

Spatial general equilibrium analysis of a large urban rail project

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Abstract

Spatial computable general equilibrium (SCGE) models provide a comprehensive and economically coherent framework for analysing public investment or policy options in metropolitan areas and regions. The Victoria University (VU) Cities SCGE framework is being applied to assess proposed transport infrastructure investments and land use planning strategies in the Australian states of New South Wales (NSW) and Victoria. In those applications, VU Cities models are coupled with strategic transport models to handle mode choice and congestion effects. In this paper, we illustrate the application of the VU Cities–NSW model with a counter-factual analysis of an outer suburban rail loop in Western Sydney that connects to the existing rail network. We base our analysis on estimates of: (i) the annualised cost of having provided this infrastructure and (ii) the direct effects on generalised travel costs between all relevant origins and destinations.

We first elucidate the long-run impacts on the spatial distribution of housing and employment. Our main focus, however, is on quantifying and explaining the overall costs and benefits and examining their sensitivity to several key modelling assumptions. As the financial costs are outweighed by gains in productivity, amenity and commuting time savings, more residents and workers are attracted to the city. Population gains are reinforced by positive externalities of residential density but also push land rents up and wage rates down. We show that these latter effects are sensitive to assumptions about the strength of both positive externalities and the operation of density-suppressing land use regulation. However, on a per capita basis, changes are much smaller and also less sensitive to these assumptions.

1 Introduction

Australia is one of the world's most highly urbanised countries and its urban population is unusually skewed towards its largest cities (Ellis, Andrews et al., 2001). Out of a national population of 25 million, Sydney and Melbourne now account for 5.3 and 5.1 million people respectively, while the next three largest state capitals (Brisbane, Perth and Adelaide) together account for a further 6.0 million people.¹ These largest cities are growing more rapidly in both population and economic terms than is the country as a whole. However, restrictive planning regulations coupled with inadequate or misdirected transport infrastructure investments have contributed to rapidly rising housing costs and road congestion (Kelly and

¹These values are the authors' own estimates for June 2019, based on the Australian Bureau of Statistics' June 2018 Estimated Residential Population (ERP) for Greater Capital City Statistical Areas.

Donegan, 2015; Kendall, Tulip et al., 2018; Stapledon, 2016; SGS Economics and Planning Pty Ltd, 2013; Daley et al., 2018; Terrill et al., 2017).²

One response of politicians and policy-makers to these challenges has been to call for major investment in transport infrastructure. A number of significant extensions to metropolitan highway and rail networks have recently been completed or are under construction in both Sydney and Melbourne. These include two light rail projects and three heavy metro rail network extensions in Sydney, the Melbourne Metro project and the removal of 75 level crossings in Melbourne, Sydney’s WestConnex and NorthConnex motorway projects and the Westgate Tunnel (road) project in Melbourne. Yet more large projects have been announced by state governments, including a long-term plan for an A\$50 billion outer suburban rail loop in Melbourne and investigations of regional fast rail projects in both New South Wales and Victoria.

Evaluating major transport infrastructure projects within or between urban areas is challenging because, in the long run, these projects may affect the size and shape of cities, which may considerably change transport demands (Van Wee, 2007). Detailed modelling supporting cost-benefit-analyses (CBA) have tended to focus almost exclusively on the ‘transport impacts’ of project with limited consideration of their wider, city-shaping effects. Accounting for such interactions requires the use of Land Use Transport Interaction (LUTI) models (Wegener, 2004; Acheampong and Silva, 2015).

Conventional four-step transport models emphasise mode choice and routing, taking the locations of populations and employment as given ‘land use’. Trip generation between these fixed origin and destination points is accounted for by empirically estimated relationships. More recently developed agent-based transport models may allow for additional choice margins including time-shifting and trip-chaining, but still require land uses to be given Rasouli and Timmermans (2014). Thus, city-shaping effects of major transport infrastructure tend to be ignored or else incorporated by means of *ad hoc* land use projections. The intention of the VU Cities spatial computable general equilibrium (SCGE) framework is to provide a complementary framework that is both economically coherent and comprehensive.

A key point of departure for VU Cities is Anas and Liu’s (2007) Regional Economy, Land use and Transportation Model. However, whereas their model divides the Chicago area into just fifteen zones, VU Cities is intended to provide both finer spatial detail and wider geographic coverage, distinguishing hundreds of zones. A second key difference with RELU is our emphasis on positive externalities from agglomeration. Following the influential empirical study of Berlin of Ahlfeldt et al. (2015), we allow for localised spillovers to affect not only the productivity of firms, but also the amenity enjoyed by residents. Our framework takes generalised travel costs (GTCs) between zones as given. These may, however, be effectively endogenised if our SCGE model is coupled with a suitable transport model.³

The VU Cities framework has thus far been applied to develop operations models of New South Wales (NSW) and Victoria. Those models are currently being used to support assessments of major transport infrastructure investments and land use planning strategies. In those projects, VU Cities models are being used in conjunction with large-scale transport models. However, in this paper we present a stand-alone application of the VU Cities–NSW model for the purposes of illustration. We apply the model to assess the spatial and state-wide macroeconomic impacts of a hypothetical western Sydney suburban rail loop.

²In the latter half of the twentieth century, real house prices grew strongly in many countries, but the long run growth rate in Australia exceeded that in the thirteen other industrialised countries studied by Knoll, Schularick, and Steger (2017).

³In Anas and Liu (2007) the ‘TRANS’ component of RELU-TRANS performs this function.

2 VU Cities SCGE framework

Our framework builds on the model of Ahlfeldt et al., with extensions including multiple types of working and non-working households, multiple industries and consumers travelling to consume non-tradable services. Non-tradable services are also consumed by tourists.

Worker-households of each type make discrete choices of their place of residence and place and industry of work. Non-working households choose their place of residence. There are positive spillovers to households' residential amenity from effective residential density. As in Ahlfeldt et al. (*ibid.*) generalised travel costs for commuters—and, in our framework, shoppers—are exogenous. However our intention is that the SCGE model should be coupled with an appropriate transport model in order to endogenise mode choices, road congestion or other relevant phenomena that may interact with the location choices that are our focus here.

Perfectly competitive firms in each sector use different types of labour together with commercial (or industrial, agricultural, etc.) property and non-structures capital (machinery, equipment, etc.) to produce tradable or non-tradable goods or services. There are positive spillovers to firms' productivity from effective job density.

Each type of residential and non-residential property is a composite of land and structures. Land resources are differentiated by planning zones that affect both land allocations to different uses and densities of development in those uses.

2.1 Households' discrete choices

2.1.1 Worker-households

Each worker-household is distinguished by their skill/collar type k : blue collar, white collar/low skill or white collar/high skill. Choosing to work in industry i located in location s , a worker of type k will earn the wage W_{kis} . Workers additionally receive non-wage income and government transfers of which part m_{1k} is taxable and part m_{2k} , consisting of government transfers plus rents on owner-occupied housing, is tax-exempt. Taxable income is taxed at the rate ϑ_k , so total after-tax income is

$$M_{kis} = (1 - \vartheta_k) (W_{kis} + m_{1k}) + m_{2k}.$$

Commuting from residence location r to work location s , workers incur time-equivalent costs τ_{rs} (i.e. actual travel times plus time-equivalents of monetary costs, e.g. private vehicle operating costs, public transport fares). As in Ahlfeldt et al., we assume that there is a negative exponential relationship between commuting times.

Living in location r , worker-households experience a level B_r of residential amenity and local housing prices R_{rH} . Prices of tradable goods are equal to p_j everywhere. However, prices P_{jt} of locally non-tradable services differ between locations and consuming these services also involves travel costs. As will be shown in section 2.2, a local cost index for consumption utility Q_{kr} can be formed from these prices, consumers' travel costs and related parameters.

Finally, each household o_k experiences a multiplicative Fréchet-distributed random shock to their indirect utility. So as to be able to calibrate the model to counts of jobs and resident workers in each location, cross-classified by skill and industry, we parameterise the distribution with scale parameters $F_{kir}G_{kis}$:

$$z_{irso_k} \sim \exp \left(-F_{kir}G_{kis}z_{irso_k}^{-\varepsilon} \right).$$

The shape parameter ε determines how substitutable the discrete choice triples are for one another.

Household o_k choosing (i, r, s) has indirect utility

$$u_{irso_k} = z_{irso_k} \frac{B_r M_{kis}}{Q_{kr} e^{\kappa_k \tau_{rs}}}. \quad (1)$$

and the share of k -type households making discrete choices (i, r, s) takes the multinomial logit form

$$\pi_{irs|k} = \frac{\psi_{irs|k}}{\sum_{i'} \sum_{r'} \sum_{s'} \psi_{i'r's'|k}} \quad \text{where } \psi_{irs|k} \equiv F_{kir} G_{kis} \left(\frac{B_r M_{kis}}{Q_{kr} e^{\kappa_k \tau_{rs}}} \right)^\varepsilon. \quad (2)$$

We estimate κ_k from Census data using a gravity relationship by ordinary least squares. As the value of ε is much more difficult to estimate, we take the value as estimated by Ahlfeldt *et al.*.

Given regional populations of worker-households $\mathcal{H}_k$, total resident workers (by skill)

$$H_{kr} = \sum_s \sum_i \pi_{irs|k} \mathcal{H}_k \quad (3)$$

while labour supply (by skill and industry) is given by

$$H_{kis} = \sum_r \pi_{irs|k} \mathcal{H}_k. \quad (4)$$

The mean after-tax income (by skill) of a resident worker is

$$\frac{\sum_s \sum_i \pi_{irs|k} M_{kis}}{\sum_s \sum_i \pi_{irs|k}} = \frac{\sum_s \sum_i G_{kis} e^{-\varepsilon \kappa_k \tau_{rs}} M_{kis}^{\varepsilon+1}}{\sum_s \sum_i G_{kis} e^{-\varepsilon \kappa_k \tau_{rs}} M_{kis}^\varepsilon}.$$

2.1.2 Non-working households

Non-working households make only residential location choices. Each non-working household of type k earns taxable and non-taxable non-wage income

$$M_k = (1 - \vartheta_h) m_{1k} + m_{2k}.$$

Household o_k choosing residence r has indirect utility

$$u_{ro_k} = z_{ro_k} \frac{B_r M_k}{Q_{kr}}. \quad (5)$$

The share of k -type non-working households choosing r is

$$\pi_{r|k} = \frac{\psi_{r|k}}{\sum_{r'} \psi_{r'|k}} \quad \text{where } \psi_{r|k} \equiv T_r \left(\frac{B_r M_k}{Q_{kr}} \right)^\varepsilon. \quad (6)$$

2.1.3 Regional populations of households

Before drawing their individual shock z_{irso_k} , an individual's expected utility for living and working in the region is

$$\mathbb{E}\{u_{irso_k}\} = \Gamma\left(\frac{\varepsilon - 1}{\varepsilon}\right) \left[\sum_{i'} \sum_{r'} \sum_{s'} \psi_{irs|k} \right]^{1/\varepsilon} \quad (7)$$

where $\Gamma(\cdot)$ is the gamma function.⁴ With the suppression of the indices i and s , this equation applies to non-working households.

⁴See Ahlfeldt *et al.* for proofs of these last two results in their canonical setting.

If the region is small and open to inward and outward migration, a logical extension of this model is to adopt a nested logit formulation such that there is a choice between living within or outside of the modelled region. This extension can be operationalised by assuming that expected utility outside of the region is held constant. Since we apply our framework to model large sub-national regions containing multiple cities and towns, we see no compelling reasons to think that choices within a region are better or worse substitutes than the choice living within or outside of the region. We therefore assume the same value ε applies in the upper nest so that the nested structure collapses back down to a single level. With these assumptions, each regional population of working or non-working households $\mathcal{H}_k$ responds to changes in regional expected utility for that household type according to

$$\frac{d\mathcal{H}_k}{\mathcal{H}_k} = \varepsilon \frac{d\mathbb{E}\{u_{irso_k}\}}{\mathbb{E}\{u_{irso_k}\}} \quad (8)$$

2.2 Consumption

We assume that each household has a constant propensity to consume out of their after-tax income. We specify the consumption (sub-)utility of working households as Cobb-Douglas at the top level. At this level enter, housing services (variables subscripted with $\mathfrak{H}$ or, for convenience, $j \in \mathfrak{H}$), tradable goods (variables subscripted with $j \in \mathfrak{T}$) and composites of spatial varieties for each type of non-tradable services (variables subscripted with $j \in \mathfrak{N}$). The sub-utility functions for each of the non-tradables composites is specified following Anas (2007) to combine a love of varieties from different locations with discrete, costly trips and diseconomies of consumption per trip. However, in difference to Anas, we treat all consumption travel costs as time costs that generate disunity through a multiplicative negative exponential form (as for commuting in section 2.1) instead of imposing an explicit time budget constraint. Finally, for tractability, we assume that all consumption travel takes the form of return trips ex the household's place of residence r .

For each worker-household, consumption sub-utility is then given by

$$d_{kir\mathfrak{H}}^{\beta_{k\mathfrak{H}}} \prod_{j \in \mathfrak{T}} d_{kirsj}^{\beta_{kj}} \prod_{j \in \mathfrak{N}} e^{-\kappa_{kj} T_{kj}} \left[\sum_t \left(n_{kirsjt} d_{kirsjt}^{\phi} \right)^{\frac{\sigma_j - 1}{\sigma_j}} \right]^{\frac{\sigma_j}{\sigma_j - 1} \beta_{kj}} \quad (9)$$

where $d_{kir\mathfrak{H}}$ is consumption of housing services, d_{kirsj} is the consumption of each tradable good, T_{kj} is the annual consumption travel time devoted to consumption of j -type services, and n_{kirsjt} and d_{kirsjt} are the annual number of consumption trips and per-trip consumption of j -type services for each destination t . The parameters specify consumption preferences at the top level (β_{kj}), scale diseconomies in per-trip consumption ($0 < \phi_j < 1$), and the substitutability of services from different locations ($\sigma_j \gg 1$). The parameters κ_{kj} will be calibrated to match aggregate data on consumption travel times (and costs).⁵ Note that, with the suppression of the indices i and s , this and what follows applies also to non-working household types.

Households choose consumption quantities and trip frequencies to maximise utility subject to the expenditure constraint

$$R_r d_{kir\mathfrak{H}} + \sum_{j \in \mathfrak{T}} p_j d_{kirsj} + \sum_{j \in \mathfrak{N}} \sum_t P_{jt} n_{kirsjt} d_{kirsjt} \leq E_{kirs}$$

⁵Notice that the overall disutility of travelling depends on a linear combination of the costs for all trip purposes, including commuting. Thus, we do not impose a specific theory of time allocation. However, we treat travel times for different purposes consistently and the functional form provides a reasonable fit to observed trip length distributions.

Anas (2007) shows that the utility-maximising distributions of travel times and expenditures between consumption locations both have logit forms. In fact, the shares of travel time and of expenditure allocated to each destination t are equal and given by

$$\frac{P_{jt}^{\phi_j(1-\sigma_j)} \tau_{rt}^{(1-\phi_j)(1-\sigma_j)}}{\sum_{t'} P_{jt'}^{\phi_j(1-\sigma_j)} \tau_{rt'}^{(1-\phi_j)(1-\sigma_j)}}.$$

This expression shows the effect of scale diseconomies: the closer ϕ_j to zero, the greater the importance of differences in travel costs to competing destinations relative to differences in prices in competing destinations. It follows also from this that per trip consumption is directly proportional to trip travel time

$$d_{krjt} \propto \frac{E_{kirs}}{T_{kj}} \frac{\tau_{rt}}{P_{jt}},$$

whereas trip frequency is inversely related to trip travel time.

Substituting the expressions for optimal d_{krjt} and n_{krjt} conditional on E_{krj} and T_{kj} into the consumption utility function 9, the indirect sub-utility function for non-tradables of type j is

$$\left(\tilde{\beta}_{kj} E_{kr}\right)^{\phi} T_{kj}^{1-\phi_j} \left[\sum_t P_{jt}^{\phi_j(1-\sigma)} \tau_{jt}^{(1-\phi_j)(1-\sigma)} \right]^{\frac{1}{\sigma-1}}$$

where $\tilde{\beta}_{kj}$ is the share of expenditure on type j services. Substituting this result into 9 and maximising overall consumption utility with respect to $\tilde{\beta}_{kj}$ and T_{kj} subject to

$$R_r d_{kirsH} + \sum_{j \in \mathfrak{T}} p_j d_{kirsj} + \sum_{j \in \mathfrak{N}} \tilde{\beta}_{kj} E_{kirs} \leq E_{kirs}$$

we obtain that for non-tradables

$$\tilde{\beta}_{kj} = \frac{\phi_j \beta_{kj}}{\beta_{kH} + \sum_{j' \in \mathfrak{T}} \beta_{kj'} + \sum_{j' \in \mathfrak{N}} \phi_{j'} \beta_{kj'}} \quad (10)$$

and

$$T_{kj} = \frac{1 - \phi_j}{\kappa_{kj}} \beta_{kj}. \quad (11)$$

For tradables and housing

$$\tilde{\beta}_{kj} = \frac{\beta_{kj}}{\beta_{kH} + \sum_{j' \in \mathfrak{T}} \beta_{kj'} + \sum_{j' \in \mathfrak{N}} \phi_{j'} \beta_{kj'}} \quad \forall j \in \mathfrak{T} + \mathfrak{H}. \quad (12)$$

Substituting the full set of optimal consumption demands into the consumption subutility function 9, we obtain an indirect utility function and consequently the following local utility cost index:

$$\mathcal{Q}_{kr} = \left(\frac{R_{Hr}}{\tilde{\beta}_{kH}} \right)^{\beta_{kH}} \prod_{j \in \mathfrak{T}} \left(\frac{p_j}{\tilde{\beta}_{kj}} \right)^{\beta_{kj}} \prod_{j \in \mathfrak{N}} \left(\frac{Q_{jr} (\kappa_j E_{kirs})^{1-\phi_j}}{((1-\phi_j) \beta_j)^{1-\phi_j} (\phi_j \tilde{\beta}_j)^{\phi_j}} \right)^{\beta_{kj}} \quad (13)$$

where

$$Q_{jr} \equiv \left[\sum_t P_{jt}^{\phi_j(1-\sigma)} \tau_{jt}^{(1-\phi_j)(1-\sigma)} \right]^{\frac{1}{\sigma-1}} \quad (14)$$

Tourists' consumption behaviour is treated similarly to that of non-working households. Tourists' place of stay stands in for the place of residence and their housing expenditure shares are set to zero. We have not, as yet, elaborated a theory of tourists' destination choices within the region, which should account for both attractiveness and costs. Instead, for each place of stay, we specify a constant elasticity of tourism demand.

2.3 Firms

Individual firms operate with constant returns to scale in perfectly competitive input and output markets. Technologies of production are specified by the nested production function

$$Y_{is} = \min \left[\frac{V_{is}}{\iota_{iV}}, \min_{j \in \mathfrak{I}} \left[\frac{X_{ij}}{\iota_{ij}} \right] \right] \quad \text{where}$$

$$V_{is} = F_{is}^{\alpha_{Fi}} \left\{ \theta_{Ljs} \prod_{k \in \mathfrak{L}} (A_{ks} L_{ks})^{\alpha_{ki} \rho_L} \dots \right. \\ \left. + (1 - \theta_{Ljs}) \left[\theta_{Hjs} \prod_{k \in \mathfrak{H}} (A_{ks} L_{ks})^{\alpha_{ki} \rho_H} + (1 - \theta_{Hjs}) K_{is}^{\rho_H} \right]^{\frac{\rho_L}{\rho_H}} \right\}^{\frac{\alpha_{Fi}}{\rho_L}} \quad (15)$$

At the lowest level, high-skill levels of labour are combined in a Cobb-Douglas sub-nest. This composite is then combined with capital/intermediate inputs K_{is} in a constant elasticity of substitution (CES) nest with an elasticity of substitution $\sigma_H \equiv 1/(1 - \rho_H) = 0.6$. This composite is in turn combined with a Cobb-Douglas sub-nest of low-skill levels of labour in another CES nest with an elasticity of substitution $\sigma_L \equiv 1/(1 - \rho_L) = 1.5$.⁶ Finally, this composite is combined Cobb-Douglas with commercial/industrial property F_{is} to form the complete value added composite V_{is} . This composite is combined in fixed proportions with tradable intermediate inputs X_{ij} .

Denoting the rental price of sector-specific developed property by R_{is} and rental prices of sector-specific equipment (also exogenously set) by r_{Ei} , firms' unit costs functions are

$$P_{is} = \iota_{iV} C_{Vis} + \sum_{j \in \mathfrak{I}} \iota_{ij} p_j \quad \text{where}$$

$$C_{Vis} = \left(\frac{R_{is}}{\alpha_{Fi}} \right)^{\alpha_{Fi}} \left(\frac{C_{Lis}}{1 - \alpha_{Fi}} \right)^{1 - \alpha_{Fi}},$$

$$C_{Lis} = \left[\theta_{Ljs}^{\sigma_L} \prod_{k \in \mathfrak{L}} \left(\frac{W_{kis}}{\alpha_{ki} A_{ks}} \right)^{\alpha_{ki} (1 - \sigma_L)} + (1 - \theta_{Ljs})^{\sigma_L} C_{His}^{\frac{1 - \sigma_L}{1 - \sigma_H}} \right]^{\frac{1}{1 - \sigma_L}} \quad \text{and}$$

$$C_{His} = \left[\theta_{Hjs}^{\sigma_H} \prod_{k \in \mathfrak{H}} \left(\frac{W_{kis}}{\alpha_{ki} A_{ks}} \right)^{\alpha_{ki} (1 - \sigma_H)} + (1 - \theta_{Hjs})^{\sigma_H} r_{Ei}^{1 - \sigma_H} \right]^{\frac{1}{1 - \sigma_H}}. \quad (16)$$

In each non-tradables sector, firms prices P_{is} adjust endogenously to clear local markets. In each tradables sector, firms set their prices equal to the exogenous price: $P_{is} = p_i$.

Firms' demands for commercial/industrial property are

$$F_{is} = \alpha_{Fi} C_{Vis} \iota_{iV} Y_{is} / R_{is}, \quad (17)$$

for each type of low skilled labour, they are

$$L_{kis} = \alpha_{ki} (1 - \alpha_{Fi}) \frac{C_{Vis} \iota_{iV} Y_{is} \theta_{Ljs}^{\sigma_L} C_{Lis}^{\sigma_L - 1}}{W_{kis}} \left(\prod_{k \in \mathfrak{L}} \left(\frac{W_{kis}}{\alpha_{ki}} \right) \right)^{1 - \sigma_L}, \quad (18)$$

for each type of high skilled labour, they are

$$L_{kis} = \alpha_{ki} (1 - \alpha_{Fi}) \frac{C_{Vis} \iota_{iV} Y_{is} (1 - \theta_{Ljs})^{\sigma_L} C_{Lis}^{\sigma_L - 1}}{\theta_{Hjs}^{\sigma_H} C_{His}^{\sigma_H - 1} W_{kis}} \left(\prod_{k \in \mathfrak{H}} \left(\frac{W_{kis}}{\alpha_{ki}} \right) \right)^{1 - \sigma_H}, \quad (19)$$

⁶ Complementarity (substitutability) between high-skilled (low-skilled) labour and equipment and the particular elasticities adopted are based on Krusell et al. (2000, p1034 and tb 1).

for equipment, they are

$$K_{is} = \alpha_{ki} (1 - \alpha_{Fi}) \frac{C_{vis} \iota_{iv} Y_{is} (1 - \theta_{Ljs})^{\sigma_L} C_{Lis}^{\sigma_L - 1}}{\theta_{Hjs}^{(1 - \sigma_H)} C_{His}^{\sigma_H - 1} r_{Ei}}, \quad (20)$$

and for each tradable intermediate, they are

$$X_{jis} = \iota_{ij} Y_{is}. \quad (21)$$

2.4 Land allocation and development

2.4.1 Land allocation

We assume that planning rules together with other (e.g. geographic, geological) factors cause bare land in each location to be imperfectly transformable between uses. Rents for zoned bare land ($\mathbb{R}_{zjs}$) thus differ by both planning zone and using sector in each location s . The allocation of zoned land resources $\mathbb{Z}_{zs}$ to uses is modelled in a two level nested logit specification.

In the first stage, total zoned land is allocated between residential (variables subscripted with H) and non-residential (variables subscripted with N):

$$\mathbb{N}_{zHs} = \frac{(\phi_{zHs} \mathbb{R}_{zHs})^{\nu_H}}{(\phi_{zHs} \mathbb{R}_{zHs})^{\nu_H} + ((1 - \phi_{zHs}) \mathbb{R}_{zNs})^{\nu_H}} \mathbb{Z}_{zs}. \quad (22)$$

Except in so-called ‘mixed use’ zonings, there zoning schemes tend to strongly limit the flexibility of transformations between these two categories of use, in which case $\nu_H < 1$.

In the second stage, the total non-residential land is allocated between specific industries

$$\mathbb{N}_{zis} = \frac{(\phi_{zis} \mathbb{R}_{zis})^{\nu_1}}{\sum_{i'} (\phi_{zi's} \mathbb{R}_{zi's})^{\nu_1}} (\mathbb{Z}_{zs} - \mathbb{N}_{zHs}), \quad (23)$$

where $\mathbb{R}_{zNs}$ is the weighted average rental rate for non-residential land

$$\mathbb{R}_{zNs} \equiv \frac{\sum_{i'} \mathbb{R}_{zi's} \mathbb{N}_{zi's}}{\mathbb{Z}_{zs} - \mathbb{N}_{zHs}}. \quad (24)$$

The flexibility between permitted competing uses is determined by ν_1 . This parameter may be higher or lower depending on the nature of the zoning, but in most cases, we can reasonably assume $\nu_1 > \nu_H$. Note that a zoning may prohibit some uses altogether in any given location (e.g. an industrial zoning would prohibit any residential use) in which case the relevant elements of ϕ_{zHs} or ϕ_{zis} are set to zero.

2.4.2 Development

Zoned land allocated to each sector is combined with structures to form property specific to that sector using sector-specific technologies. As for non-structures capital used by industries, we assume that structures of each type are supplied perfectly elastically in the long run at a given rental price r_{sj} . The production functions for each industry or residential sector j are:

$$F_{zjs} = S_{zjs}^{\mu_j} \mathbb{N}_{zjs}^{1 - \mu_j} \quad (25)$$

The effects of density-limiting regulations are mimicked by the imposition of shadow taxes and offsetting subsidies on structures and land inputs respectively (Horridge, 1994). For each planning zone, we define a non-linear functional relationship between the shadow

tax rate and the developed density. In effect, these functions define ‘soft thresholds’ whereby at densities well below the threshold there is little distortion while at densities well above the threshold, the level of distortion is rapidly increasing. There is a smooth transition between these two regimes around the threshold. The effect of this is that as demand for property in a given location increases, development densities increase less on restrictively zoned land than they do on unrestrictively zoned land.

Concretely, we model the pseudo-tax rate on structures ς_{zjs} as

$$\varsigma_{zjs} = \log \left(\frac{1 + \exp(\chi_{1z} S_{zjs} / \mathbb{N}_{zjs} - \chi_{2z})}{1 + \exp(-\chi_{2z})} \right) \quad (26)$$

where parameters χ_{1z} and χ_{2z} determine the asymptotic gradient and point of inflection for each zoning z .

We assume that users of residential or non-residential types of property are indifferent to the underlying land use zonings so property rents R_{js} are common independent of zonings. From developers’ first order conditions, we obtain demands for structures as

$$S_{zjs} = \mu_{js} \frac{R_{js} F_{zjs}}{(1 + \varsigma_{zs}) r_{js}} \quad (27)$$

and for land as

$$\mathbb{N}_{zjs} = (1 - \mu_{js}) \frac{R_{js} F_{zjs}}{(1 - \zeta_{zs}) \mathbb{R}_{zjs}}. \quad (28)$$

respectively, where r_{js} are the (exogenous) rental prices of structures,

Pseudo-subsidy rates for land ζ_{zs} are determined by

$$\varsigma_{zjs} r_{sj} S_{zjs} = \zeta_{zjs} \mathbb{R}_{zjs} \mathbb{N}_{zjs}. \quad (29)$$

Developers’ rental cost functions are

$$R_{js} = \left[\frac{(1 + \varsigma_{zjs}) r_{sj}}{\mu_{js}} \right]^{\mu_{js}} \left[\frac{(1 - \zeta_{zjs}) \mathbb{R}_{zjs}}{1 - \mu_{js}} \right]^{1 - \mu_{js}} \quad (30)$$

2.5 Spatial externalities

Agglomeration effects on productivity and on amenity are specified following as

$$A_{is} = a_{is} \sum_t \left(e^{-\delta \tau_{st}} \sum_k \sum_{i'} L_{ki't} \right)^{\lambda_i} \quad (31)$$

We assume that the relevant densities for productivity spillovers are of skilled workers in all sectors per hectare of developed non-residential land.⁷ There is a common rate of spillover decay with travel time δ but we allow for a different elasticity of productivity to effective density λ_i in each industry.

To model positive externalities of effective residential density, we use the density of residents per developed hectare and common decay and elasticity parameter ϱ and η .

$$B_r = b_r \sum_s \left(e^{-\varrho \tau_{rs}} \sum_i H_{ks} \right)^{\eta} \quad (32)$$

⁷The most appropriate ways to define density for the purposes of these equations require further investigation.

2.6 Calibration

2.6.1 Spatial delineation

In the application of the framework to NSW, we distinguish 473 statistical areas (SAs) in which there is significant residential and/or commercial activity. In the Sydney–Newcastle–Wollongong conurbation, each SA corresponds to an ABS SA2. A few SA2s in which there is not significant economic activity are omitted from the model. Beyond this conurbation, SA2s are generally consolidated such that each town is represented by one model SA comprising one or several SA2s. Rural SA2s are similarly aggregated. Only a few model SAs are distinguished in far-western NSW. The Australian Capital Territory (ACT) is also located within NSW and is currently represented as one single model SA but we plan to disaggregate it to SA2 level in future work.

2.6.2 Data sources

The model has been calibrated using the following main sources:

- 2016 Census data on population and employment
- Estimates of generalised travel costs (GTCs) between model SAs derived from skims of the NSW Strategic Transport Model (STM) for road, bus and car trips.
- Supplementary estimates of travel costs outside of the region covered by STM (in most cases, considering only road trips).
- A spatial data layer with information on NSW Local Environmental Plans and State Environmental Planning Policies.
- State level economic supply and use tables maintained by the Centre of Policy Studies.

2.6.3 Parameters

We base our parameter values for spillover decay rates on Ahlfeldt et al. (2015). This is also the only source of which we are aware that estimates spillover strength with respect to effective residential densities. However, given the very different urban form and cultural context of Berlin relative to Australian cities, we conservatively take a somewhat lower value of 0.1 in our default parametrisation. For firms, spillover strengths differ by sector, grouped into high, medium and low spillover strengths. These groupings as well as the elasticities of 0.12, 0.05 and 0.01 applied to group are based loosely on sector-specific estimates for Australian and New Zealand Standard Industry Classification industry Divisions in the literature (Maré and Graham, 2013; KMPG, 2017).⁸ The weighted average of our parameters close to the aggregate estimate of 0.07 in Ahlfeldt et al. (2015).

3 Analysis of an outer suburban rail loop

3.1 Characterisation of the project

Our hypothetical project involves a 43.5km extension of the Sydney metropolitan rail network stretching from Epping in the north-west to Sutherland in the south-east. The line passes through Baulkham Hills, Pendle Hill, Fairfield, Warwick Farm, East Hills and Menai. This

⁸The first of these provides estimates for New Zealand and the second for Australia. There are also some significant methodological differences between these studies. While results for some sectors are similar, for others are differ markedly.

takes it approximately five kilometres to the west of Parramatta, which is a significant secondary business district.

Estimating the impacts of this new service on travel times between all origin–destination pairs requires several steps:

1. Costs between origin and destination SA2s along the rail line are set to reflect the speeds and fare structure of the existing network.
2. Local (i.e. within-SA2) rail access costs are estimated based on the perpendicular distance of each SA2 centroid from the line.
3. For trips involving an origin and/or destination SA2 not intersected by the line, the minimum rail trip cost is estimated, allowing for a leg of the trip to be taken along the new line if the cost is lowered. The baseline rail costs are used for rail legs to/from SA2s along the new line.
4. Having estimated a full origin–destination matrix of rail costs in which entries are either lower than or identical to baseline costs, new all-mode GTCs are estimated using the same simple nested logit model that was used to compute baseline GTCs.

To reflect the financial costs of undertaking this network extension, we assumed a capital cost of A\$12b to be financed by a 40-year 3% annuity, which corresponds to an annual payment of A\$612m. We do not account for any change in network operating subsidies that might be required by the extension. The capital cost of A\$12b is deliberately very modest since we made no attempt to mitigate the real topographic, geological and land acquisition difficulties our hypothetical alignment would doubtless entail. A carefully designed alignment—considering also long-term development expectations for the west of Sydney—would doubtless differ significantly from our hypothetical example.

The project is modelled as a counter-factual relative to the model’s base year of 2016. That is, we model the impacts in 2016 as if the rail loop had been constructed several decades earlier. To implement the simulation, changes in GTCs are introduced directly into the model. The annuitised capital cost is modelled by increasing a stylised income tax to raise A\$612m additional to the amount implied by the baseline per capita rate.

The ACT is currently represented in the model as a one aggregated area within NSW.

3.2 Spatial impacts

3.2.1 Resident workers, jobs and commuting costs

Figure 1 shows the percentage changes in total resident workers by SA2 in Greater Sydney⁹ as well as in the Blue Mountains to the west of Sydney (e.g. Katoomba) and the central coast to the north of Sydney (e.g. Gosford). Beyond the mapped area, modelled changes are in the same direction as seen in Katoomba and Gosford, but are in most cases smaller in magnitude. Both the existing suburban and regional rail passenger network and our hypothetical new rail loop are shown for context. Rural areas are masked in the maps to avoid over-emphasising large land areas that account for a very small fraction of economic activity.¹⁰ These use of rural land in primary production and other minor uses of rural land are, however, represented in the model itself.

Large increases in the resident workforce are seen along the rail corridor. These positive effects decay rapidly with distance from the line. East of the line, changes become negative

⁹Unless otherwise specified, we refer to the Greater Sydney Capital City Statistical Area defined by the Australian Bureau of Statistics.

¹⁰For this purpose, we use the Australian Bureau of Statistics’ Urban Centres and Localities (UCL) to define urban areas.

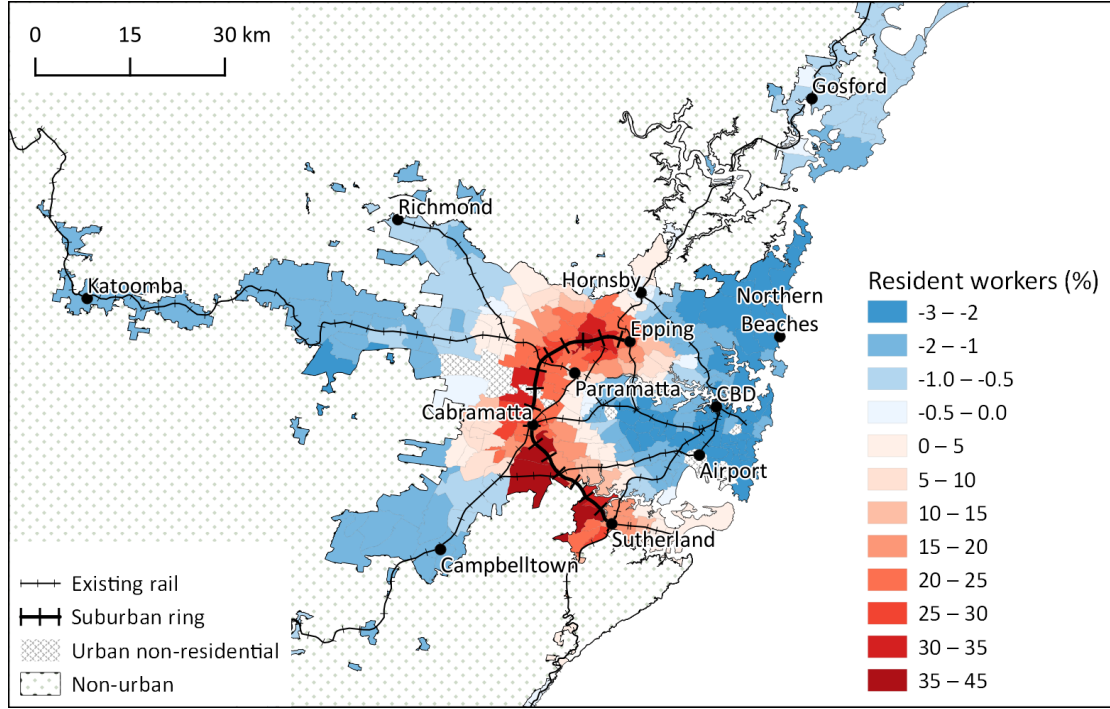


Figure 1: Percentage change in resident workforce vs BaU.

within 5 – 10km. There is a slightly slower drop-off north and west of the line, reflecting the smaller populations, lower densities and poorer transport connectivity in these outer-most suburbs. Changes in jobs (Figure 2) are much more diffused. Indeed, employment increases in every part of Greater Sydney. There are small negative impacts on employment in most of the rest of the NSW/ACT region, as can be seen for example around the city of Gosford (which itself sees slight gains) on the NSW Central Coast.

The outer western suburbs of Sydney are relatively job-poor and jobs are relatively unproductive relative to the city, inner suburbs and secondary business districts such as Parramatta or Chatswood. Employment is mostly in local population-serving jobs or in industrial parks, only some of which would be well served by our rail loop. On the other hand, these suburbs contain large swathes of housing at low densities. The rail loop therefore improves access from relatively low cost housing to higher wage jobs in the central city and secondary business districts. At the same time, increased residential populations along the rail corridor raise demands for local services. Since households ‘shop’ for these services, their demands are spatially diffused around their places of residence.

Figure 3 shows trip-weighted average commuting costs for low-skill, white collar workers by place of residence while figure and 4 shows corresponding averages by place of work. These results depend only on changes in commuting patterns due to the project, thus far enough away from Sydney they go to zero. That more concentrated pattern of time savings by place of residence relative to time savings by place of work reflects the net increase in out-commuters from the rail corridor implied by the previous two sets of results. In fact, since the ratio of residents to jobs declined in eastern Sydney and in the far outer suburbs, Blue Mountains and Central Coast, average commute times by place of work actually increase slightly in these areas.

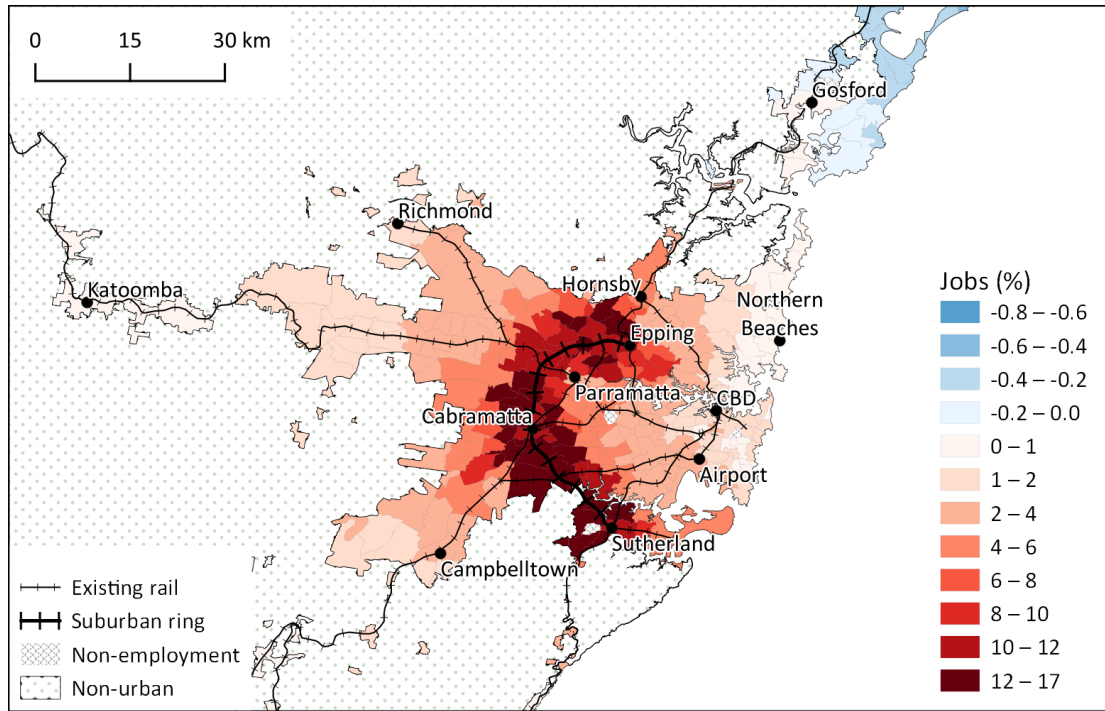


Figure 2: Percentage change in employment vs BaU.

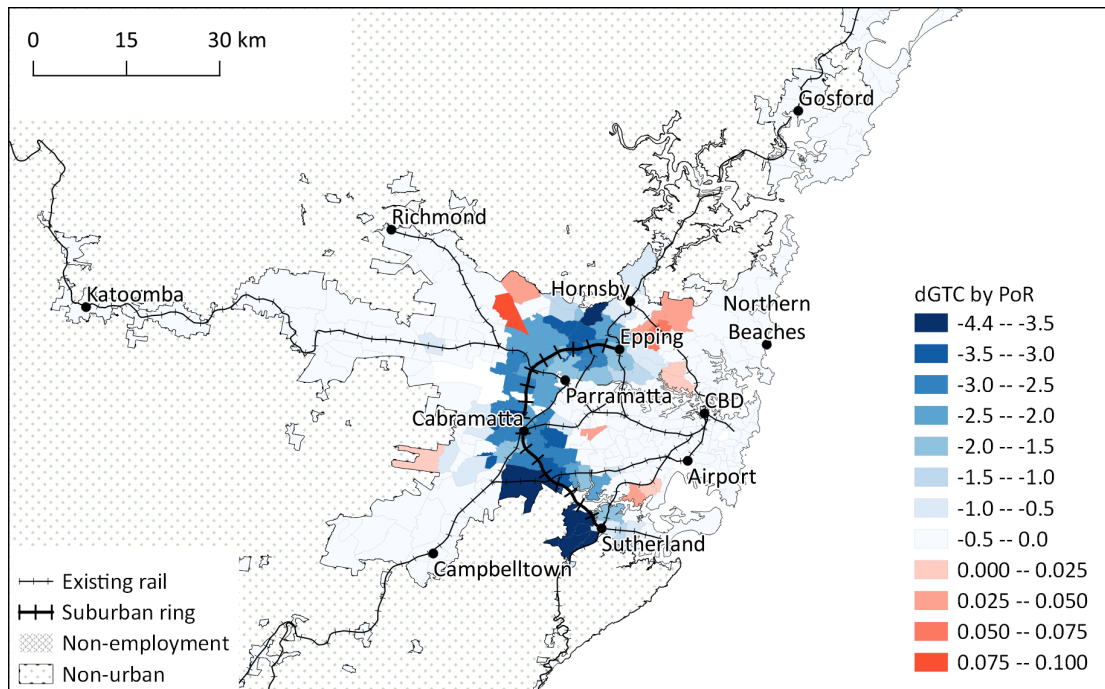


Figure 3: Average change in generalised commuting cost (mins) by place of residence for low-skill, white collar workers.

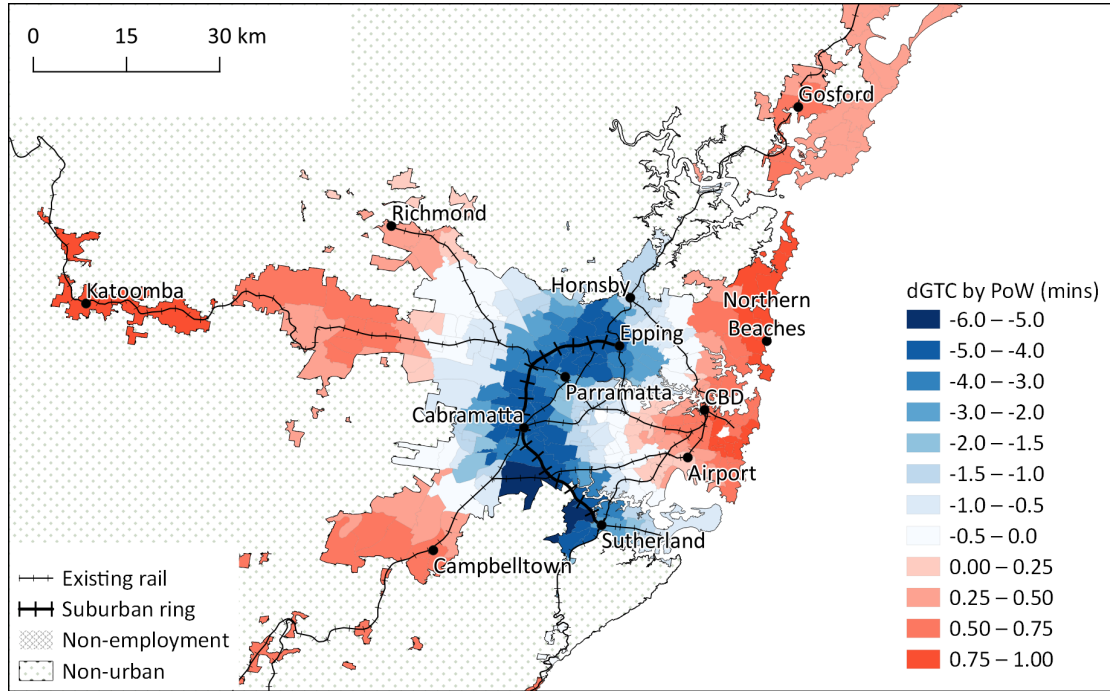


Figure 4: Average change in generalised commuting cost (mins) by place of work for low-skill, white collar workers.

3.2.2 Housing

Changes in housing volumes (Figure 5) have a spatial pattern similar to changes in the resident workforce, but are approximately half as large. This occurs firstly because household substitute away from housing services as they become more expensive relative to other goods and services (Figure 6). Secondly, our index of housing volume allows for substitution between land and structures. Although there is some scope to reallocate land from commercial to residential uses, land supply for housing is relatively inelastic. Consequently, as land prices rise, development densities increase so that the increases in floorspace (proxied by structures) exceed increases in property volumes (not shown).

Figure 7 shows that changes in residential amenity are important in reinforcing relocation of the resident population. In terms of utility, increased residential amenity compensates residents for roughly a third of the increases in their housing costs in the rail corridor (Figure 6).

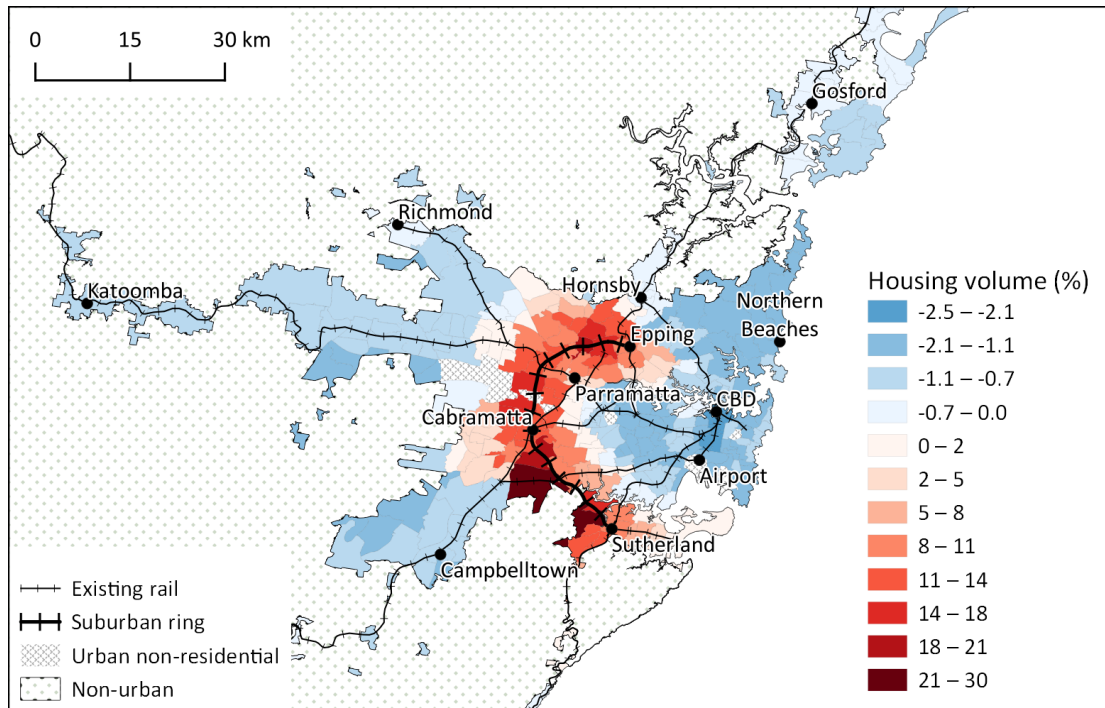


Figure 5: Percentage change in housing volume vs BaU.

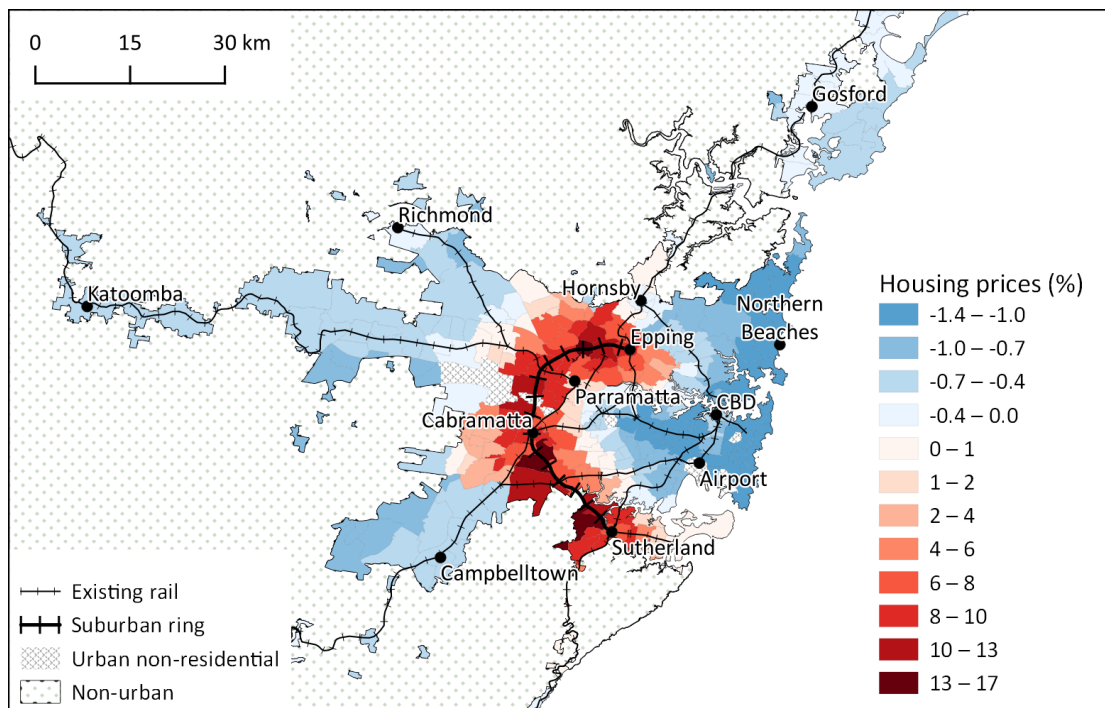


Figure 6: Percentage change in housing rental rates vs BaU.

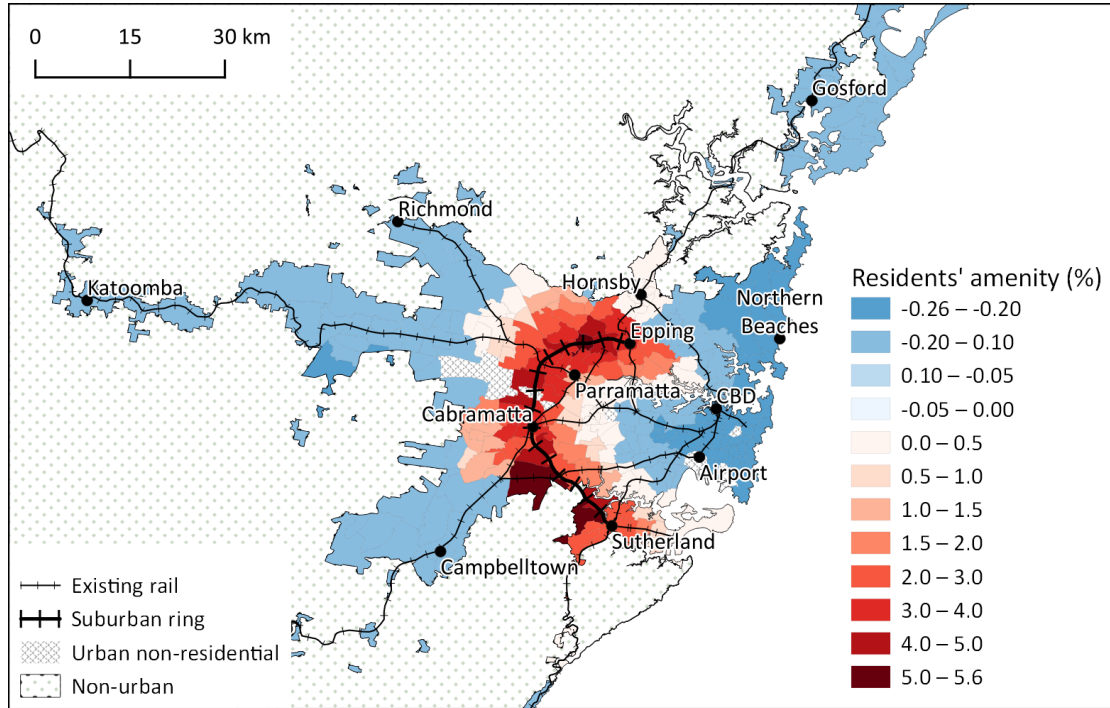


Figure 7: Percentage change in residential amenity vs BaU.

3.2.3 Wages and productivity

Figures 8 and 9 show changes in labour-augmenting productivity due to spillover effects and changes in wage rates respectively. While productivity increases 1 – 2% along the rail corridor due to higher job densities, the positive effects on wages of higher productivity are more than offset by local labour supply increases. Thus, the spatial pattern of wage changes is negatively correlated with the pattern of employment changes. They are, however, much smaller, reflecting the high mobility of both residential and work locations in the long run.

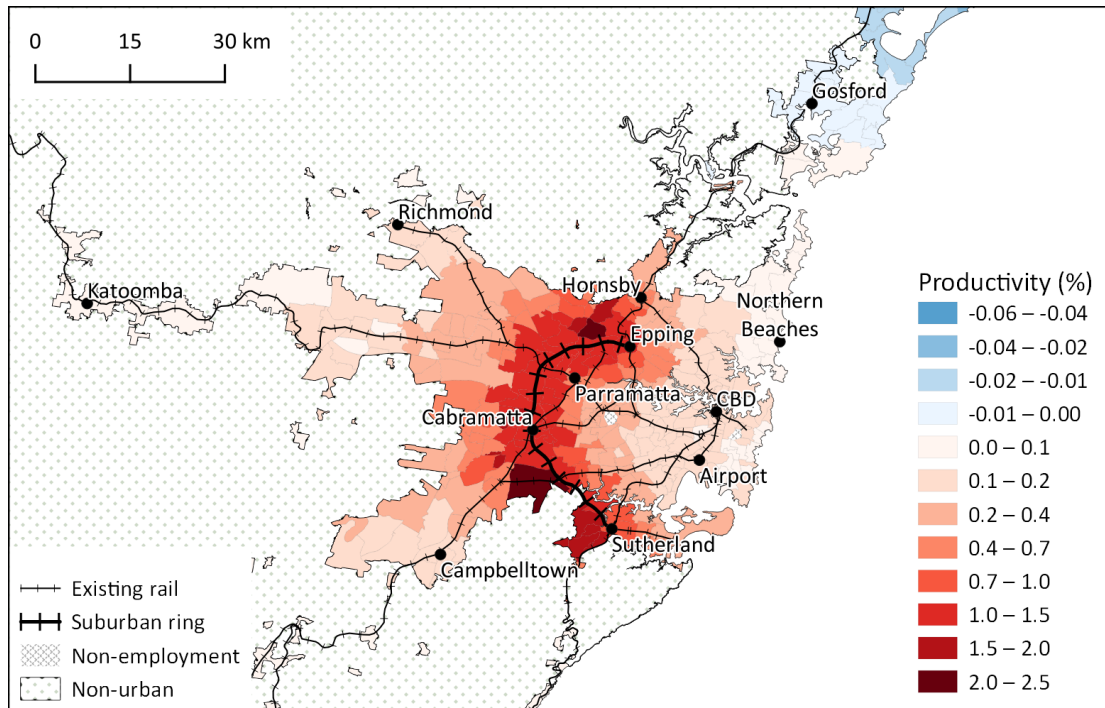


Figure 8: Percentage change in labour-augmenting productivity vs BaU.

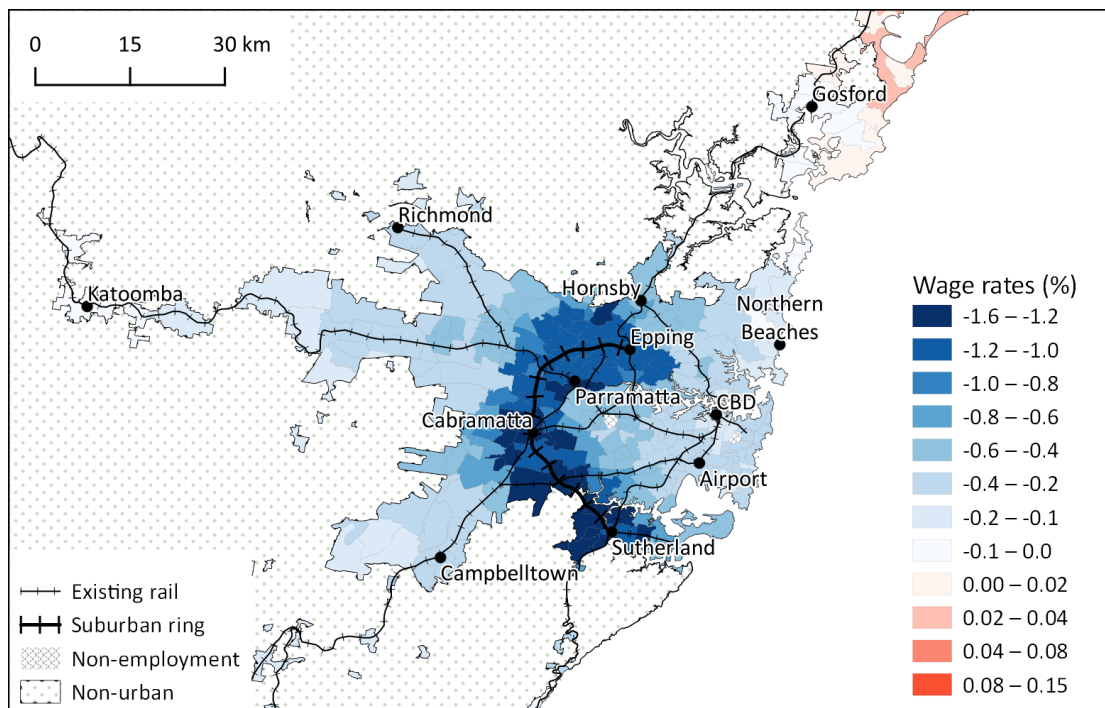


Figure 9: Percentage change in wage rates vs BaU.

3.3 Commuting patterns

Table 10 shows changes in commuting flows between ABS SA4s of Greater Sydney and the rest of the NSW/ACT region. The right-hand margin of the table gives the change in total resident workers in each SA4 and the lower margin gives the change in total jobs in each SA4.

It can be seen, for example, that increased in-commuting to the City and Inner South SA4 from the first five listed SA4s (four of these are traversed by the rail loop) more than offsets small decreases in in-commutes from other SA4s. There is a total increase of 83,800 workers/jobs in the NSW/ACT region and noting the net loss of 7,700 persons who both live and work outside of Greater Sydney (i.e. in Rest of NSW/ACT), the increase within Greater Sydney is 91,500.

	Parramatta	S West	Sutherland	Baulkham Hills	Ryde	Inner SW	Blacktown	Outer SW	Outer W / Blue Mtns	N Syd / Hornsby	Inner W	N Beaches	Eastern	City Inner S	Rest of NSW/ACT	Total resident workers
Parramatta	5.50	3.09	0.82	2.34	3.18	1.85	2.12	0.51	0.90	3.10	1.33	0.58	0.51	4.44	0.38	30.63
S West	4.32	3.72	1.92	1.58	1.79	3.43	1.72	1.01	0.90	1.29	0.96	0.30	0.54	3.73	0.46	27.66
Sutherland	2.28	2.91	2.32	0.50	0.80	2.71	0.62	0.56	0.24	0.62	0.55	0.18	0.56	3.49	0.49	18.81
Baulkham Hills	2.38	1.28	0.29	0.47	1.43	0.66	0.65	0.19	0.32	1.37	0.57	0.27	0.18	1.81	0.20	12.04
Ryde	1.93	0.76	0.19	0.84	1.22	0.49	0.60	0.12	0.22	1.48	0.56	0.35	0.28	2.35	0.15	11.50
Inner SW	0.85	1.64	0.58	0.44	0.37	0.08	0.39	0.16	0.16	0.10	0.01	0.04	0.05	0.43	0.13	5.40
Blacktown	0.49	0.78	0.26	0.14	0.74	0.44	0.07	0.14	0.10	0.65	0.13	0.11	0.06	0.57	0.09	4.76
Outer SW	-0.08	-0.55	0.19	0.17	0.19	-0.19	0.00	-0.64	-0.08	-0.04	-0.08	-0.01	-0.04	-0.23	-0.07	-1.46
Outer W / Blue Mtns	-0.59	-0.04	0.07	-0.03	0.38	0.04	-0.51	-0.07	-0.81	-0.01	-0.10	-0.01	-0.03	-0.18	-0.03	-1.91
N Syd / Hornsby	0.31	0.26	-0.02	0.06	-0.73	-0.05	0.13	0.02	0.02	-0.97	-0.14	-0.15	-0.11	-0.74	0.01	-2.09
Inner W	-0.47	-0.04	-0.11	0.06	-0.18	-0.33	-0.06	-0.02	-0.02	-0.26	-0.35	-0.05	-0.13	-0.80	0.00	-2.75
N Beaches	-0.12	0.02	-0.03	-0.07	-0.33	-0.08	-0.03	-0.01	-0.01	-0.68	-0.10	-0.64	-0.11	-0.74	-0.01	-2.92
Eastern	-0.18	0.00	-0.10	-0.06	-0.20	-0.18	-0.03	-0.01	-0.01	-0.30	-0.15	-0.07	-0.38	-1.26	-0.01	-2.92
City Inner S	-0.30	0.00	-0.14	-0.04	-0.24	-0.30	-0.05	-0.02	-0.02	-0.48	-0.27	-0.11	-0.36	-2.03	-0.01	-4.38
Rest of NSW/ACT	0.10	0.39	-0.21	0.12	-0.19	0.00	0.06	-0.09	-0.04	-0.46	-0.10	-0.08	-0.06	-0.31	-7.69	-8.56
Total jobs	16.42	14.21	6.01	6.50	8.22	8.56	5.68	1.85	1.86	5.41	2.82	0.71	0.95	10.52	-5.92	83.81

Figure 10: Changes in commuting flows between SA4s ('000 workers)

3.4 Macroeconomic impacts

The suburban rail loop has the direct impacts of: (i) reducing travel costs; and (ii) requiring higher regional savings to cover the projects net financial costs. Table 1 shows changes in each of the four populations in the mode together with changes in the expected utility for these types. The gains are similar for all four household types, although slightly larger for blue collar workers. The population increases range from 2.31% for low skilled white collar workers to 2.83% for non-working households.

In table 2, population weighted averages of expected utility for the three classes of worker-households are decomposed into contributions from commuting cost savings, real income effects and changes in residential amenity. Whereas the first and last of these effects are positive (the first unambiguously so since all travel times were either reduced or unchanged) the second is negative and large enough to more than offset the net gains attributable to changes in residential amenity. The most important cause of the negative real income effects is the requirement to repay the project’s capital costs. A second reason that there is a negative effect on aggregate real incomes is that the larger labour force causes land rents to rise relative to wages.

As concerns the role of land rents, it should be noted that our simulation treated all land as being owned by absentee landlords. A limitation of our framework is that it is not practically possible to account for the ownership of property in specific locations by specific persons (even if corresponding data were available). Nevertheless, it might be more realistic to treat land in NSW as being owned collectively by the population of NSW, in which case gains in land rental income would have contributed positively to residents’ real incomes.

Figure 11 shows the impact of the project on the GRP of the NSW/ACT region, decomposed to show the contributions of each primary factor and distinguishing between commercial and residential structures and land. Contributions of each factor are coloured differently. Negative contributions are indicated by cross-hatching. The last bar shows the total increase in GRP, which is 2.30%. This is slightly less than the increase in workforce: GRP per worker falls by -0.07% . Such a result should not be unexpected given that the direct effect of the project is to reduce passenger travel costs and, given our modelling assumptions, this has no direct impact on productivity nor labour supply per worker.¹¹

Of the 2.30 percentage point (*p.p*) increase in GRP, 57% is directly attributable to increased population. The next three bars show the contributions due to changes in (i) workforce composition and allocation to industries; (ii) allocation in space; and (iii) spillover effects that raise the productivity of workers in given industries and locations. For the rail loop, the last of these contributions dominates because the significant increases in employment do not occur in very high productivity areas (e.g. the CBD) and neither the location

¹¹It is likely that there are productivity impacts associated with changed loading of the transport network. Most importantly, average freight costs may increase or decrease as a result of changes in both car and freight demands. These impacts cannot be quantified without using a transport network model in conjunction with our SCGE model.

Table 1: Population and expected utility by household type

Household group	Population (%)	Expected utility (%)
Blue collar	2.48	0.328
White collar - low skill	2.31	0.305
White collar - high skill	2.35	0.310
Non-working	2.83	0.373

Table 2: Decomposition of expected utility¹

Contribution	Percentage points
Commuting costs	0.25
Residential amenity	0.44
Real income	-0.45
Non-tradables sub-utility	0.11
Expected utility	0.31

¹ Weighted average over skill/collar types.



Figure 11: Decomposition of change in GRP, distinguishing changes in non-structures capital, structures and land proportionate to population from changes per worker or per resident.

nor the nature of the project favours particular skill groups very strongly. Note that if the total population had been held constant, small reductions of employment in most areas away from the rail corridor would have caused productivity losses that would have made the aggregate impact of changes in productivity spillovers much smaller.

For other factors of production, net contributions to GRP are in all cases less than the increase in relevant population: the ‘per worker’ bars all show negative contributions, indicating negative capital deepening effects. For non-structures capital this negative contribution is minimal, while for commercial and residential structures, it is significant. In the modelled scenario, productive land resources are fixed both in area and in zoning. Thus net contributions associated with land are close to zero, although there is a slight shift from residential towards commercial land use.

4 Sensitivity analysis

4.1 Motivations

Additional simulations were conducted to assess the sensitivity of the results to:

1. density-restricting effects of planning regulations; and
2. different strengths of spillovers to residential amenity.

Not only are these among the least certain of our applied parameter values, but there are also reasons to doubt that their values are truly fixed in the context of a long-run response to some major intervention, such as development of a new rail line.

In reality, development densities are restricted by many individual regulations and regulatory processes, even within individual local jurisdictions. Even considering just clearly specified quantitative constraints, we find maximum building heights, minimum set-backs, maximum floor-area-ratios, maximum site coverage, minimum lot sizes, etc. It has been theorised that such regulations are the outcome of political bargaining processes between local governments, voters (especially home-owners) and developers. These actors will undoubtedly respond in different ways to changing local demands. Spatial interactions between communities may also arise. Thus, it may be more reasonable to interpret equation 26 as representing the effects of land use regulations in cross section (i.e. across locations at one point in time) rather than in a panel setting.

Rather than attempting to incorporate a more complicated theory of planning into our model, we simplify by exogenising the pseudo-tax rates at their calibrated levels. This has the effect that all densities within one SA increase or decrease proportionately, instead of increasing more (less) than proportionately in less (more) restrictive zonings. There remain differences in the weighted average level of development tax rates between SAs, but those rates no longer increase as aggregate demand increases.

As concerns the effects of effective residential density on amenity, the literature is replete with studies of different positive and negative consequences of physical and/or economic density. Ahlfeldt et al. (2018) review this literature and attempt to assess the overall balance of costs and benefits using various meta-analytical approaches. Of the fifteen outcome areas they consider, the following subset relates most directly to our model variable for ‘residential amenity’. We list these ranked by the elasticities listed in Ahlfeldt et al. (2018, table 7):¹²

- Green density (0.23)
- Efficiency of public services due to scale economies (0.144)
- Crime rate reduction (0.08)
- Pollution reduction (0.03)
- Subjective well-being (0.004)
- Wage gap reduction (-0.035)
- Health (-0.09)¹³

The dependence on density in some of these outcomes areas is likely to be relatively mechanical. Economies of scale in public service provision is a case in point. In many areas though, it is more likely that the results are mediated by local governance and planning processes that are themselves subject to change. It is a simple matter to find urban areas having very similar densities and income levels but appearing to offer dramatically different

¹²Conservatively, we omit ‘energy efficiency’, although there is a large literature addressing the fact that residential energy costs are often poorly internalised.

¹³This elasticity relates specifically to transport-associated mortality.

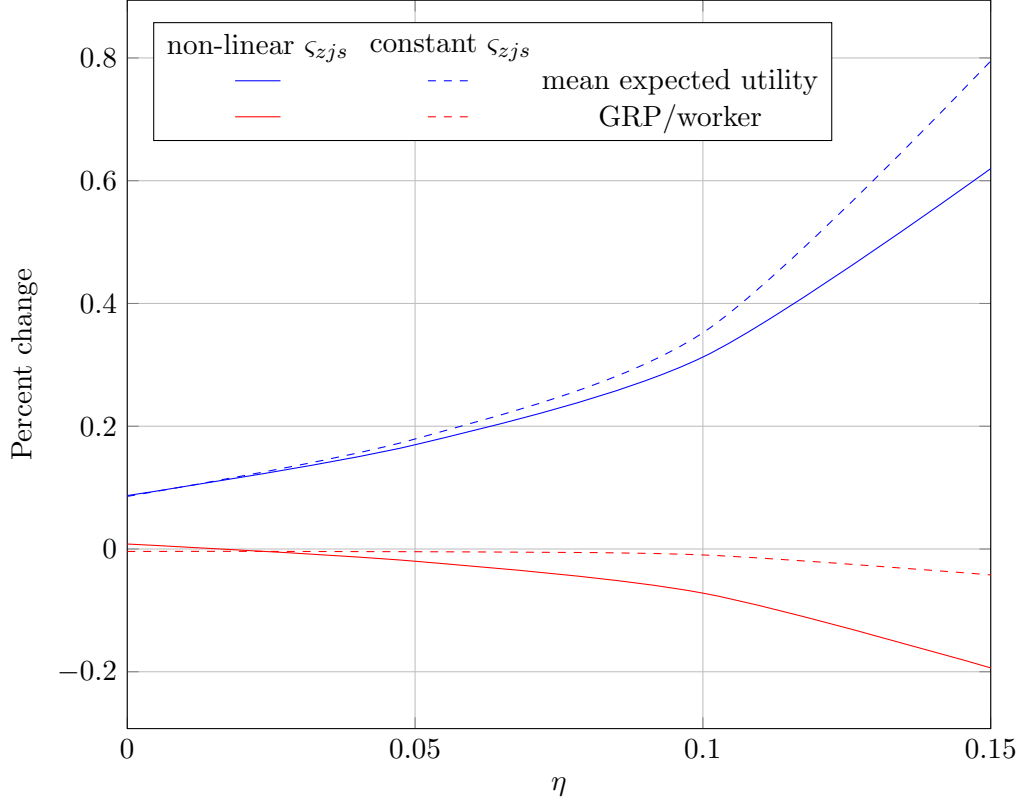


Figure 12: Response of mean regional utility and output per worker to different η with non-linearly varying vs. constant planning pseudo-tax rates

levels of amenity. As for the regulation of density, we do not attempt to model these factors but simply conduct simulations with alternative elasticities, ranging from zero through 0.15.

4.2 Results

Figure 12 shows how the weighted mean expected utility (blue lines) for the three skill/collar groups and GRP per worker (red lines) vary as a function of the spillover elasticity for residential amenity η . One set of simulations is conducted with planning pseudo-taxes varying according to the non-linear function 26 (solid lines) and another set of simulations is conducted holding these pseudo-tax rates at their calibrated levels (dotted lines).

Changes in utility are positive with $\eta = 0$. Since higher utility attracts more residents, changes in utility are increasing in η . The opposite effect would have occurred had the project decreased utility before accounting for effects on amenity. Thus, positive spillovers to residential amenity only serve to reinforce the welfare effects that would pertain in their absence. Although not shown in the figure, the increases in residential property demand stemming from increased residential amenity cause land rents to be bid up, which partly offsets the gains in utility. There are negligible impacts on the contribution of commuting costs to utility, given that modelled travel costs are exogenous. If we were to account endogenously for the increased costs congestion resulting from a larger population, these would further offset gains in utility due to increased amenity.

GRP increases as η increases (not shown). However, the impact on GRP per capita are slightly negative if planning pseudo-tax rates increase with development density or close to zero and much flatter if they are held constant. Intuitively, a planning regime that is restrictive of density in an absolute sense depresses both economic activity and economic

growth, whereas a planning regime that is restrictive of a density in relative sense (i.e. density in some locations relative to that in other locations) depresses economic activity but not economic growth. Thus, although our model produces substantial differences in aggregate quantities depending on assumptions made about amenity effects, per capita outcomes are insensitive to these assumptions, except insofar as there are strong regulatory constraints on increasing residential densities.

5 Conclusions

Our illustrative application of the VU Cities framework shows its potential to quantify long-run spatial and macroeconomic impacts of major transport projects. While the relocation of residents and jobs—in transport modelling parlance, ‘land use change’—may often be qualitatively predictable, the model allows us to quantify them. Moreover, the model provides a coherent framework within which the overall costs and benefits and economic impacts of a project can be quantified.

Some general lessons can also be drawn from our analysis of the rail loop. Firstly, there is no close relationship between the impacts of a project on economic output, as summarised here by GRP, and its welfare impacts. The decomposition of changes in utility shows the importance of private travellers’ time savings and increases in residential amenity. Secondly, changes in GRP may be sensitive to changes in regional population. Those changes are, in turn, sensitive to modelling assumptions, including assumptions relating to amenity and to effects of land use regulations. However, overall per capita impacts will usually be much less sensitive to these factors. For example, larger amenity effects tend to increase population, but increased labour supply and housing demand depresses real incomes and these two effects may be largely offset each other. Similarly, effects on GRP per capita are more weakly influenced by aggregate population change than by interventions directly affecting firms’ costs or shifting jobs to locations that already had higher levels of agglomeration.

In this illustrative application, we used a very simple method to estimate change in travel costs and thus could not account for some effects of our hypothetical project, including its impacts on road congestion. The VU Cities model can (and generally should) be used in conjunction with suitable large-scale a transport model. In ongoing work in both NSW and Victoria, we are running iterative simulations ‘soft-linking’ VU Cities with such models. This will allow a comprehensive assessment of long-run land use transport interactions.

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