constant. Then, if utility is constant, then the house price gradient is constant and the floorspace gradient is constant. Then we must invoke a key result of AMM: the

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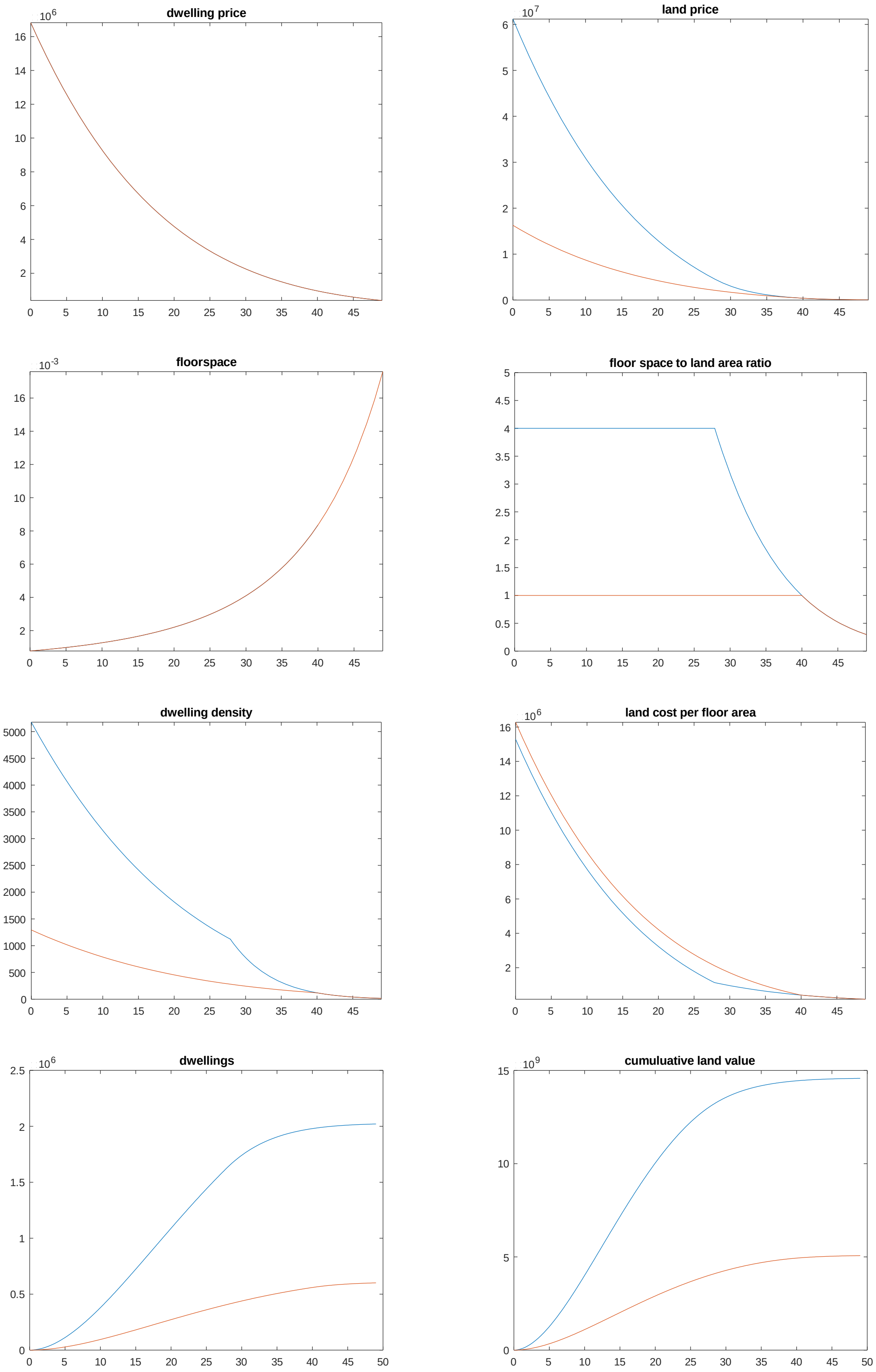
[4] Incorporating congestion costs would entail t becoming an increasing function of N. This would tilt demand towards the centre of the city. Incorporating agglomeration effects would entail wages increasing in N. This has the effect of increasing demand at every distance from downtown. The net effects on the land price curve depend on the parameterizations employed.

Figure 2: The impact of upzoning under Alonso-Muth-Mills model with in-migration



Notes: Housing market outcomes when maximum FAR is set to one (red line) and four (blue line) when utility is held constant. x-axis is distance (km) from downtown.

ratio of the land price gradient to the house price gradient is equal to the floorspace to land area ratio (FAR) (see (19) in Duranton and Puga, 2015). The house price gradient is constant, while the FAR increases once we relax LURs. The land price gradient must therefore become steeper. Given the radius of the city is unchanged, a steeper land price gradient implies land prices increase at all distances x from the CBD.

3 Land Cost per Floor Area

In this section we introduce the Land Cost per Floor Area indicator. Let $q_{i,t}$ denote the LCFA in a given planning zone i in a given time period t. It is defined as:

$$q_{i,t} = \frac{r_{i,t}}{h_{i,t}} \tag{1}$$

where $r_{i,t}$ denotes (average) land price and $h_{i,t}$ denotes the maximum floor area ratio (FAR) permitted in the zone. FAR is a building's floor area in relation to the size of the parcel of land that the building is located on. In practice the FAR is constrained by a variety of regulations, including maximum height, site coverage ratios, minimum lot sizes, setbacks, and height in relation to boundary recession planes. The interaction of these regulations produce the FAR. If, for example, a zone permitted a site coverage ratio of 50% and two storeys, the FAR would be one (= 0.5 × 2) in the zone. If the site coverage ratio was 50% and up to four storeys are permitted, the FAR would be two (= 0.5 × 4). Rules such as setbacks and recession planes interact with the geometry of a specific parcel, so that the FAR depends on the exact shape of the parcel.[5]

Upzoning directly increases $h_{i,t}$. Upzoning also increases $r_{i,t}$ in many areas where the former level of $h_{i,t}$ is binding. If the percent increase in $h_{i,t}$ exceeds the percent increase in $r_{i,t}$, then the cost of land inputs to housing production decreases. Changes in $q_{i,t}$ thereby measure the extent of the reduction in land input costs.

3.1 Empirical Example

To showcase the benefits of LCFA we construct a prototype of the indicator over a period spanning the introduction of the Auckland Unitary Plan (AUP). The AUP upzoned a significant proportion of the area of the city. Preliminary drafts of the AUP were released in March 2013. After subsequent revision, the final version was implemented in November 2016. A full timeline and details of the plan can be found in the Appendix.

We construct indicators for the four main residential zones introduced in Auckland under the Unitary Plan (AUP): Terrace Housing and Apartment Buildings (THAB), Mixed Housing Urban (MHU), Mixed Housing Suburban (MHS) and Single House (SH). THAB permits the most site development, whereas SH permits the least. Following Greenaway-McGrevy, Pacheco and Sorensen (2021) and Greenaway-McGrevy and Phillips (2022), we treat SH as a non-upzoned area. We use

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[5] In our prototypical example we ignore setbacks and recession planes so that we have a uniform FAR for each zone. FARs for individual parcels can be constructed given geographic information on the geometry of the parcel.

annual data spanning 2010 to 2020 and focus on the urban core of Auckland, which we define as the four former Territorial Authorities of North Shore, Waitakere, Auckland City and Manukau.

The LCFA indicators are based on an approximation of the FARs that apply before and after the introduction of the AUP. These FARs are the product of site coverage ratios and building height limits (measured in storeys) in different the residential planning zones. The FARs therefore ignore setbacks and recession planes, which interact with the geometry of individual parcels to produce an effective FAR. Our FARs may be thought of as applying in the case where parcel geometries do not impact the FAR – in other words, parcels are sufficiently large to ensure that recession planes and setbacks have no affect on the FAR of the parcel.

Figure 3 below exhibits the LCFA for each of the four residential zones considered over the 2010 to 2020 period. It also exhibits time series for the constituent components of the LCFA for each zone over the time period: land price per square metre and FARs. Details on the calculation these constituent components can be found in the Appendix. In each figure we also make clear the year in which the upzoning policy is first announced (2013) and the year in which it is implemented (2016).

The top panel of Figure 3 shows that land prices in Auckland increased substantially between 2010 and 2016. After the initial announcement of the policy, land prices in THAB appreciate at a faster rate than those of SH. This is consistent with upzoning increasing the value of upzoned land (in THAB) relative to non-upzoned land (in SH), as predicted by the AMM model. Greenaway-McGrevy, Pacheco and Sorensen (2021) show that upzoning generated a price premium in land intensive properties in THAB, MHU and MHS zones.

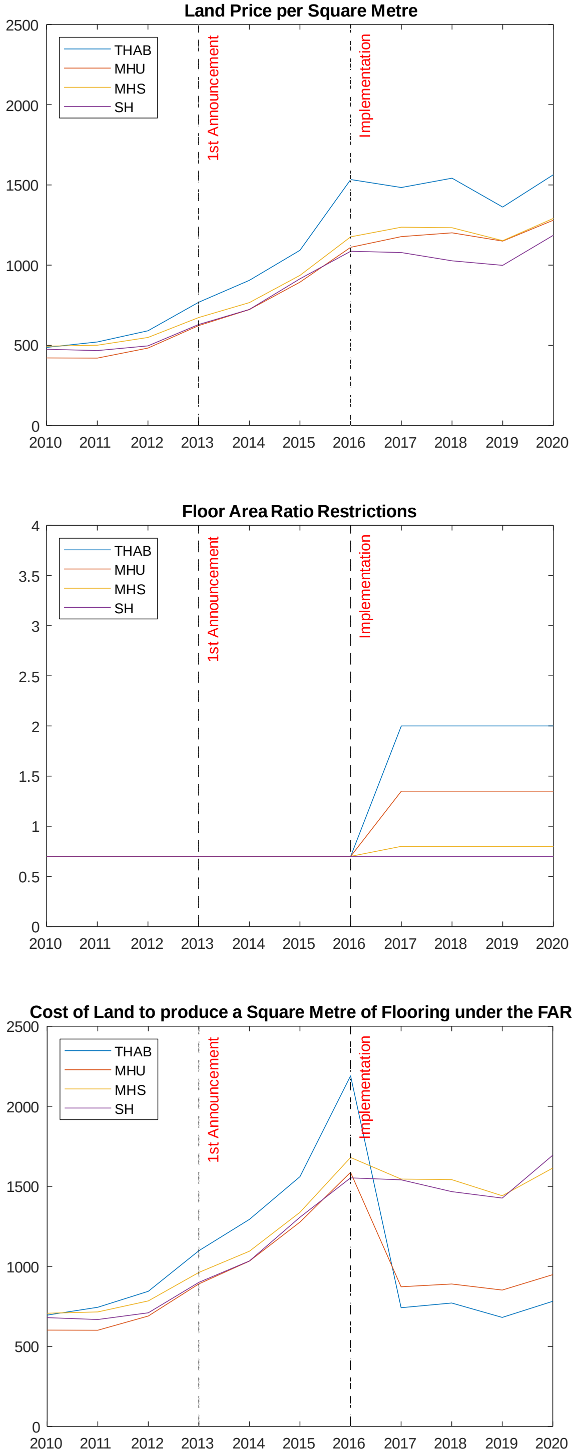
In late 2016 the new land use regulations under the AUP take effect. There is therefore a one-off increase in the FARs (middle panel) in upzoned areas (THAB, MHU, MHS) from 2017 onwards. There is consequently also a marked reduction in the LCFA indicator because land prices stabilize from 2017 onwards. This illustrates the responsiveness of the LCFAs to changes in land use regulations. By 2020, land cost per square metre of flooring in THAB is back to where it was in 2010, at approximately $700 per square metre of flooring. Meanwhile, land cost per square metre of flooring in the most restrictive SH zone is above $1600 by 2020.

4 Discussion and Extensions

In this note we propose a market indicator of land input costs to housing construction that is highly responsive to changes in land use regulations. The indicator captures the impacts of LUR changes on both the intensive and extensive margin of land inputs. This is important because intensification policies such as upzoning reduce the quantity of land required to build a dwelling while also potentially increasing the price of land. Focusing on only one margin – quantity or prices – only gives half the picture of the impact of intensification policies.

To illustrate the benefits of the indicator, we produce a prototype for Auckland over a period spanning the implemented of the Auckland Unitary Plan, in which large areas of the city were upzoned. The indicator illustrates that the regulatory changes coincided with a significant decrease

Figure 3: Land Prices, FARs and the Cost of Land Inputs to Housing in Auckland, 2010-2020



Notes: The impact of upzoning on the cost of land inputs to housing construction. The top figure depicts land prices ($ per square metre); the middle depicts floor to area ratios (FARs); the bottom figure depicts land cost per unit of flooring (LCFA), or the ratio of land price to FAR. THAB = Terrace Housing and Apartments; MHU = Mixed Housing Urban; MHS = Mixed Housing Suburban; SH = Single House. The SH zone is not upzoned.

in the cost of land inputs to housing, as the policy intended.

The land cost indicator can also be an input to commercial-viability calculations and capacity assessments that are designed to assess the profitability of development of different areas within a jurisdiction. Given that capital costs are convex in floorspace when 'building up' (i.e. costs increase on a per m^2 basis as additional storeys are built), in many locations it may not be profitable to build to the limit that the LURs permit. LCFAs that are calculated at intervals below the maximum permissible FAR would be useful in assessments of the commercial viability of development. For example, below headline LCFA indicators could be calculated for each storey up to the maximum storeys permissible under the LURs, which could then be used as an input to assessments of the commercial viability of development to different building heights.

A related issue is that the measure would capture the impact of upzoning in areas with low demand for development where there is unlikely to be much uptake. This is a problem faced by many other price efficiency and market indicators in the HUD suite. One way to address this would be to combine the measure with information about demand in different locations, such as distances to locations of work (job hubs) and amenities such as coastlines and green spaces. Another more complicated approach would be to back out the LCFA that developers would build to using a model of housing demand, such as the monocentric AMM model. The modelling option is more opaque, however.

Several caveats on the indicator are worth emphasizing. We stress that these LCFA indicators are prototypes, or proofs-of-concept, with further development of the indicator necessary to bring it to the point where it can inform policymaking. These weaknesses can be addressed in refinements of the indicator from the proof-of-concept presented in this paper.

First, the FARs used to make the LCFA indicators are approximations. Further refinement of the indicators must include the refinement of FARs that take into account the geometry of the parcels that constitute each zone. This can be achieved using GIS information on land parcels to obtain an average FAR restriction across a given geography and in a given zone. A related issue is that, for FARs prior to the implementation of the AUP, we used the FAR that applies in the Single House zone in all four zones. Information on the LURs that applied in different regions of Auckland prior to the AUP would be necessary to gain a more accurate measure of the historic effect of upzoning in Auckland.

Second, regulated site coverage ratios are much more conservative than what we see in practice in Auckland. New developments frequently exceed these ratios, which is permissible under resource consent notification. The reductions in land inputs costs are larger if these site coverage ratios can be exceeded. Addressing this in a satisfactory manner will present difficulties, but a sensitivity analysis using an informed exceedance of the regulation would be one way to address this shortcoming. The exceedance would be expressed in percentage terms and could be informed by planning practice or observed outcomes in comparable upzoned areas.

Third, land prices are computed based on transaction prices net of assessed value of improvements. Developers must frequently also demolish the dwellings on the parcel as not all extant structures can be sold and removed. These costs could also be incorporated into the measure of land prices.

Fourth, the land prices we have employed ignore the impact of changes in interest rates on the carrying cost of land for developers. Developers purchase land with the expectation that it will be resold as part of a redeveloped bundle of land and buildings. Reductions in interest rates therefore reduce the carrying cost of land (all else equal).

In future iterations of the paper we hope to further refine the indicator to address these and other shortcomings.

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5 Appendix

5.1 Institutional Background and Timeline of the AUP

This section provides some background features of Auckland city and relevant policies and processes preceding the relaxation of land use regulations. It is based on section 2 of Greenaway-McGrevy, Pacheco and Sorensen (2021).

Auckland is the largest city in New Zealand with a population of approximately 1.5 million within the metropolitan region (as of 2017). Prior to 2010, the Auckland metropolitan region comprised one regional council and seven city and district councils. The seven district councils used different land use zones and regulations. On 1 November 2010, Auckland Council (AC) was formed when the eight previous governing bodies in the region were amalgamated. Special legislation was also passed by the central government requiring AC to develop a consistent set of planning rules for the whole region under the Local Government Act 2010. This set of planning rules is embodied in the Auckland Unitary Plan (AUP).

Key dates in the development and implementation of the AUP are as follows:

- 15 March 2013: AC releases the draft AUP. The next 11 weeks comprised a period of public consultation, during which AC held 249 public meetings and received 21,000 items of written feedback.
- 30 September 2013: AC released the Proposed AUP (PAUP) and notified the public that the PAUP was open for submissions. More than 13,000 submissions (from the public, government, and community groups) were made, with over 1.4 million separate pints of submission.
- April 2014 to May 2016: an Independent Hearings Panel (IHP) was appointed by the central government, which subsequently held 249 days of hearings across 60 topics and received more than 10,000 items of evidence.
- 22 July 2016: the IHP set out recommended changes to the PAUP. One of the primary recommendations was the abolition of minimum lot sizes for existing parcels. The AC considered and voted on the IHP recommendations over the next 20 working days. On 27 July the public could access and view the IHP's recommendations.
- 19 August 2016: AC released the 'decisions version' of the AUP, including the new zoning maps. Several of the IHP's recommendations were voted down, including a IHP recommendation to abolish minimum floor sizes on apartments. However, the abolition of minimum lot sizes for existing parcels was maintained. This was followed by a 20-day period for the public to lodge appeals on the 'decisions version' in the Environment Court. Appeals to the High Court were only permitted if based on points of law.
- 8 November 2016: A public notice was placed in the media notifying that the AUP would become operational on 15 November 2016.
- 15 November 2016: AUP becomes operational.[6]

All versions of the AUP ('draft', 'proposed', 'decisions' and 'final') announced changes to LURs that would potentially change restrictions on the extent of site development, depending on where a site was located. These proposed changes could be viewed online, so that any interested member of the public could observe the specific LURs proposed for a given parcel of land. This meant that it was relatively straightforward for developers to observe the new land use regulations prior to the policy becoming operational.

The amount of development permitted on a given site is restricted by the residential planning zone in which the site is located. In this study we focus on four zones, listed in declining levels of permissible site development: Terrace Housing and Apartments (THA); Mixed Housing Urban (MHU); Mixed Housing Suburban (MHS); and Single House (SH). Thus THA permits the most site development, and SH permits the least. Table 1 summarizes the various LURs for each of the four residential zones considered. These regulations include site coverage ratios, minimum lot sizes

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[6] There were two elements of the AUP that were not fully operational at this time: (i) any parts that remain subject to the Environment Court and High Court under the Local Government Act 2010; and (ii) the regional coastal plan of the PAUP that required Minister of Conservation approval.

Table 1: Summary of Land Use Regulation by Residential Zone under the Unitary Plan

Regulation	Terraced Housing & Apartments Zone	Mixed Use Urban Zone	Mixed Use Suburban Zone	Single House Zone	Large Lot Zone
Max. height	16m (five storeys)	11 to 12m (three storeys)	8 to 9m (two storeys)	8 to 9m (two storeys)	8 to 9m (two storeys)
Height in relation to boundary (side & rear)	3m + 45° recession plane	3m + 45° recession plane	2.5m + 45° recession plane	2.5m + 45° recession plane	does not apply*
Setback (side & rear)	0m	1m	1m	1m	does not apply*
Site Coverage	50%	45%	40%	35%	lesser of 20% or 400m^2
Impervious Area	70%	60%	60%	60%	lesser of 35% or 1400m^2
Min. dwelling size (1 bedroom)	45m^2	45m^2	45m^2	n/a	n/a
Max. dwellings per site	does not apply	3	3	1	1
Min. Lot Size	1200m^2 (subdivision)	300m^2 (subdivision)	400m^2 (subdivision)	600m^2 (subdivision)	2000m^2

Notes: Tabulated restrictions are ‘as of right’ and can be exceeded through resource consent notification. Less restrictive height in relation to boundary rules than those tabulated apply to side and rear boundaries within 20m of site frontage. Maximum dwellings per site are the number permitted as of right in the Unitary Plan. Minimum lot sizes do not apply to extant residential parcels.*Planners have discretion in setting height in relation to boundary and setbacks in the large lot zone. The regulations “[r]equire development to be of a height and bulk and have sufficient setbacks and open space to maintain and be in keeping with the spacious landscape character of the area”.

for new subdivisions, and height restrictions, among others. For example, between five to seven storeys and a maximum site coverage ratio of 50% is permitted in THA, whereas only 2 storeys and a coverage ratio of 35% is permitted in SH.

5.2 Upzoning under the Alonso-Muth-Mills Model

We model upzoning as a relaxation of FARs. Our model follows Bertaud and Brueckner (2005) but does not set $p_K = 1$. We begin with the AMM model without FAR constraints. We then introduce FAR constraints before discussing how model upzoning as a relaxation on these constraints.

Households. Households have Cobb-Douglas preferences described by

$$U\left(C,H\right)=C^{1-\alpha}H^{\alpha}$$

where C is the consumption numeraire (price set to unity) and H is housing floorspace. The budget constraint is

$$C=W-tx-p\left(x\right)H$$

where $p\left(x\right)$ is the price of housing floor space, t is commuting cost, W is the wage, and x is distance from downtown. Households maximize utility subject to their budget constraint, which yields

$$p\left(x\right)=\left(W-tx\right)^{\frac{1}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}\alpha U^{-\frac{1}{\alpha}}=\frac{\left(W-tx\right)^{\frac{1}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}\alpha}{U^{\frac{1}{\alpha}}} \tag{2}$$

and thus

$$H\left(x\right)=\left(W-tx\right)^{-\frac{1-\alpha}{\alpha}}\left(1-\alpha\right)^{-\frac{1-\alpha}{\alpha}}U^{\frac{1}{\alpha}}=\frac{U^{\frac{1}{\alpha}}}{\left(W-tx\right)^{\frac{1-\alpha}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}} \tag{3}$$

Developers. Housing floorspace is produced via Cobb-Douglas production

$$H\left(K,L\right)=AK^{\gamma}L^{1-\gamma}$$

Since this Cobb-Douglas production exhibits constant returns to scale, we can define housing per unit of land

$$h\left(k\right)=\frac{H}{L}=A\left(\frac{K}{L}\right)^{\gamma}=Ak^{\gamma}$$

Developer profits per unit of land are then

$$p\left(x\right)h\left(k\right)-p_{K}k-r\left(x\right)$$

where $r\left(x\right)$ denotes per unit land rent at x. Developers take prices as given and choose k to maximize profit, which yields

$$k=p\left(x\right)^{\frac{1}{1-\gamma}}\left(A\gamma\right)^{\frac{1}{1-\gamma}}p_{K}^{-\frac{1}{1-\gamma}}$$

Under zero profits,

$$p(x)\,h(k) - p_K k - r(x) = 0$$

Rearranging,

$$r(x) = p(x)\,h(k) - p_K k$$

and substituting in the expression for k from profit maximization we simplify this to

$$r(x) = (1-\gamma)\,p(x)^{\frac{1}{1-\gamma}}\,A^{\frac{1}{1-\gamma}}\gamma^{\frac{\gamma}{1-\gamma}}p_K^{-\frac{\gamma}{1-\gamma}} \tag{4}$$

which is the same as given by Glaeser (2008, p.31) when $A = 1$.

Equilibrium conditions. There are three equilibrium conditions used to solve the model. First, land rent at edge of the city $\bar{x}$ is equal to exogenous agricultural rents $\bar{r}$,

$$r(\bar{x}) = \bar{r}$$

Second, utility is equalized at all locations x. Substituting (4) into the above condition we have

$$(1-\gamma)\,p(\bar{x})^{\frac{1}{1-\gamma}}\,A^{\frac{1}{1-\gamma}}\gamma^{\frac{\gamma}{1-\gamma}}p_K^{-\frac{\gamma}{1-\gamma}} = \bar{r}$$

Then substituting in the expression for $p(\bar{x}) = (W - t\bar{x})^{\frac{1}{\alpha}}\,(1-\alpha)^{\frac{1-\alpha}{\alpha}}\,\alpha\bar{U}^{-\frac{1}{\alpha}}$ from (2) into the above we get

$$(W - t\bar{x})^{\frac{1}{\alpha(1-\gamma)}}\,(1-\alpha)^{\frac{1-\alpha}{\alpha(1-\gamma)}}\,\alpha^{\frac{1}{1-\gamma}}\bar{U}^{-\frac{1}{\alpha(1-\gamma)}}A^{\frac{1}{1-\gamma}}\gamma^{\frac{\gamma}{1-\gamma}}p_K^{-\frac{\gamma}{1-\gamma}}\,(1-\gamma) = \bar{r}$$

Rearranging

$$(1-\alpha)^{\frac{1-\alpha}{\alpha(1-\gamma)}}\,\bar{U}^{-\frac{1}{\alpha(1-\gamma)}} = \frac{\bar{r}p_K^{\frac{\gamma}{1-\gamma}}}{(1-\gamma)\,\alpha^{\frac{1}{1-\gamma}}\gamma^{\frac{\gamma}{1-\gamma}}A^{\frac{1}{1-\gamma}}\,(W - t\bar{x})^{\frac{1}{\alpha(1-\gamma)}}} \tag{5}$$

We leave the expression in this form for reasons that become clear below. Third, the population constraint is that all people must fit into the city. That is

$$\int_0^{\bar{x}} \theta x \frac{h(x)}{H(x)} dx = N$$

where N is the number of households and θ are the radians of the city. We must solve for $\frac{h(x)}{H(x)}$. Now

$$h(x) = Ak^{\gamma} = p(x)^{\frac{\gamma}{1-\gamma}}\,\gamma^{\frac{\gamma}{1-\gamma}}A^{\frac{1}{1-\gamma}}p_K^{-\frac{\gamma}{1-\gamma}} \tag{6}$$

while from (3) we have $H(x) = \alpha(W - tx)/p(x)$, so that

$$\frac{h(x)}{H(x)} = \frac{p(x)^{\frac{1}{1-\gamma}}}{\alpha(W - tx)}\gamma^{\frac{\gamma}{1-\gamma}}A^{\frac{1}{1-\gamma}}p_K^{-\frac{\gamma}{1-\gamma}}$$

Then substituting in $p(x) = (W - tx)^{\frac{1}{\alpha}} (1-\alpha)^{\frac{1-\alpha}{\alpha}} \alpha U^{-\frac{1}{\alpha}}$ from (2) we get

$$\frac{h(x)}{H(x)} = (1-\alpha)^{\frac{1-\alpha}{\alpha(1-\gamma)}} U^{-\frac{1}{\alpha(1-\gamma)}} (W - tx)^{\frac{1-\alpha(1-\gamma)}{\alpha(1-\gamma)}} \alpha^{\frac{\gamma}{1-\gamma}} \gamma^{\frac{\gamma}{1-\gamma}} A^{\frac{1}{1-\gamma}} p_K^{-\frac{\gamma}{1-\gamma}}$$

Noting that $U = \bar{U}$ in equilibrium and substituting in (5) yields

$$\begin{aligned} \frac{h(x)}{H(x)} &= \frac{\bar{r} p_K^{\frac{\gamma}{1-\gamma}}}{\alpha^{\frac{1}{1-\gamma}} \gamma^{\frac{\gamma}{1-\gamma}} A^{\frac{1}{1-\gamma}} (1-\gamma)} \frac{(W - tx)^{\frac{1-\alpha(1-\gamma)}{\alpha(1-\gamma)}}}{(W - t\bar{x})^{\frac{1}{\alpha(1-\gamma)}}} \alpha^{\frac{\gamma}{1-\gamma}} \gamma^{\frac{\gamma}{1-\gamma}} A^{\frac{1}{1-\gamma}} p_K^{-\frac{\gamma}{1-\gamma}} \\ &= \frac{\bar{r}}{\alpha(1-\gamma)} \frac{(W - tx)^{\frac{1-\alpha(1-\gamma)}{\alpha(1-\gamma)}}}{(W - t\bar{x})^{\frac{1}{\alpha(1-\gamma)}}} \end{aligned}$$

so that

$$\int_0^{\bar{x}} \theta d \frac{h(x)}{H(x)} x dx = \frac{\theta \bar{r}}{\alpha(1-\gamma)} \int_0^{\bar{x}} \frac{(W-tx)^{\frac{1-\alpha(1-\gamma)}{\alpha(1-\gamma)}}}{(W-t\bar{x})^{\frac{1}{\alpha(1-\gamma)}}} x dx = N$$

Based on this expression we can solve for $\bar{x}$.[7] Note that $\bar{x}$ is independent of A and p_K. We can then solve for $\bar{U}$ from (5) as follows

$$\bar{U} = \frac{\alpha^{\alpha} \gamma^{\alpha\gamma} A^{\alpha} (1-\gamma)^{\alpha(1-\gamma)} (W - t\bar{x}) (1-\alpha)^{(1-\alpha)}}{\bar{r}^{\alpha(1-\gamma)} p_K^{\alpha\gamma}}$$

We can then go on to solve for (i) $p(x)$ using (2); (ii) $r(x)$ using (4); (iii) $h(x)$ using (6)[8] and (iv) $H(x)$ using (3). Note that $h(x)/H(x)$ is then dwelling density and $\int_0^{y} \theta \frac{h(x)}{H(x)} x dx$ yields population that lives within y distance of the city centre.

5.2.1 Constraints on Building Height

Following Bertaud and Brueckner (2005) we examine the effects of a height (FAR) restriction that is binding within a radius $\hat{x}$ of the city. The equilibrium conditions become

$$r(\bar{x}) = \bar{r}$$

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[7] We can solve the integral as follows.

$$\begin{aligned} N &= \frac{\theta \bar{r}}{\alpha(1-\gamma)} \frac{\alpha(1-\gamma)}{t^2(1+\alpha(1-\gamma))} \left(\frac{\alpha(1-\gamma) W^{\frac{1+\alpha(1-\gamma)}{\alpha(1-\gamma)}}}{(W-\bar{x}t)^{\frac{1}{\alpha(1-\gamma)}}} - \bar{x}t - W\alpha(1-\gamma) \right) \\ &= \frac{\theta \bar{r}}{t^2(1+\alpha(1-\gamma))} \left(\frac{\alpha(1-\gamma) W^{\frac{1+\alpha(1-\gamma)}{\alpha(1-\gamma)}}}{(W-\bar{x}t)^{\frac{1}{\alpha(1-\gamma)}}} - \bar{x}t - W\alpha(1-\gamma) \right) \end{aligned}$$

This is however unnecessary when using numerical solutions.

[8] Note that another way to solve for $h(x)$ is

$$h(x) = p(x)^{\frac{\gamma}{1-\gamma}} \gamma^{\frac{\gamma}{1-\gamma}} A^{\frac{1}{1-\gamma}} p_K^{-\frac{\gamma}{1-\gamma}} = \frac{r(x)}{(1-\gamma)p(x)}$$

and

$$h\left(\hat{x}\right)=\hat{h}$$

which is a direct restriction on the floorspace per unit of land, and

$$\textstyle\int_0^{\hat{x}}\theta\dfrac{\hat{h}}{H\left(x\right)}xdx+\textstyle\int_{\hat{x}}^{\bar{x}}\theta\dfrac{h\left(x\right)}{H\left(x\right)}xdx=N \tag{7}$$

Bertaud and Brueckner (2005) and Kulish et al. (2011) impose a fixed $\hat{h}$ and then solve for $\hat{x}$ and $\bar{x}$.

We first solve for the first term in (7). Using $H\left(x\right)=\alpha\left(W-tx\right)/p\left(x\right)$ from (3) we have

$$\frac{\hat{h}}{H\left(x\right)}=\frac{\hat{h}p\left(x\right)}{\alpha\left(W-tx\right)}$$

Then substituting in $p\left(x\right)=\left(W-tx\right)^{\frac{1}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}\alpha U^{-\frac{1}{\alpha}}$ from (2) yields

$$\frac{\hat{h}}{H\left(x\right)}=\hat{h}\left(W-tx\right)^{\frac{1-\alpha}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}U^{-\frac{1}{\alpha}}$$

Rearranging the equality from (5) we get

$$\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}\bar{U}^{-\frac{1}{\alpha}}=\frac{\bar{r}^{1-\gamma}p_K^{\gamma}}{\left(1-\gamma\right)^{\left(1-\gamma\right)}\alpha\gamma^{\gamma}A\left(W-t\bar{x}\right)^{\frac{1}{\alpha}}}$$

and thus

$$\frac{\bar{h}}{H\left(x\right)}=\hat{h}\left(W-tx\right)^{\frac{1-\alpha}{\alpha}}\left(1-\alpha\right)^{\frac{1-\alpha}{\alpha}}U^{-\frac{1}{\alpha}}=\frac{\hat{h}\bar{r}^{1-\gamma}p_K^{\gamma}\left(W-tx\right)^{\frac{1-\alpha}{\alpha}}}{\left(1-\gamma\right)^{\left(1-\gamma\right)}\alpha\gamma^{\gamma}A\left(W-t\bar{x}\right)^{\frac{1}{\alpha}}}$$

Putting this into the integral $\int_0^{\hat{x}}\theta\frac{\hat{h}}{H(x)}xdx$ and simplifying yields

$$\textstyle\int_0^{\hat{x}}\theta\dfrac{\hat{h}}{H\left(x\right)}xdx=\theta\hat{h}\dfrac{\bar{r}^{1-\gamma}p_K^{\gamma}}{\left(1-\gamma\right)^{\left(1-\gamma\right)}\alpha\gamma^{\gamma}A}\cdot\textstyle\int_0^{\hat{x}}\dfrac{\left(W-tx\right)^{\frac{1-\alpha}{\alpha}}}{\left(W-t\bar{x}\right)^{\frac{1}{\alpha}}}xdx$$

The integrand in the second term in (7) is the same as under the unconstrained case. The only difference is the support of the integral. Thus we have

$$\frac{\theta\hat{h}\bar{r}^{1-\gamma}p_K^{\gamma}}{(1-\gamma)^{(1-\gamma)}\alpha\gamma^{\gamma}A}\int_0^{\hat{x}}\frac{(W-tx)^{\frac{1-\alpha}{\alpha}}}{(W-t\bar{x})^{\frac{1}{\alpha}}}xdx+\frac{\theta\bar{r}}{\alpha(1-\gamma)}\int_{\hat{x}}^{\bar{x}}\frac{(W-tx)^{\frac{1-\alpha(1-\gamma)}{\alpha(1-\gamma)}}}{(W-t\bar{x})^{\frac{1}{\alpha(1-\gamma)}}}xdx=N \tag{8}$$

This is one constraint with two unknowns ($\hat{x}$ and $\bar{x}$). The other constraint is

$$h\left(\hat{x}\right)=\hat{h}$$

This is solved for as

$$h(\hat{x}) = Ak(\hat{x})^{\gamma} = A^{\frac{1}{1-\gamma}} p(\hat{x})^{\frac{\gamma}{1-\gamma}} (\gamma / p_K)^{\frac{\gamma}{1-\gamma}} = \hat{h}$$

where

$$p(x) = \frac{(W - tx)^{\frac{1}{\alpha}} (1-\alpha)^{\frac{1-\alpha}{\alpha}} \alpha}{U^{\frac{1}{\alpha}}}$$

We can then define

$$h_0(x) = \min\left(\hat{h}, h(x)\right) \tag{9}$$

as the floorspace function with FAR imposed.

Having solved for $\hat{x}$ and $\bar{x}$, we then (i) solve for $\bar{U}$ using $\bar{x}$ and (**??**); (ii) $p(x)$ using (2); (iii) $H(x)$ using (3) and (iv) $h_0(x)$ using (9). The FAR affects developer profit maximization and thus demand for land. When building to $\hat{h}$ the developer uses $\hat{k} = \left(\hat{h}/A\right)^{\frac{1}{\gamma}}$. This results in profits of $p(x)\hat{h} - p_K\hat{k} - r(x)$ such that under zero profits $r(x) = p(x)\hat{h} - p_K\hat{k}$. Thus letting $k_0(x) = \left(\min\left(\hat{h}, h(x)\right)/A\right)^{\frac{1}{\gamma}}$ we have

$$r_0(x) = p(x)h_0(x) - p_K k_0(x)$$

which yields land rents as a function of x.

5.2.2 Upzoning

We model upzoning as an increase in $\hat{h}$ and examine the effects on the outcome variables of interest under different static equilibria.

5.3 Data Construction

5.3.1 Land Prices

Land prices per square metre are constructed using residential real estate sales and includes vacant and developed lots. Land values are divided by land area to obtain land prices on a square metre basis. For developed lots, land values are calculated by subtracting the assessed value of improvements from the latest rating valuation record from the transaction price net of any chattels. Transactions on titles with joint land ownership (such as cross leases and unit titles) are excluded from the sample.

5.3.2 FARs

We construct FARs based on the reported site coverage ratios (SCRs) and height limits in the four main residential zones introduced under the AUP. The SCRs for THAB, MHU, MHS and SH are 50%, 45%, 40% and 35%, respectively. In should be noted, however, that these ratios can be exceeded via notification. The height limit in each zone is 16m, 11m, 8m and 8m, which we take to correspond to 5, 3, 2 and 2 storeys, respectively. The FAR is given by the product of the SCR and the storey limit.

5.3.3 Effective FARs

Effective FARs account for how the floor to area ratio is affected by both site coverage ratios and building envelopes (i.e., the three-dimensional geometries formed by setbacks, recession planes and maximum height limits). Building envelopes interact with the shape of the individual parcels to limit the floor to area ratio of a parcel.

Our procedure to calculate effective FARs is as follows:

(*i*) We determine the number of storeys implied by height limits in each zone. Our baseline modelling assumptions are that each storey requires 2.5 metres and roof pitches require an additional two metres. The first storey is built at ground level on a concrete pad.

(*ii*) We calculate the floor area for each storey as determined by the site coverage ratio and the land area of the parcel. It is determined by the site coverage ratio multiplied by the land area of the parcel. Let $FA_{1,j,s}$ denote the floor area for storey s for parcel j calculated under this approach. Note that $FA_{1,j,s} = FA_{1,j}$ for all s.

(*iii*) We calculate the floor area for each storey as determined by the geometry of the parcel and the building envelope. First, any parts of the parcel that are less than four metres across (such as driveways) are excluded from the potential building site. Using the setbacks, recession planes and maximum height limits, we determine the maximum floorspace for each storey. We do not distinguish between road front, and side and rear boundaries. Typically the roadfront has a deeper setback but a less restrictive height in relation to boundary. Let $FA_{2,j,s}$ denote the floor area for storey s for parcel j calculated under this approach.

(*iv*) We then determine the floor area for each storey as the minimum of the site coverage ratio and the building envelope methods. We then sum these over the number of storeys permitted, and divide by land area A_j to arrive at the FAR for the parcel:

$$FAR_j = \frac{\sum_s \min(FA_{1,j}, FA_{2,j,s})}{A_j}$$