More Working From Home Will Change the Shape and Size of Cities

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More working from home will change the shape and size of cities

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Abstract

Experiences of and investments in working from home (WFH) during the COVID-19 pandemic may permanently alter commuting behaviour and employment practices, ultimately changing the shape and size of cities. Using a spatial computable general equilibrium (SCGE) model, we study the effects of a shift to working-from home on labour supply, housing demands and the sectoral and spatial structure of the Australian economy. The model accounts for households' choices of occupations, residence and work locations, and for trade and input-output linkages between firms in different locations and industries.

Simulating increased WFH in selected occupations causes labour supply to shift towards these occupations at the expense of others. This is particularly favourable for many business services industries, which use the WFH occupations most intensively. Within cities, workers choosing WFH occupations opt for longer, but less frequent commutes from residential locations that are more attractive or have cheaper housing. Although this depresses house prices in inner areas, attracting workers choosing non-WFH occupations and non-working households, the net effects are flatter residential density gradients and increased urban sprawl. Jobs, become more centralised within cities and increase overall in the largest and most productive cities. Smaller cities and towns close to large employment centres attract more residents who commute out, but the majority of Australian cities and towns shrink, relative to the baseline.

Keywords: commuting; working from home; telecommuting; SCGE model; COVID-19

JEL codes: C68, R12, R13, R41

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1 Introduction

As in other countries, social distancing measures adopted in Australia in response to the COVID-19 pandemic have required many people to work from home. A survey by the Australian Institute of Family Studies (2020) finds that the percentage of people 'always working from home' rose from 7% pre-COVID-19 to 60%. Employers and employees have been forced to invest in the use of remote working technologies. 'Zoom' has entered the English lexicon as a verb alongside 'Skype' and 'Google'. There is an expectation that the current crisis will ultimately be brought to an end by discovery and production of effective vaccines and/or treatments. Nevertheless, it does not follow that work arrangements will then return to the status quo ante. Experts and media commentators are already questioning how the pandemic and in particular, experiences of working from home (WFH)—or in American parlance, telecommuting—may ultimately affect the world of work, transport demands and even the shape of cities (e.g. UN News, 2020; Hopkins, 2020; Beck and Hensher, 2020; Wheeler, 2020; Bloom, 2020).

Businesses surveyed in the US expected paid days worked from home to rise three-fold after the pandemic Altig et al. (2020). In an unpublished survey, just one in ten Australians working from home during the pandemic did not wish to work from home at all in future; whereas nearly four in ten had never worked from home in the past Bardoel (2020). Of course, during the pandemic, many of those working from home have had to juggle work and full-time care of school-aged children Australian Institute of Family Studies (2020), but presumably that will not be a feature of post-COVID-19 WFH. In Belgium, a similarly positive outlook on WFH is reported by Baert et al. (2020): two thirds of survey respondents wished to work more from home in future. A Lithuanian survey highlights significant gender and age differences in perceptions of WFH: younger workers and women tended to be more positive than older workers, especially older men.

Even prior to the pandemic, there was a growing body of evidence that workers in certain roles opting to work from home were as or more productive and satisfied than their those opting to work from the office. Bloom et al. (2015) shows that call-centre workers who self-select into working from home take fewer breaks and sick days, are more productive in their working hours and are less likely to quit. However, over time these workers did come to miss the social contact provided by the office environment. Choudhury, Foroughi, and Larson (2019) show that US patent examiners choosing to 'work from anywhere' are more productive. Moreover, workers chose locations with below-average living costs. However, for the majority of workers, the ability to combine home and office working is probably most attractive. For employers too, complete abandonment of face-to-face interactions in an office environment risks undermining creativity, motivation and loyalty Bloom (2020).

Arntz, Sarra, and Berlingieri (2019) finds that occasional WFH increases satisfaction and also slightly increases work hours amongst German workers. The positive effect on contractual hours amongst parents is stronger for mothers than for fathers. On the other hand, fathers' hourly wages increase while mothers' hourly wages increase only if they switch employers. Of particular relevance to our study, these authors also find that those choosing to work from home have longer commutes. In the United States, Pabilonia and Vernon (2020) find that both sexes in most occupations receive a wage premium of 5–15% for occasional WFH.[1] As in the German study, most avoided commuting time is devoted to leisure, childcare and/or housework. These changes in time use reduced gender inequality in unpaid work.

Implications of WFH/telecommuting[2], for urban form have been previously studied using computational urban economic models. In Rhee (2009), workers in a linear city with dispersed

[1] The exception is females working in professional and technical occupations.

[2] An advantage of the American terminology is that 'telecommuting' clearly evokes the substitution of a physical commute with digital connections to an office, whereas 'working from home' may also refer to home-based self-employment. Nevertheless, in the Australian context, we prefer the term 'working from home' (WFH) except where this could lead to confusion or to awkward constructions such as 'WFH workers'.

employment choose their WFH frequency, trading off working, commuting and leisure time, non-wage benefits of in-office work time and costs for home office space. Telecommuting workers reduce firms' requirement for office space but also their productivity. With stronger preferences for WFH, the city's radius is likely to expand, but commuting times and distances are reduced. In apparent conflict with the empirical evidence cited above though is that most commuting time savings are allocated to additional work, not additional leisure (or home production). Larson and Zhao (2017) abstract from most of the phenomena incorporated by Rhee, focussing on WFH in a monocentric city subject to congestion effects. Their simulations too suggest that increased WFH induces urban sprawl. With a mixed population of WFH and non-WFH households, an increasing rate of WFH amongst the former reduces congestion and therefore commuting times for the latter. However, these gains may be eroded by in-migration to the city. The authors observe that in a system of cities with a fixed aggregate population, increased WFH would thus result in fewer, larger cities.

Delventhal, Kwon, and Parkhomenko (2020), like our paper, is motivated by observations during the COVID-19 pandemic. The authors adapt the framework of Ahlfeldt et al. (2015) so that there are exogenous shares of WFH and non-WFH households. The intensity of WFH is fixed and they consider (exogenous) changes in the incidence of WFH. As in Rhee (2009), they model the related phenomena of firms reducing their demands for office space, households increasing their demands for housing (for home office space) and effects on productivity. However, productivity effects are modelled quite differently: increased WFH reduces effective employment densities and consequently, productivity spillovers between firms. They also incorporate endogenous congestion effects, although these are a spatially uniform function of total vehicle commuting kilometres, whereas in the circular city model of Larson and Zhao (2017), commuting flows and hence congestion effects depend on distance from the CBD. Calibrating their model to the Los Angeles metropolitan area, they find that more WFH causes housing demand to shift towards outer areas of the city and jobs to become more agglomerated. Despite the direct negative effect of WFH on employment densities, there is a slight overall gain in productivity.

In this paper, we use a multi-sectoral spatial computable general equilibrium (SCGE) model to make a preliminary assessment of the impacts of increased WFH in Australia. The SIRCA model (Spatial Interactions within and between Regions and Cities in Australia) provides a detailed, nation-wide representation of economic interactions within and between local labour, land and product markets. Following Allen, Arkolakis, and Li (2015); Monte, Redding, and Rossi-Hansberg (2018); Faber and Gaubert (2019) and others, we draw on both the trade and urban economic literatures on spatial interactions. For a review, see Redding and Rossi-Hansberg (2017). We model discrete residence and workplace location choices of working households as in Ahlfeldt et al. (2015), but introduce an additional dimension of occupational choice. The dimension of occupational choice is considered in a spatial model in Eckert (2019), although their setup is rather different to ours and includes a dependence on education levels from which we abstract here. Working households in our model commute regularly between their residence and workplace. We also distinguish a separate population of non-working households who receive capital and transfer income and choose only their residential locations.

Production involves input-output linkages and markets for all goods and services other than housing are connected by trade flows, as in Caliendo and Parro (2015) and Caliendo, Dvorkin, and Parro (2019). In addition to differentiation of labour inputs by occupation, firms are restricted to using a particular type of land, depending on their industry. These types of land are imperfectly transformable, allowing e.g. for the local expansion of urban areas. However, due to the complex multi-industry structure in our model, we do not explicitly model the production of 'floorspace', as is typically done in single sector urban economic models (e.g. Ahlfeldt et al., 2015). We allow for positive effects of localised job densities on firms' productivity—and on the household side, for positive effects of localised residential densities on amenities—as in Ahlfeldt et al. (2015) that are important to consider at smaller spatial scales (Allen and Arkolakis, 2014).

Since our model is intended to operate at a high spatial resolution within metropolitan areas, all services except housing are treated as being tradable. The associated transport costs are intended to include business trips associated with the provision of intangible business services (e.g. accountancy) and consumption trips associated with the consumption of services in person (e.g. restaurant meals). At these spatial scales, we have no data on bilateral trade from which to estimate trade costs. Instead, trade costs are based on bilateral transport costs we estimate using a routing algorithm to find shortest paths over the national road network. In longer trips (but not for freight transport) we allow for the possibility of taking commercial flights. Commuting costs are estimated in a similar way to trade costs.

Our paper makes three distinctive contributions relative to the existing literature. First, our model is national in scope and so can account for interactions both within and between cities. We show quantitatively the effect referenced by Larson and Zhao (2017), whereby smaller cities shrink and the largest cities grow; along with smaller cities in their periphery that are attractive to inter-city commuters. Second, working households in our model may choose between many occupations. Reduced commuting costs associated with WFH apply only in a subset of these (see e.g. Dingel and Neiman, 2020; Bartik et al., 2020), leading to changes in workforce composition with implications for spatial and sectoral structure and aggregate productivity. Third, by considering both commuting and local consumption travel linkages, we account for households' valuation of proximity to both employment and consumption opportunities. The former becomes relatively less important for workers in WFH occupations.

2 SIRCA model

2.1 Households

There are two populations of households: working (W) and non-working (N). Each working household supplies one unit of labour and chooses the occupation (o), place of residence (r) and place of work (s) that maximise their utility, given their individual idiosyncratic preferences across these three dimensions. Each non-working household chooses only a place of residence (r).

For working households, utility depends positively on local residential amenities B_r, wage rates W_{os} and their idiosyncratic preferences $\boldsymbol{\epsilon}^{\mathrm{W}}_{ors}$. The population of working households receives a fixed share of all non-wage income, which is allocated to individual households in proportion χ to their wage income. Utility depends negatively on the local level of prices $\mathcal{P}^{\mathrm{W}}_r$, the rate of income tax τ^{W} and commuting costs t^{C}_{rs}. Commuting costs enter in a negative power law form.[3] The indirect utility function of a working household can be written

$$u^{\mathrm{W}}_{ors} = \boldsymbol{\epsilon}^{\mathrm{W}}_{rso} B_r \frac{(1-\tau^{\mathrm{W}})(1+\chi) W_{os}}{\mathcal{P}^{\mathrm{W}}_r} (t^{\mathrm{C}}_{rs})^{-\zeta_o}. \tag{1}$$

For non-working households, utility depends positively on residential amenity, their fixed transfer and capital income T, and idiosyncratic preferences over locations $\boldsymbol{\epsilon}^{\mathrm{N}}_r$. Utility depends negatively on local price levels. Their indirect utility function can be written

$$u^{\mathrm{N}}_{rso} = \boldsymbol{\epsilon}^{\mathrm{N}}_r B_r \frac{T}{\mathcal{P}^{\mathrm{N}}_r}. \tag{2}$$

Both household types have Cobb-Douglas preferences for local composite goods, services and housing. Thus, local ideal consumption price indices are given by

$$\mathcal{P}^h_r = \prod_j \left(\frac{P_{sj}}{\beta^h_j}\right)^{\beta^h_j}, \quad h \in \{\mathrm{W}, \mathrm{N}\} \tag{3}$$

[3] We find this form fits our data much better than the negative exponential form used in Ahlfeldt et al. (2015) and many other recent contributions to the literature.

where β_j^h are consumption expenditure shares for each household type and the P_{sj} are the local prices of composite goods, composite services or housing.

We model working households discrete choices using a three level nested logit structure: (i) occupational choice; (ii) city of residence; and (iii) locality of residence within a city and locality of work (which may be in a different city). Options at lower levels are closer substitutes than those at higher levels.[4]

Conditional on choosing occupation o and city of residence u, the probability of choosing localities of residence and work, $r \in u$ and s respectively, is given by

$$\pi_{rs|uo}^{\mathrm{W}} = \frac{E_{or}\left(B_r W_{os}\left(t_{rs}^{\mathrm{C}}\right)^{-\zeta_o}/\mathcal{P}_r^{\mathrm{W}}\right)^{\epsilon_\ell}}{\sum_{r'\in u}\sum_{s'} E_{or'}\left(B_{r'} W_{os'}\left(t_{r's'}^{\mathrm{C}}\right)^{-\zeta_o}/\mathcal{P}_{r'}^{\mathrm{W}}\right)^{\epsilon_\ell}}, \tag{4}$$

where E_{or} reflect average preferences for particular occupation–residence combinations and ε_ℓ reflects their variance. The conditional probability of choosing city u is given by

$$\pi_{u|o}^{\mathrm{W}} = \frac{\Psi_{uo}^{\epsilon_u/\epsilon_\ell}}{\sum_{u'}\Psi_{u'o}^{\epsilon_u/\epsilon_\ell}}, \qquad \Psi_{uo} \equiv \sum_{r\in u}\sum_{s} E_{or}\left(B_r W_{os}\left(t_{rs}^{\mathrm{C}}\right)^{-\zeta_o}/\mathcal{P}_r^{\mathrm{W}}\right)^{\epsilon_\ell} \tag{5}$$

and the probability of choosing occupation o is given by

$$\pi_o^{\mathrm{W}} = \frac{\Omega_o^{\epsilon_o/\epsilon_u}}{\sum_{o'}\Omega_{o'}^{\epsilon_o/\epsilon_u}}, \qquad \Omega_o \equiv \sum_u \Psi_{uo}^{\epsilon_u/\epsilon_\ell}. \tag{6}$$

The number of resident workers by occupation in each locality is

$$H_{or}^{\mathrm{W}} = \pi_o^{\mathrm{W}}\pi_{u|o}^{\mathrm{W}}\sum_s \pi_{rs|uo}^{\mathrm{W}}\mathcal{H}^{\mathrm{W}}, \tag{7}$$

where $\mathcal{H}^{\mathrm{W}}$ is the total working population. The number of jobs by occupation in each locality is

$$L_{os} = \pi_o^{\mathrm{W}}\sum_u \pi_{u|o}^{\mathrm{W}}\sum_{r\in u}\pi_{rs|uo}^{\mathrm{W}}\mathcal{H}^{\mathrm{W}}, \tag{8}$$

In each occupations, the distribution of jobs is directly related to that of resident workers by

$$L_{os} = W_{os}^{\epsilon_\ell}\sum_r \frac{H_{or}^{\mathrm{W}}\left(t_{rs}^{\mathrm{C}}\right)^{-\zeta_o\epsilon_\ell}}{\sum_s\left(W_{os}\left(t_{rs}^{\mathrm{C}}\right)^{-\zeta_o}\right)^{\epsilon_\ell}}.$$

Note that the outer summation is over all r, since workers may commute between cities.

For non-working households, there are two levels of choice: (i) city of residence; and (ii) locality of residence within that city. Choice probabilities are given by

$$\pi_{r|u}^{\mathrm{N}} = \frac{\left(B_r/\mathcal{P}_r^{\mathrm{N}}\right)^{\epsilon_\ell}}{\sum_{r'\in u}\left(B_{r'}/\mathcal{P}_{r'}^{\mathrm{N}}\right)^{\epsilon_\ell}}, \tag{9}$$

and

$$\pi_u^{\mathrm{N}} = \frac{\Xi_u^{\epsilon_u/\epsilon_\ell}}{\sum_{u'}\Xi_{u'}^{\epsilon_u/\epsilon_\ell}}, \quad \Xi_u \equiv \sum_{r\in u}\left(B_r/\mathcal{P}_r^{\mathrm{N}}\right)^{\epsilon_\ell}. \tag{10}$$

The number of non-working households in each locality $r \in u$ is given by

$$H_r^{\mathrm{N}} = \pi_u^{\mathrm{N}}\sum_s \pi_{r|u}^{\mathrm{N}}\mathcal{H}^{\mathrm{N}}, \tag{11}$$

where $\mathcal{H}^{\mathrm{N}}$ is the total non-working population.

[4]See Rouwendal, Levkovich, and Mulalic (2017) for further details on nested logit models of location choice and commuting. Cardell (1997) proves that the nested logit model may be formulated in terms of multiple variance components, each independently and identical distributed.

2.2 Production

Production in each sector is undertaken by a continuum of heterogeneous firms à la Eaton and Kortum (2002). Firms operate constant returns to scale technologies to produce intermediate varieties. In each industry i and locality r, firms produce many varieties of intermediate goods using Cobb-Douglas technologies combining primary factor and intermediate inputs. The latter are local sectoral composites of intermediates sourced from all locations s, described below.

The unit cost of a firm's input bundle is given by

$$p_{ri} = \frac{1}{(1-\tau_i)} \left(\frac{R_{r\mathrm{K}}}{\alpha^i_{\mathrm{K}}}\right)^{\alpha^i_{\mathrm{K}}} \left(\frac{R^i_{r\mathrm{D}}}{\alpha^i_{\mathrm{D}}}\right)^{\alpha^i_{\mathrm{D}}} \prod_o \left(\frac{W_{or}}{\alpha^i_{or}}\right)^{\alpha^i_{or}} \prod_j \left(\frac{P_{rj}}{\alpha^i_j}\right)^{\alpha^i_j}. \tag{12}$$

The output tax rate τ_i and cost shares α^i_{K}, α^i_{D} and α^i_j are assumed identical across locations because we calibrate the model using a national input-output table. Overall labour cost $\alpha^i_{\mathrm{L}} \equiv \sum_o \alpha^i_{or}$ shares are also location-independent, but the cost shares for each occupation α^i_{or} vary by location to match employment data. $R_{r\mathrm{K}}$ is the rental price of the local composite capital good, also produced using a Cobb-Douglas technology. The capital rental cost function is

$$R_{r\mathrm{K}} = (\delta + r) \prod_j \left(\frac{P_{rj}}{\alpha^{\mathrm{V}}_j}\right)^{\alpha^{\mathrm{V}}_j}, \tag{13}$$

where δ is the depreciation rate and r is the interest rate.

Four types of productive land are distinguished: Rural, Industrial, Commercial and Residential. Land used for transportation infrastructure is not explicit in the model. Nor are areas of parklands, natural reserves and the like that do not directly support significant economic activity. In any given location, firms in each non-housing industry may use only their most preferred available land type. For this type, the type-specific cost share is equal to the overall land cost share α^i_{D}:

$$\alpha^i_{rd} = \begin{cases} \alpha^i_{\mathrm{D}}, & \text{for the highest priority } d \text{ available in } s \\ 0 & \text{otherwise} \end{cases}, \tag{14}$$

where d indexes land types. For example, accommodation firms are assigned to Commercial land if available, but otherwise may be assigned to the Residential or even the Rural land type. This system is *ad hoc.* but effectively works around the general unavailability of data on actual land uses by industries in Australia. It also addresses the problem of working with an industry- rather than function-based classification of establishments.[5] Thus, the effective land rental rate for non-housing industries is given by

$$R^i_{r\mathrm{D}} = r_{rd} \quad \text{if} \quad \alpha^i_{rd} > 0, \tag{15}$$

where r_{rd} is the market-clearing rental rate for a hectare of land of type d in location r.

Housing may use one or both of Residential and Commercial land types, as we have population data for each of the Mesh Blocks from which initial land areas by type are calculated. For simplicity, we model the provision of housing services as involving a Cobb-Douglas aggregation of these land types.[6] The land rental price for housing is given by

$$R^i_{r\mathrm{D}} = \left(\frac{r_{r\mathrm{RES}}}{\alpha^i_{r\mathrm{RES}}}\right)^{\alpha^i_{r\mathrm{RES}}} \left(\frac{r_{r\mathrm{COM}}}{\alpha^i_{r\mathrm{COM}}}\right)^{\alpha^i_{r\mathrm{COM}}}, \quad \text{where} \quad \alpha^i_{r\mathrm{RES}} + \alpha^i_{r\mathrm{RES}} = \alpha^i_{\mathrm{D}}. \tag{16}$$

[5] For example, the head office of a coal mining firm will be classified as 'Coal Mining', whereas its function is to provide services (management, financial, legal, marketing, human resources, etc.) to the firm's business units that actually extract coal from the ground. While we could devise some sort of functional classification relating to occupations, this would then be difficult to relate to industries' full input-output structures.

[6] More realistically, households would make discrete choices between different types of housing produced using either Residential or Commerical land. In Anas and Liu (2007), households make choices between housing types with a discrete range of building heights.

As in Caliendo and Parro (2015), firms' productivity is explained by two terms. The first term, A_{sj}, accounts for systematic differences in total factor productivity between regions. The second term, z_{sj}, is a Fréchet-distributed variety-specific effect augmenting the productivity of all inputs. Firms are competitive, and so output (mill) prices are given by

$$\frac{p_{ri}}{z_{rj} A_{rj}^{\alpha_{\mathrm{F}}}} \tag{17}$$

where, for convenience, $\alpha_{\mathrm{F}} \equiv \alpha_{\mathrm{L}}^{i} + \alpha_{\mathrm{K}}^{i} + \alpha_{\mathrm{D}}^{i}$.

2.3 Spillovers

Firms operate with constant returns to scale, but as in Ahlfeldt et al. (2015), total factor productivity is positively influenced by spillovers related to the effective density of all jobs in their vicinity; i.e. urbanisation rather than localisation effects. The elasticity γ_i of firms' productivity to effective job density varies between industries. Effective job density is measured by travel distance-weighted job counts.

$$A_{si} = a_{si} \left(\sum_{r} \exp^{-\nu_a t_{rs}^{\mathrm{C}}} \sum_{o} L_{or} \right)^{\lambda_i} \tag{18}$$

Productivity of housing service provision is assumed to be uniform. However, on the consumption side, households enjoy residential amenities that are positively affected by spillovers related to the effective density of residents in their vicinity.

$$B_r = b_r \left(\sum_{s} \exp^{-\nu_b t_{rs}^{\mathrm{C}}} H_s \right)^{\varrho} \tag{19}$$

2.4 Trade

As in Caliendo, Dvorkin, and Parro (2019), local sectoral composite goods and services are formed by combining individual varieties sourced from different locations. Here, given the much finer spatial resolution of our model, all services except housing are considered to be tradable. This includes trade by means of travel to consume services in person (e.g. restaurant meals). Each variety is sourced from the location that can supply it at the lowest delivered cost. As we model an open economy, these locations include an 'external zone' that represents trade with the rest of the world.[7] The production of composite sectoral goods is given by

$$Q_{rj} = \left(\int \left(x_{rsj}(z_j) \right)^{1-1/\eta_j} d\phi_j(z_j) \right)^{\eta_j/(\eta_j - 1)}, \tag{20}$$

where $\phi_j(z_j)$ is the joint distribution of variety-specific productivity levels z_{nj}.

Assuming again a Fréchet distribution and that $1 + \sigma_j > \eta_j$, the price of composite sectoral goods j for users in location r is given by

$$P_{rj} = \Gamma_{nj} \left(\sum_{s} \left(\frac{\kappa_j t_{rsj} p_{rsj}}{A_{sj}^{\alpha_{\mathrm{F}}}} \right)^{-\sigma_j} \right)^{-1/\sigma_j}, \tag{21}$$

where A_{sj} is the average productivity level of industry j firms in s, t_{rsj} is the shipping cost between r and s and κ_j converts this to an iceberg cost for transport of good j and Γ_{nj} is

[7] Multiple external zones could be defined to differentiate trade flows by domestic and/or international regions of origin/destination. Each such zone would have its own set of transport costs.

a constant (see Caliendo, Dvorkin, and Parro (2019) for details, noting some differences in nomenclature).

For users in a given location r, expenditure shares are given by

$$\Pi_{rsj} = \frac{\left(\kappa_j t_{rsj} p_{rsj} / A_{sj}^{\alpha_{\mathrm{F}}}\right)^{-\sigma_j}}{\sum_{s'} \left(\kappa_j t_{rs'j} p_{rs'j} / A_{s'j}^{\alpha_{\mathrm{F}}}\right)^{-\sigma_j}}, \tag{22}$$

thus the more productive are firms in location s and the lower transport costs between r and s, the more is purchased from s by firms and households in r.

2.5 Land allocation

Our model of land allocation accounts for the following stylised facts. Firstly, rural to urban conversions are practically irreversible. Reasons for this include the value of investments made in urban infrastructure when land is developed (e.g. town water and sewerage connections), increasing demands for urban land, and the contamination and compaction of soils caused by urbanisation. Secondly, the costs of reallocating urban land between most urban uses are modest. However, industrial uses are an exception because they tend to generate large negative externalities, e.g. heavy vehicle traffic, noise, odour, air pollutants, soil contaminants. For these reasons, new industrial sites are almost always established outside of existing urban areas. Conversely, while the emergence of higher value uses may ultimately lead to the conversion of established industrial sites, this process is typically very slow. In many cases, historic site contamination is a major barrier to redevelopment. A limitation of this account is that it ignores urbanisation of natural areas (forest, mangroves, native grasslands, etc.), which still occurs on a significant scale in Australia. We return to this point in the discussion.

Areas of (non-industrial) Urban land (U) are allocated to Residential (H) and Commercial (C) land types in proportions that respond to changes in relative prices:

$$N_{rd} = \frac{\zeta_r r_{rd}^{\mu_{\mathrm{U}}}}{r_{r\mathrm{U}}} N_{r\mathrm{U}}, \quad d \in \{\mathrm{H}, \mathrm{C}\} \tag{23}$$

where

$$r_{r\mathrm{U}} \equiv \left(\zeta_{r\mathrm{H}} r_{r\mathrm{H}}^{\mu_{\mathrm{U}}} + \zeta_{r\mathrm{C}} r_{r\mathrm{C}}^{\mu_{\mathrm{U}}}\right)^{1/\mu_{\mathrm{U}}}. \tag{24}$$

Rural land (R) can be irreversibly converted to Industrial (I) land

$$\hat{N}_{r\mathrm{I}} = \max\left[\left(\frac{\hat{r}_{r\mathrm{I}}}{\hat{r}_{r\mathrm{R}}}\right)^{\mu_{\mathrm{R}}} \hat{N}_{r\mathrm{R}}, 1\right], \tag{25}$$

or to Urban land

$$\hat{N}_{r\mathrm{U}} = \max\left[\left(\frac{\hat{r}_{r\mathrm{U}}}{\hat{r}_{r\mathrm{R}}}\right)^{\mu_{\mathrm{R}}} \hat{N}_{r\mathrm{R}}, 1\right]. \tag{26}$$

where a circumflex denotes the ratio of a price or area to the corresponding price or area in the initial calibration.

2.6 Markets

Wages, land rental prices and product prices clear local occupational labour markets, land markets and product markets respectively. We denote the population of working and non-working households by $\mathcal{L}^{\mathrm{W}}$ and $\mathcal{L}^{\mathrm{N}}$ respectively.

Output markets clear, so denoting revenue of sector j in location s by V_{sj},

$$V_{sj} = \sum_r \Pi_{rsj} \left(\beta_j^{\mathrm{W}} (1-\tau) \mathcal{H}^{\mathrm{W}} \sum_o \pi_{or}^{\mathrm{W}} \tilde{W}_{or} \;+\; \beta_j^{\mathrm{N}} \mathcal{H}^{\mathrm{W}} \pi_r^{\mathrm{N}} T \;+\; \sum_i \alpha_j^i V_{ri}\right) \tag{27}$$

for all sectors except housing services. For the housing services sector, there is no trade and no intermediate uses, so in this case,

$$V_{rj} = \beta_j^{\mathrm{W}} (1-\tau)\, \mathcal{H}^{\mathrm{W}} \sum_o \pi_{or}^{\mathrm{W}} \tilde{W}_{or} \; + \; \beta_j^{\mathrm{N}} \mathcal{L}^{\mathrm{W}} \pi_r^{\mathrm{N}} T. \tag{28}$$

The balance of occupational labour supply (see above) and demand in location s is given by

$$L_{os} = \frac{\sum_i \alpha_{os}^i V_{si}}{W_{os}}. \tag{29}$$

The demand for each type of land in each location is given by

$$N_{rd} = \frac{\sum_i \alpha_d^i V_{ri}}{R_{rd}}. \tag{30}$$

3 Data and calibration

3.1 Spatial delineation and land areas

The SIRCA model has 2255 economic zones in which residential and/or business activity occurs. They correspond to Statistical Area Level 2 (SA2) of the Australian Bureau of Statistics' (ABS) Australian Statistical Geography Standard 2016 (ASGS) and cover mainland Australia, Tasmania and several offshore islands.[8] While there are some jobs in every zone, not all industries are active in all zones and not all occupations are demanded in all zones. Eighty-four zones have zero housing supply because they represent sea ports, airports, industrial parks or similar areas.

Of the 2255 zones, 1721 are contained within 101 Significant Urban Areas (SUAs) as defined in the ASGS.[9] The remainder cover diverse economically productive land uses including but not limited to towns of less than 10,000 inhabitants, rural or remote settlements, improved agricultural lands, unimproved grazing lands, forestry plantations, natural forests, and mine sites. Appendix **??** lists all SUAs, their 2016 Estimated Residential Population (ERP) and the number of SA2s they contain. For the purpose of modelling residential location choice between cities, we treat the SUAs as 'cities'. For each of Australia's six States and two Territories, we treat their entire non-urban area as one additional location choice at the 'city' level. We treat each SA2 within these cities (or within the non-urban areas) as 'localities'.

Initial land areas are based on areas of ASGS Mesh Blocks. These are delineated by the ABS to 'broadly reflect land use' and are assigned one of ten categories. With a few exceptions (e.g. Mesh Blocks that include an airport terminal) we ignore the ABS categories 'Parkland', 'Transportation', 'Water' and 'Other'. We subsume the original 'Commercial', 'Hospital/Medical' and 'Education' into our 'Commercial' category. Some minor adjustments are also made to address incompatibilities between the data and the model. The most significant of these is that we do not permit housing supply on 'Rural' land whereas the data show small populations residing in ABS Rural Mesh Blocks (e.g. in farm houses). To resolve this discrepancy, we reallocate small areas of 'Rural' land to 'Residential' so that we may treat Rural land as being used solely for non-housing production. The reallocated areas are based on Rural Mesh Block populations multiplied by population densities of Residential Mesh Blocks within the same SA2.

[8] The ASGS (https://www.abs.gov.au/websitedbs/D3310114.nsf/home/geography) defines 2292 geographic SA2s. Excluded from the model are those of Australia's offshore territories, the SA2s of Lord Howe Island (NSW) and Jervis Bay (federal) and other SA2s in which there is no or negligible economic activity. The latter include large lakes, national parks and large city parks, nature reserves or cemeteries.

[9] 1270.0.55.004 - Australian : Volume 4 - Significant Urban Areas, Urban Centres and Localities, Section of State, July 2016

3.2 Employment and non-working households

Labour is differentiated into 38 occupational groups. Of these, 34 correspond directly to two-digit, Sub-Major Groups in the Australian and New Zealand Standard Classification of Occupations (ANZSCO). The remaining four are aggregations of several Sub-Major Groups, based on similarity of skill levels and wage rates and the spatial distribution of employment.[10] National average wage rates are set to match values based on the ABS' Employee Earnings and Hours, aggregating values by sex and four-digit occupation to the occupational groups in the model.

SIRCA distinguishes 101 industries: 10 produce primary products, 40 produce manufactures, 5 provide utilities, 4 undertake construction activities, 41 produce non-housing services and one produces housing services. Each corresponds to one or several ABS Input-Output Industry Groups (IOIG). Several IOIG are aggregated to permit exact concordances with Australian and New Zealand Standard Industry Classification (ANZSIC) Groups (i.e. 3-digit codes), as data on employment were obtained at this level. Additionally, several very small industries are aggregated with larger, related industries.

Initial distributions of jobs and of resident workers by occupations are estimated from the 2016 Census (tables retrieved using ABS TableBuilder Pro), the Small Area Labour Markets (SALM) publication (Department of Education, Skills and Employment) and the ABS Labour Force Survey (LFS). LFS values were taken as definitive counts by place of residence at State/Territory for 2-digit occupations and at SA4 level for 1-digit occupations. SALM data were used to downscale employment to SA2 level. Counts by place of work were constructed using commuting propensities estimated from the Census data.

Counts of non-working households are based on Census Data alone. They count sole persons and single parent households not in the labour force, and couple households with neither member working. For greater consistency with working households (which correspond to individuals in employment) individual adults are counted rather than actual households. Such measures are convenient constructs for modelling, but policy-makers often require estimates of changes in total resident population. To construct such a measure, we 'up-rate' the number of working households by a factor accounting for the average number of child dependents and non-working adults, and non-working households by the average number of child dependents. These factors—1.65 for workers and 1.09 for non-workers—are estimated from the ABS Household Income Survey.

3.3 Transport costs

Each trip or freight shipment incurs a transport cost that is based on the fastest route by road between the origin and destination zones. The road network includes major car ferry services, which is particularly important for freight transport between Tasmania and mainland states, but also relevant to some smaller near-shore islands. For consumption and business travel and for long-distance commutes, we also allow for the use of an air leg within an otherwise road-based journey.

Road travel times were estimated using an algorithm programmed in C++ and the RoutingKit C++ toolbox Dibbelt, Strasser, and Wagner (2016). The same toolbox was used to build a complete representation of the Australian road network in OpenStreetMap (OSM)OpenStreetMap contributors (2017), on which the routing algorithm was then run. By combining distances from multiple point origins and destinations within each SA2, it is possible both to estimate more representative travel times between SA2s, and travel times within each SA2. Flying times were manually compiled from the *FlightsFrom.com* database.

Estimated freight/travel times have significant limitations, especially for commuting purposes. Posted road speeds are inferred from OSM and may be missing or incorrect. Particularly in urban areas, actual driving speeds may be substantially below the posted speeds because of congestion. In addition, bus, light or heavy rail or ferry services are used for a significant

[10] In terms of two-digit ANZSCO codes, the aggregations are: 31 with 34; 53, 54 and 55; 62 and 63; 82 and 89.

share of trips. This is especially true of trips into the CBDs of the largest cities, where public transport may actually be the dominant commuting mode. We plan to address some of these limitations in future research.

For travel, a fixed cost of five minutes is added to the combined road–air OD matrix to represent access and egress times. This approach is conservative in that it allows minimal time to search for parking, assumes one can park quite close to the ultimate destination, and ignores possible parking fees. For freight, a fixed cost of 45 minutes was added to account for loading, unloading and logistical overheads. For air legs, a fixed cost of 60 minutes was added to account for access, egress and wait times. A further 15 minute penalty was added for each regional (vs. capital city) airport departure and/or arrival. The penalty reflects lower frequencies and less competitive fares of flights to/from/between regional airports relative to those between capitals.

The gravity cost coefficients κ_j are calibrated so that value-weighted mean iceberg transport cost match mean transport costs estimated from input-output tables. The ABS produces tables of road, rail, water, air and pipeline margins on intermediate and final uses of goods. These were used to compute mean transport costs for each good. While we treat business travel as a margin on trade in services, statistics are not compiled on this basis. We therefore assume that all direct (i.e. non-margin) uses of transportation services by industries are related to business travel. We divide this total expenditure by the total value of intermediate services used in the economy, obtaining a cost share of 0.041. We double this value to reflect the costs to firms of business travel time. For retail and other services that are predominantly consumed by households, we assume a higher but arbitrary cost share of 0.33 that reflects combined monetary and time costs of private consumption travel.

For commuting, we estimated the value of $\zeta_o \varepsilon_\ell$ by using a line search algorithm to minimise the mean square error of predicted commuting flows at SA3 level. SA3 is one hierarchical level above SA2 and was chosen to avoid having an excessive number of very small flows (which the ABS randomly perturbs for confidentiality reasons). In this paper, we calibrate assuming a single value of ζ_o applies in all occupations. However, estimating the value of $\zeta_o \varepsilon_\ell$ for individual occupations, we found substantial heterogeneity. The problem is that this heterogeneity could in fact be caused (partly or wholly) by occupation-specific $\varepsilon_e ll$. For example, Schmutz, Sidibé, and Vidal-Naquet (2020) argue that workers in low-wage occupations are less mobile because spatial frictions are relatively larger compared to expected wage gains from relocation. We leave the resolution of this problem for future research.

3.4 Parameters and calibration

The SIRCA model has a very large number of calibrated parameters, including the input cost shares and household expenditure shares. Here, we present just the key behavioural parameters, including our estimate of the commuting gravity coefficient and other values that we adopt/adapt from the literature.

Table 1: Estimated and assumed parameter values

Parameter	Value
Discrete choice parameters:	
- local choices	$\varepsilon_\ell = 6.5$
- SUA choices	$\varepsilon_u = 3.8$
- occupational choices	$\varepsilon_o = 1.5$
Estimated commuting gravity coefficient	$-\zeta_o \varepsilon_\ell = -2.425$
- implied commuting exponent	$\zeta_o = 0.373$
Frèchet parameters for trade:	
- goods, business services, accommodation:	$\sigma_j = 5$
- urban services:	$\sigma_j = 5$
- retail and local consumer services:	$\sigma_j = 10$
Effective residential density decay rate	$\nu_a = 0.76$
Effective job density decay rate	$\nu_a = 0.36$
Elasticity of amenity to density	$\varrho = 0.07$
Elasticities of productivity to density:	
- primary production:	$\lambda_i = 0.0$
- manufacturing:	$\lambda_i = 0.056$
- services:	$\lambda_i = 0.047 - 0.18$

For choices of localities, we use the value estimated for Berlin in Ahlfeldt et al. (2015) while for choices between cities, we use the upper end of the range in Baum-Snow and Han (2019) for choice between neighbourhoods in the United States. For choice between occupations, we choose a value of 1.5. This is just above the upper end of the range of estimates ($1.21 \sim 1.44$) in Lee (2020) for occupational choices in the United States conditional on different levels of education.

For trade elasticities, we adopt values of 5 for goods, business services, accommodation and 'urban' services (e.g. arts, healthcare) and a value of 10 for retail and 'local' services (e.g. school education, personal services). For goods, this is in line with aggregate estimates in the trade literature, e.g. 4.8 in Caliendo and Parro (2015). That and other studies provide sectoral estimates that are in some cases, significantly larger or smaller. However, it is difficult to use such estimates given substantial differences in the definitions/aggregations of sectors and wider variation in sector-specific estimates across studies. For internationally traded services, the value of 5 is also in keeping with the literature (e.g. Costinot and Rodríguez-Clare, 2014); however, these elasticities are rarely estimated because of trade data limitations. There is very little data, or indeed literature, on trade in urban and consumer services. Arguably though, most 'local' services such as schools, supermarkets, cafes tend to be very close substitutes for similar services provided in different locations. Indeed, many chain stores aim explicitly to provide near-identical services to customers in all of their outlets. For industries providing these types of services, we adopt an elasticity of 10.

Maré and Graham (2013) estimate spillover elasticities for ANZSIC Divisions, to which our industries map exactly (i.e. many-to-one). However, some Divisions contain several industries that seem very likely to have much lower or much higher elasticities than average. For these, we make some ad hoc adjustments. For example, the estimated elasticity for Education (Division) is 0.107, but we apply a lower value of 0.06 for school education and higher value of 0.12 for post-school education. These adjustments are only made for services Divisions. For the (single) Division of Manufacturing, we apply the value of 0.056 to all industries. We assume that local agglomeration effects do not operate at all in agricultural or mining industries.

From the solution of the commuting gravity sub-model, average occupational wages rates by place of residence can be determined in every locality. Applying households' expenditure shares to their disposable incomes, the value of final demand for each product is identified in each location. Assuming a constant labour cost share for each industry, the value of each industry's output in every location is obtained from its wage bill (i.e. the sum over occupations of local wage rates times jobs). Assuming constant cost shares also for each intermediate input, the total value of intermediate demands for each product in each location is also determined. A second gravity sub-model is solved iteratively to determine the set of market-clearing prices of composite goods.

4 Counterfactual simulation of increased WFH

4.1 WFH scenario and results for occupations

It is common to stipulate in gravity-based models of commuting that workers commute daily. However, there is rarely anything in the model that specifically requires this. It could equally be that workers commute at frequencies that, implicitly, decline with increasing commute time. Indeed, it is difficult to explain people making very long commutes otherwise. In extreme cases, workers may even be accommodated at or near their workplaces for several days or weeks. Fly-in, fly-out workers at remote mine sites are a prominent example of this in Australia. Thus, we model an increased propensity for WFH by lowering the value of ζ_o for relevant occupations.

For seven modelled occupations, accounting for 28.5% of the workforce in the calibration, we reduce ζ_o from 0.373 to 0.280. We focus on occupations in which most tasks could be performed with little more than a laptop and a fast internet connection. Dingel and Neiman (2020) and others identify a broader range of occupations that could be performed from home, but some of these have much wider implications. For example, as seen in the pandemic, children may engage in education remotely. However, this generally requires that they be supervised by an adult and means they will not travel from home to school.

Our seven WFH occupations are:

- CEOs, General Managers and Legislators
- Specialist Managers
- Business, Human Resource and Marketing Professionals
- Design, Engineering, Science and Transport Professionals
- ITC Professionals
- Legal, Social and Welfare Professionals
- General, Inquiry and Numerical Clerks and Receptionists

The last of these is an aggregation of three ANZSCO sub-major groups.

Fundamentally, reduced annual commuting costs in WFH occupations increase their attraction to workers relative to non-WFH occupations: WFH jobs increase $14.1 - 15.7\%$ (right panel of Figure 1). Average wage rates in WFH decline $8.5 - 10.3\%$ while wages in non-WFH occupations rise. More distant origin–destination pairs become relatively more attractive to those choosing WFH occupations and mean one-way commute times approximately double (left panel of Figure 1.

Figure 2 shows changes in jobs and average wage rates in each industry (except housing). Employment and output (not shown) tends to fall in industries that are intensive users of non-teleworking occupations and rise in those that are intensive users of teleworking occupations. This reflects changes in labour costs and possibilities to substitute WFH occupational labour for non-WFH occupational labour. Industry-average wage rates rise in many of the former industries and decline in many of the latter. These patterns explain many of the differences in employment losses across non-WFH occupations. For example, Farmers or Farm Managers work almost exclusively in the three agricultural industries whereas employment of Personal Assistants and Secretaries is relatively concentrated in business services industries.

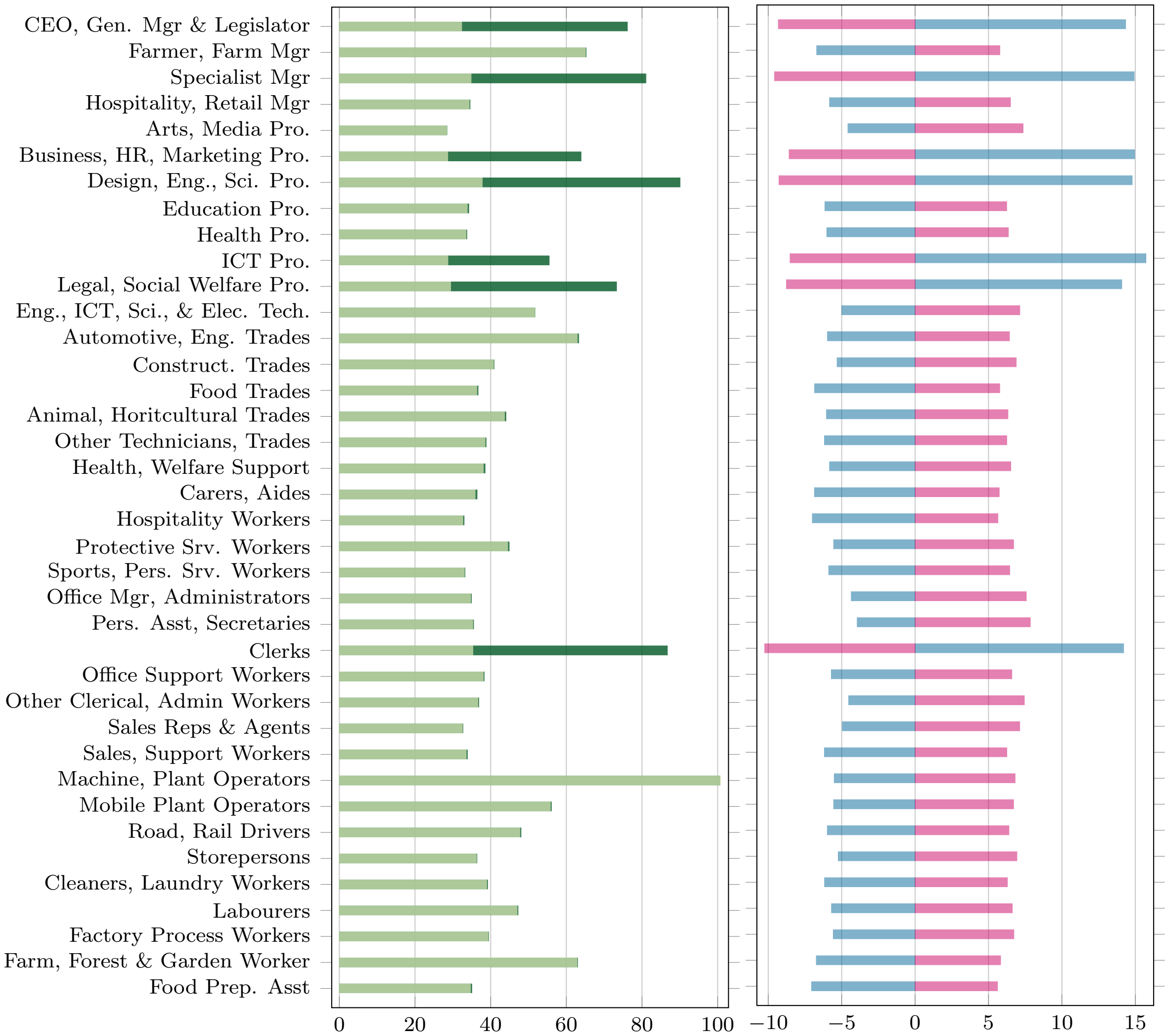

Figure 1: Left panel shows mean commute times (one-way) in the calibration (light green) and the WFH scenario (dark green). Right panel shows changes in employment (blue) and wage rates (magenta) (%)

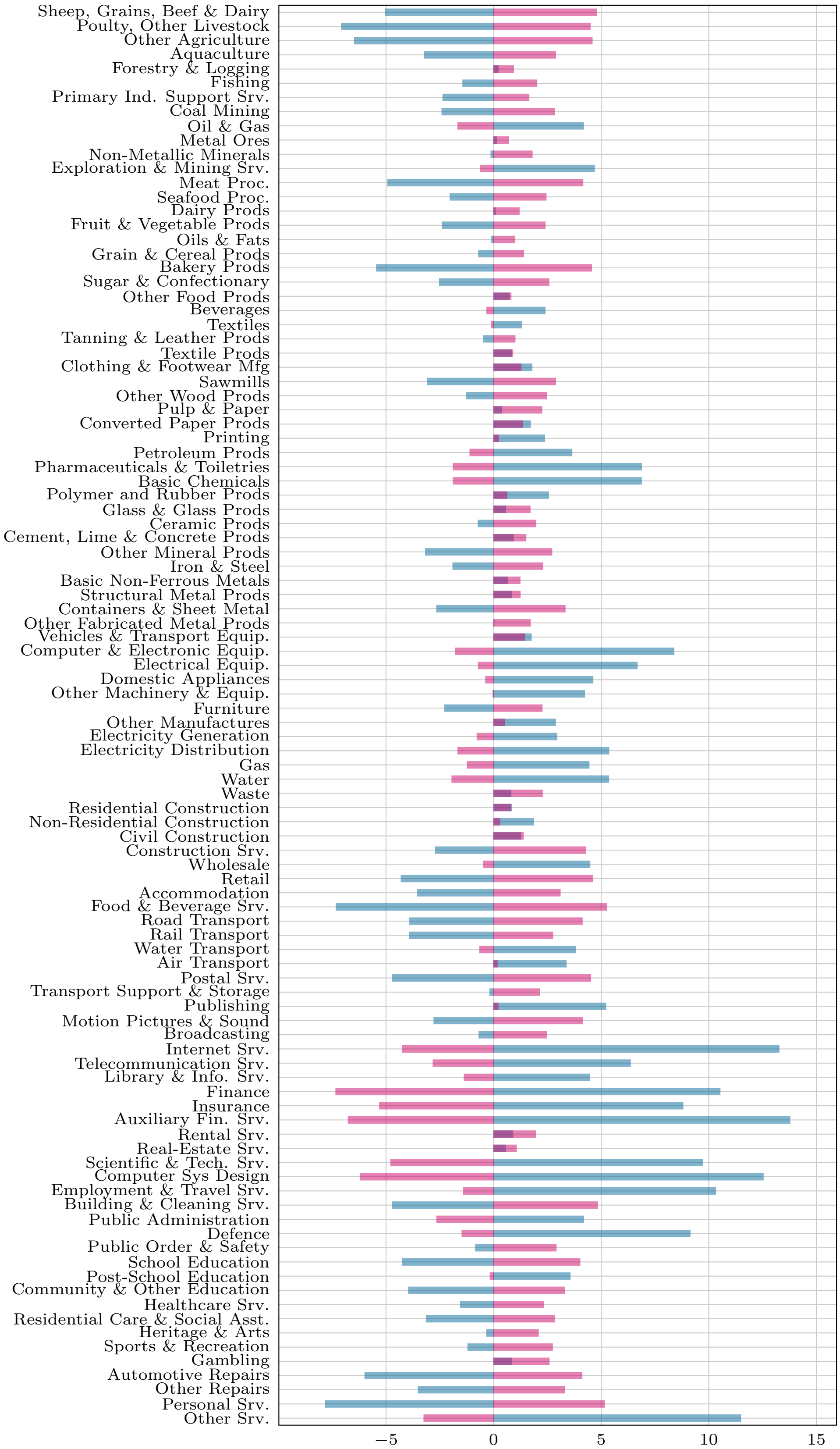

Figure 2: Changes in jobs (blue) and average wage by industry (magenta) (%)

4.2 Capital city regions

Figure 3 shows changes in resident population of SA2s in the Sydney, Melbourne and Brisbane regions. The map of the Sydney region includes the cities of Newcastle (north-east) and Wollongong (south-west), that of the Melbourne region includes the cities of Geelong (south-west) and Ballarat (north-west) and that of the Brisbane region includes the cities of the Gold Coast/Tweed Heads (south-east) and Toowoomba (west). The same map scale and colour shading is used for all three maps. Note the extended range represented by the darkest shade of red. While model results are not resolved spatially below SA2 level, non-urban areas are masked with hatching to avoid over-emphasising large rural, parkland or other areas that have low or zero densities of economic activity. Figures 4 and 5 show corresponding maps of changes in jobs and in land rental prices respectively.

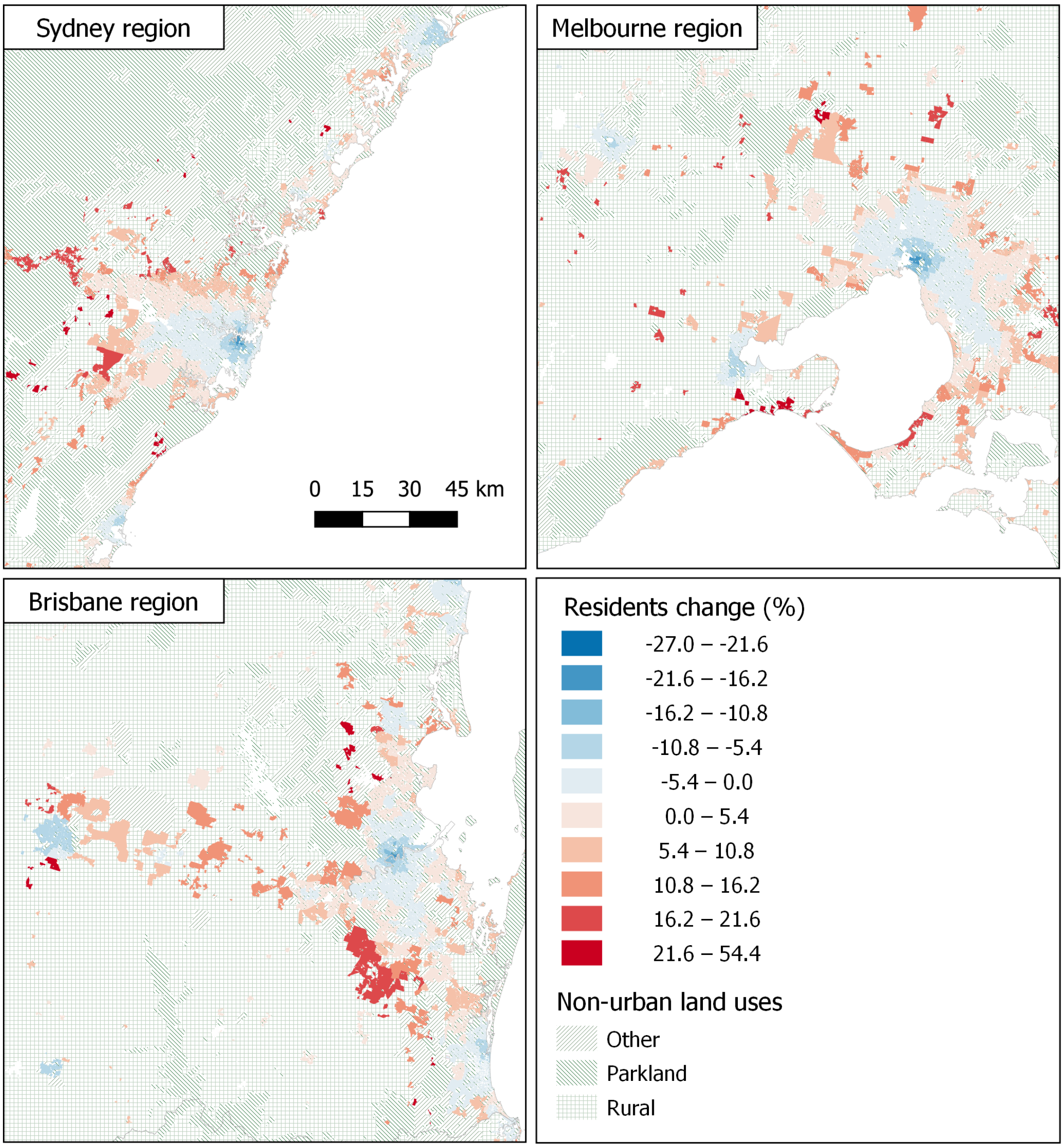

Figure 3: Changes in local resident population in the Sydney, Melbourne and Brisbane regions.

In all three capital cities resident populations decrease in the inner suburbs but increase in the outer suburbs. Populations also increase in peri-urban towns (e.g. Blue Mountains towns, west of Sydney; Macedon and Bacchus Marsh, west of Melbourne) and coastal ribbon developments (e.g. the NSW Central Coast, north of Sydney; Mornington Peninsula, south of Melbourne). Thus, urban density gradients become flatter overall. Although not shown in the figure, residential areas also expand outwards in many locations: nationally, the area allocated to the residential land type increases 3.6% increase at the expense of the rural land type. On a smaller spatial scale, a similar flattening of residential density gradients also occurs in neighbouring secondary cities: Newcastle and Wollongong in NSW; Geelong and Bendigo in Victoria; the Gold Coast and Toowoomba in Queensland.

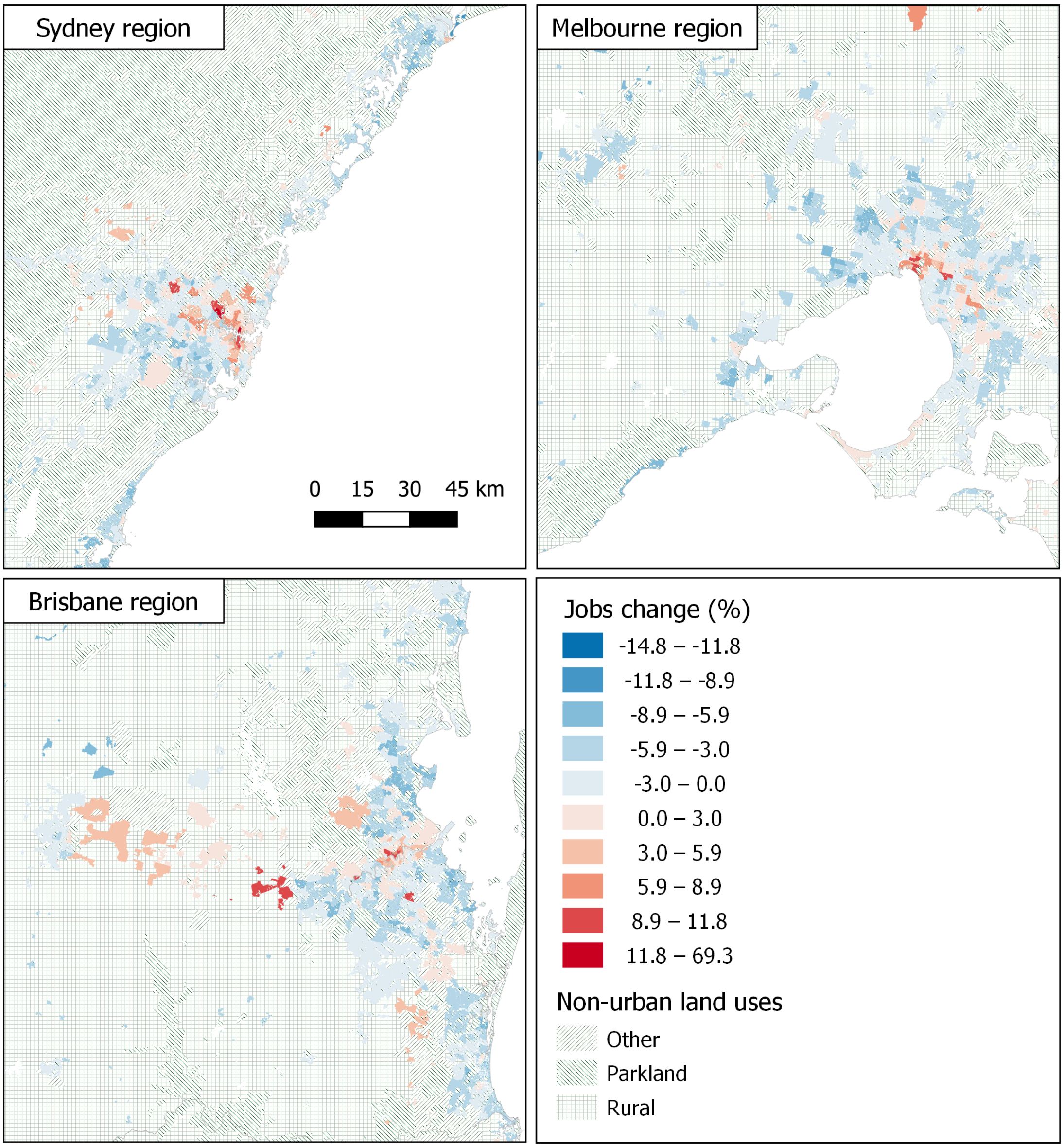

Figure 4: Changes in local jobs in the Sydney, Melbourne and Brisbane regions.

Agglomeration of employment is stronger with increased WFH (Figure 4), although spatial patterns of changes are less clear-cut than for residence. There is especially strong job growth in central and secondary business districts of Sydney, Melbourne and Brisbane. Under our modelling assumptions, firms have undiminished incentives to agglomerate while doing so becomes less costly. Alternative modelling assumptions could reinforce or weaken this tendency. If firms required less floorspace because workers were present less often, agglomeration would become cheaper still. On the other, if WFH weakened productivity spillovers, benefits of agglomeration would be smaller.

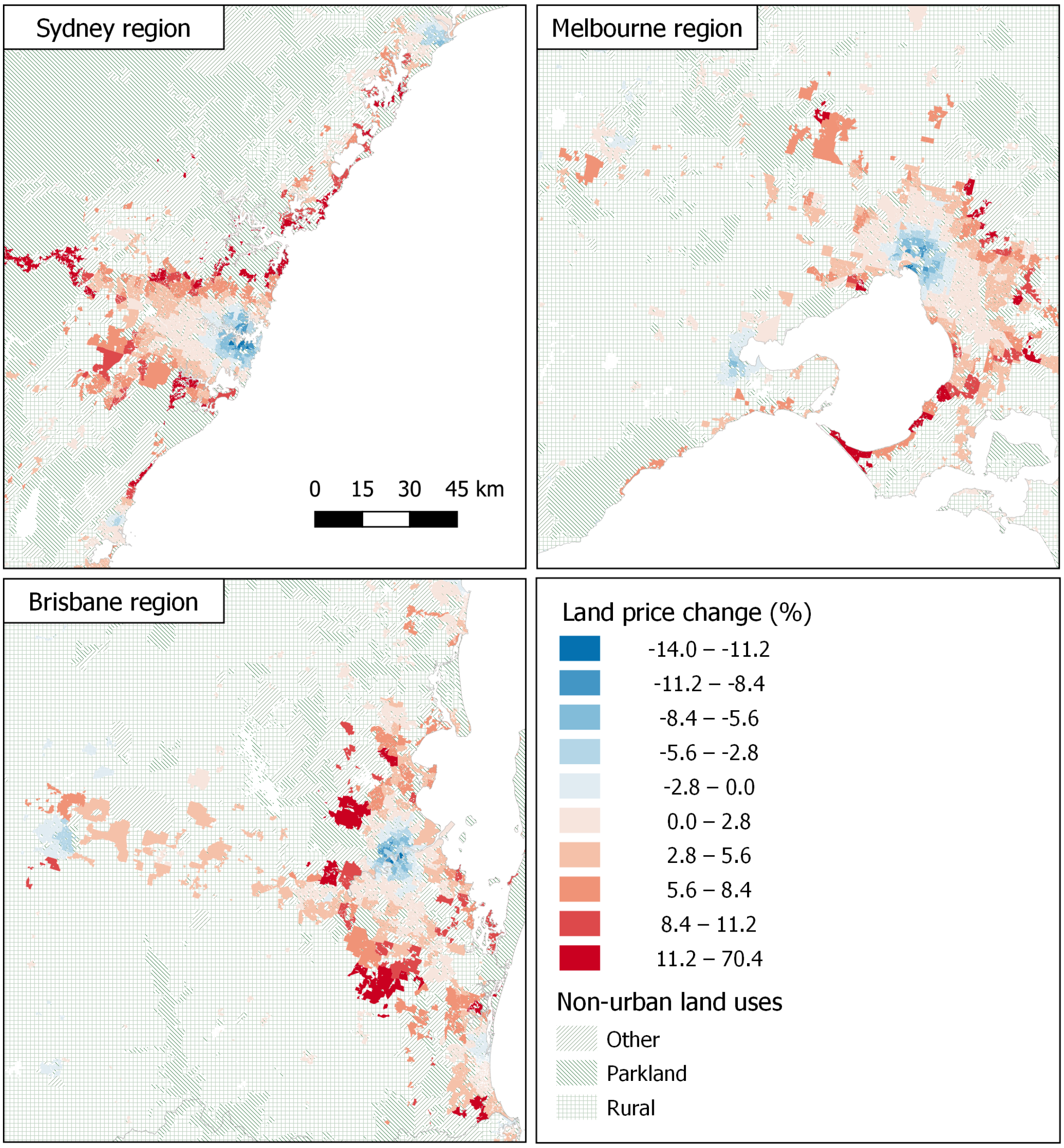

Figure 5: Changes in local land rents in the Sydney, Melbourne and Brisbane regions.

Agglomeration of employment is not limited to the CBD. For example in Sydney, there are substantial concentrations of commercial activity in locations such as North Sydney, Ryde and Macquarie Park. In these SA2s, jobs increase by 14.5%, 12.9% and 11.5% respectively, comparable to the 11.8% increase in the CBD. A 6.0% increase is seen in Mascot–Eastlakes, where there are substantial commercial and distribution activities associated with the adjacent Sydney Airport. Modest job growth is also seen in some locations within more residential areas that see strong population growth.

In residential areas, SA2-level land rental price indices vary mainly as a function of housing demand. Rental price changes are highly correlated with population changes. However, in SA2s corresponding to primary or secondary business districts, or containing commercial or industrial parks, land rental prices depend more (or entirely) on land demands of other sectors. In some of these areas, modest price increases are seen, including the CBDs of Sydney and Melbourne and in sea and air ports in all three cities. More generally, price increases tend to begin closer to the CBD than do population increases. For example, in the southern half of the City of Parramatta (western suburbs of Sydney), land rental prices rise 0.8 – 2.4% despite resident populations falling 1.1 – 2.6%.

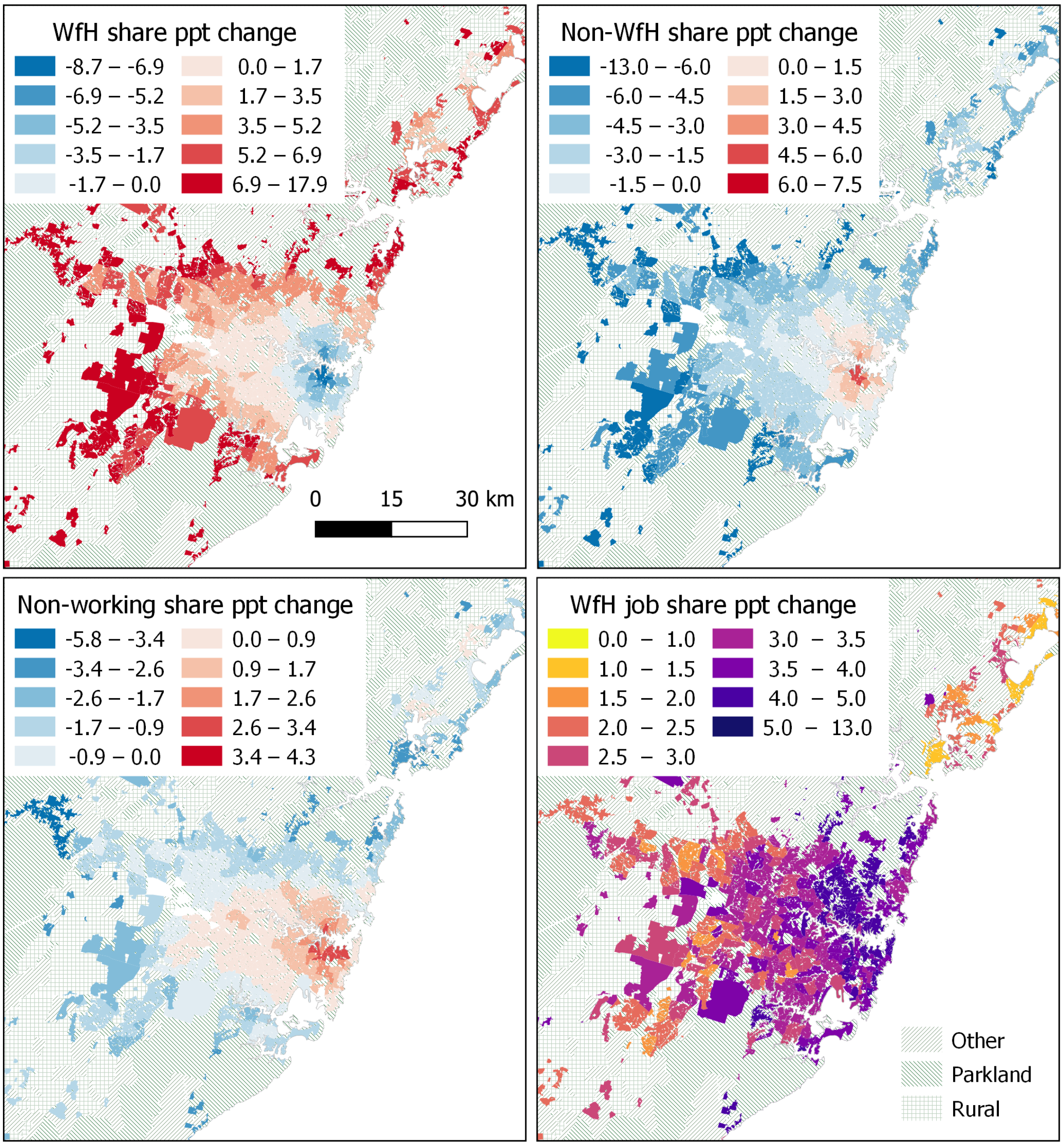

Figure 6: Percentage point changes in resident teleworkers, resident non-teleworkers, non-working household and teleworking jobs.

Figure 6 shows changes in the composition of resident populations and of jobs. The top two and bottom-left maps show percentage point changes in shares of resident teleworkers, non-teleworkers and non-working households respectively. The bottom-right map shows percentage point changes in the share of teleworking jobs. Local WFH and non-WFH shares also reflect the aggregate changes in these groups of occupations. However, there is also a clear sorting effect: workers choosing WFH occupations become more likely to reside in outer suburban and peri-urban areas while the reverse is true of those choosing non-WFH occupations. Non-working households also locate more centrally. WFH jobs increase everywhere but (with a some localised exceptions) most strongly in inner suburban and central city areas.

4.3 Significant Urban Areas

Figure 7 shows that increased WFH has strong effects across, as well as within cities. Only Sydney and Melbourne, the two largest capitals, see increases in both resident workers and jobs. Brisbane and Canberra see increases in jobs but reductions in resident workers. There are only two other small and relatively isolated towns in this quadrant: Lismore (NSW) and Bairnsdale

(Vic.). The large majority of cities and towns lose both resident workers and jobs (south-west quadrant) while a significant minority gain resident workers but lose jobs (north-west quadrant). The rural (meaning here non-SUA) areas of five of the states are also found in this quadrant.[11]

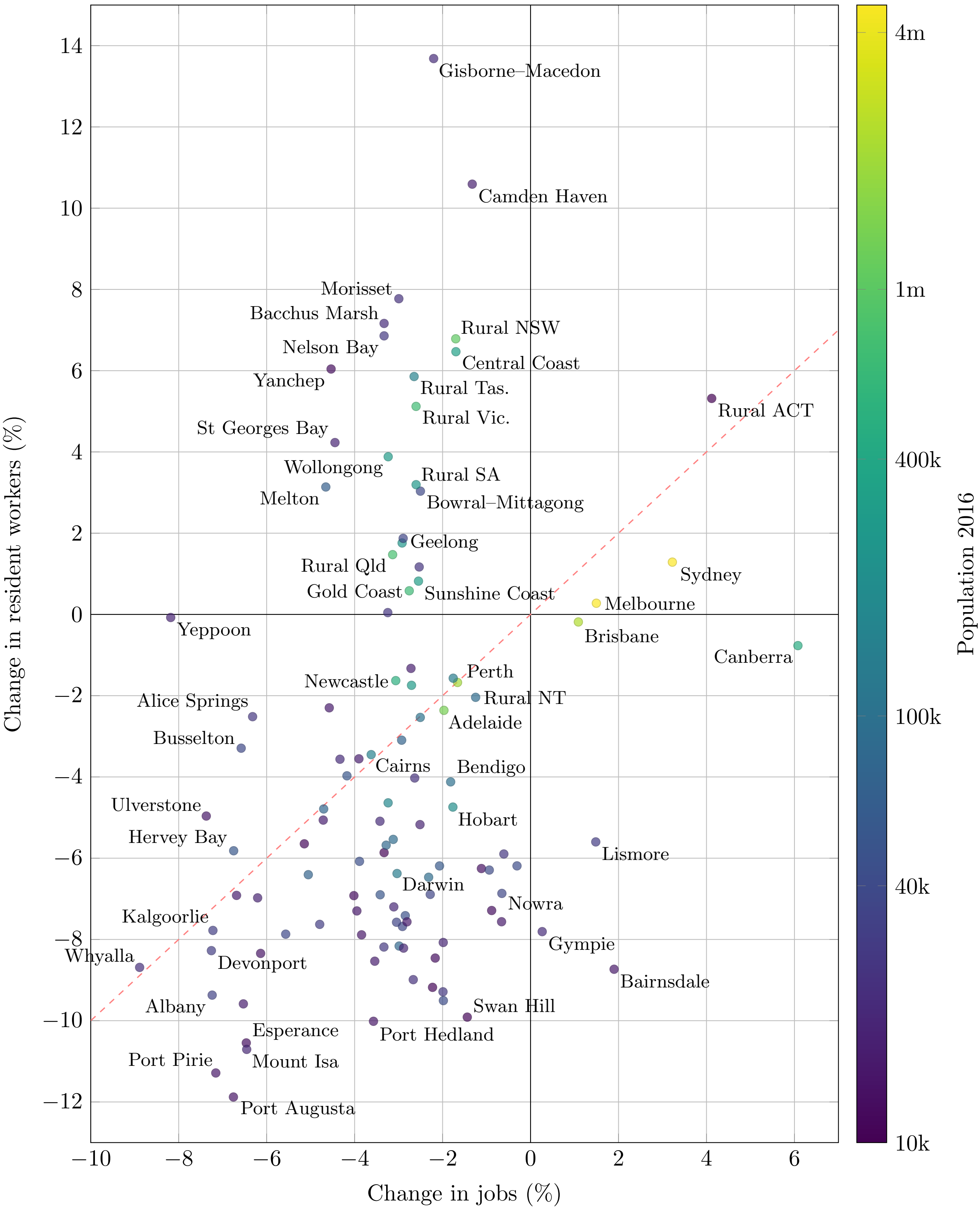

Figure 7: Change in resident workers and jobs by Significant Urban Area (%)

[11]Rural ACT lies in the north-east quadrant, but has an extremely small population. Rural WA and Rural NT lie in the south-west quadrant.

The figure is perhaps best understood rotating the axes 45 degrees. Cities that lie on the 45 degree line grow or shrink while maintaining their pre-existing balance between jobs and resident workers; or put another way, their net rate of out-commuting. The further cities lie to the north-west (or south-east) of this line, the greater then increase (or decrease) in their net rate of out-commuting. Thus Sydney, Melbourne, Brisbane and Canberra, all see their rates of net in-commuting increase, with most of these commuters coming from the nearby towns and cities in the north-west quadrant.

Small cities and towns in more remote regions of the six states all see population declines. Most see increased rates in-commuting. These commuters will predominantly live in nearby SA2s that we have classified as 'Rural' for the purposes of the figure. If we were to disaggregate these areas, there would be many more points above the 45 degree line in the south-west (and perhaps also north-west) quadrant. The greatest population declines are seen in towns that are remote both in absolute geographic terms and relative to the few large cities that see growth. This includes for example Whyalla, Port Pirie and Port Augusta in South Australia (capital city, Adelaide) and Esperence, Kalgoorlie and Port Hedland in Western Australia (capital city, Perth) and Mt Isa in Queensland (capital city, Brisbane).

4.4 Regressions

More localised effects can be visualised using maps, but to 'visually integrate' mapped changes over space is difficult. Results for SUAs integrate out changes within cities entirely and have the further problem that the SUA boundaries can be somewhat arbitrary—both in defining urban–rural boundaries and in distinguishing urban areas within large conglomerations.[12] To address these limitations, we regress results at SA2 level on continuous measures of centrality. For this purpose, we divide a gravity-based measure of accessibility to jobs by a comparable measure of accessibility to resident workers.[13] In addition, the effects of occupational and industry composition are assessed using Bartik-style measures, i.e. predicting local changes using the initial local shares to weight national changes.

The strongest correlation is between jobs and the Bartik-style measures for occupations. This explains 49% of the variation. Thus, increased WFH in selected occupations induces large shifts towards those occupations and away from others. The half of the local variation in employment can be explained by the initial job shares in those locations: locations in which WFH occupation jobs are more (less) concentrated tend to gain (lose) jobs. However, the upper right panel shows that such a measure cannot predict local changes in the resident workforce. Instead, changes in the resident workforce are correlated with the ratio of resident to employment accessibility (R-squared of 35%, upper left panel). This is in line with our observations above that there is increased residential decentralisation. Similarly, the increased centralisation of jobs is confirmed by the negative (although weaker) correlation between job changes and the ratio of resident to employment accessibility (R-squared of 18%, lower left panel).

[12]For example, many of the dormitory towns referred to above would for many purposes be considered as part of the cities that they serve. Even sizeable cities such as Geelong or Wollongong that geographically, politically and socially distinct entities could still reasonably be considered as part of larger functional urban areas defined by connectivity of labour markets.

[13]The gravity measure reflects the disutility of commuting in the model for non-WFH occupations.

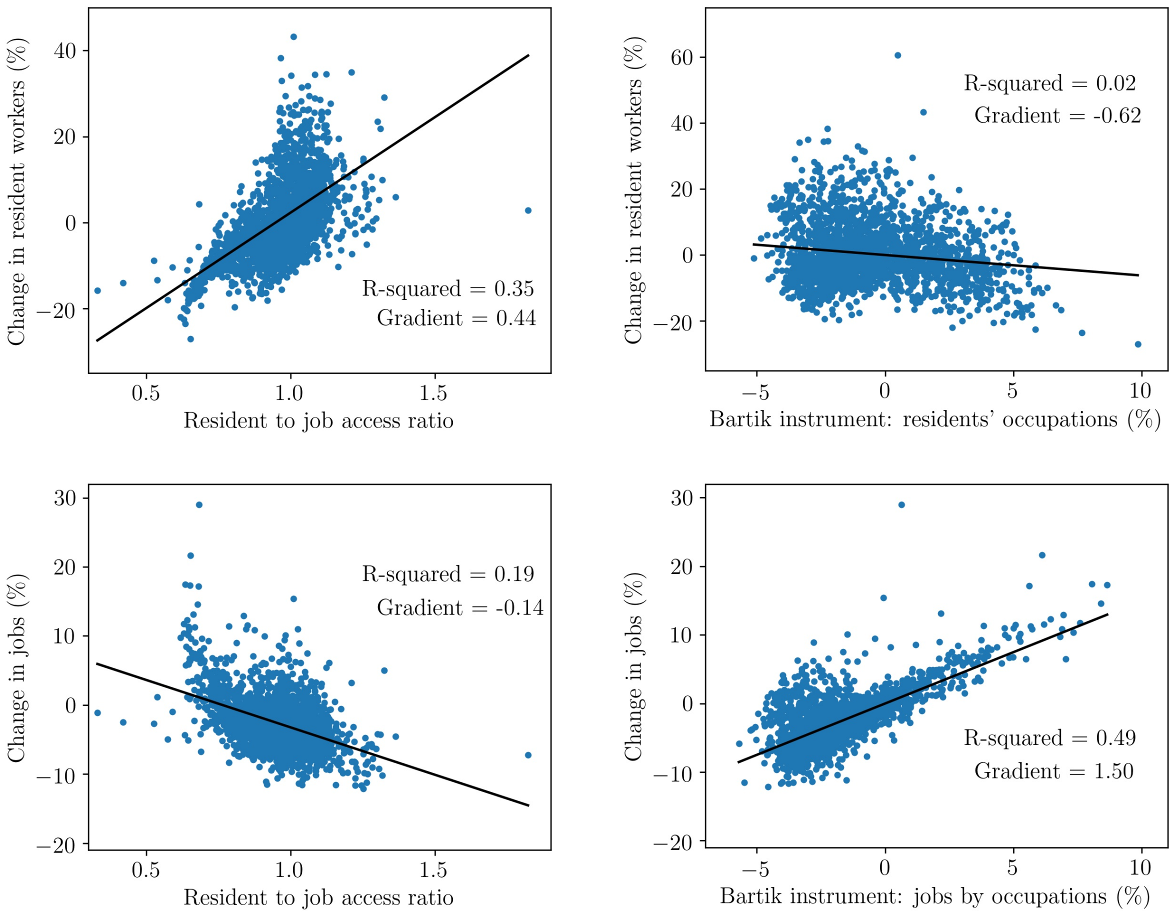

Figure 8: Scatter plots of percentage changes in resident workers (upper panels) or jobs (lower panels) vs. accessibility ratios (left panels) or Bartik-style instruments (right panels).

4.5 States and Territories

As national populations are held fixed, population gains in some jurisdictions imply losses in others. In our simulation, Australia's six states and two territories fare differently with increased WFH. This reflects differences in their size and spatial distributions of cities, and their occupational and industry mixes.

The two largest states, NSW and Victoria gain working and non-working resident households at the expense of the other six jurisdictions (Figure 9). The changes in the two household types are positively correlated, but are larger for working than for non-working households. Changes in jobs differ from changes in resident workers, reflecting changed interstate commuting patterns.[14] For the ACT, this discrepancy is dramatic and largely reflects the ACT's small size and geographic location within the state of NSW.

[14]For Tasmania and for mainland states lacking urbanised border areas (WA, NT), interstate commutes are necessarily very long commutes. In reality, many such commutes are made by 'fly-in, fly-out' or drive-in, drive-out' workers who are temporarily accommodated at their workplaces, rather than by telecommuters. However, this distinction is beyond the scope of our model.

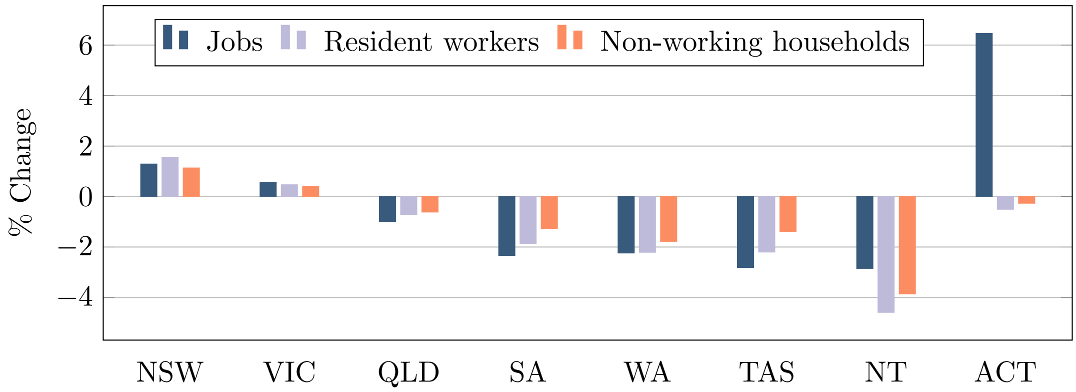

Figure 9: Change in jobs, resident workers and non-working households by state/territory

The strong correlation of changes in working and non-working household populations in the eight jurisdictions highlights the role of local markets for goods and services in location choices, especially at larger spatial scales. Although non-working households do not benefit directly from accessibility to employment, they do benefit from accessibility to retail and other services that are provided by many workers. Prices fall most in jurisdictions that see the largest increases in labour supply. Residential sorting is thus a more localised phenomenon occurring within cities rather than between them.

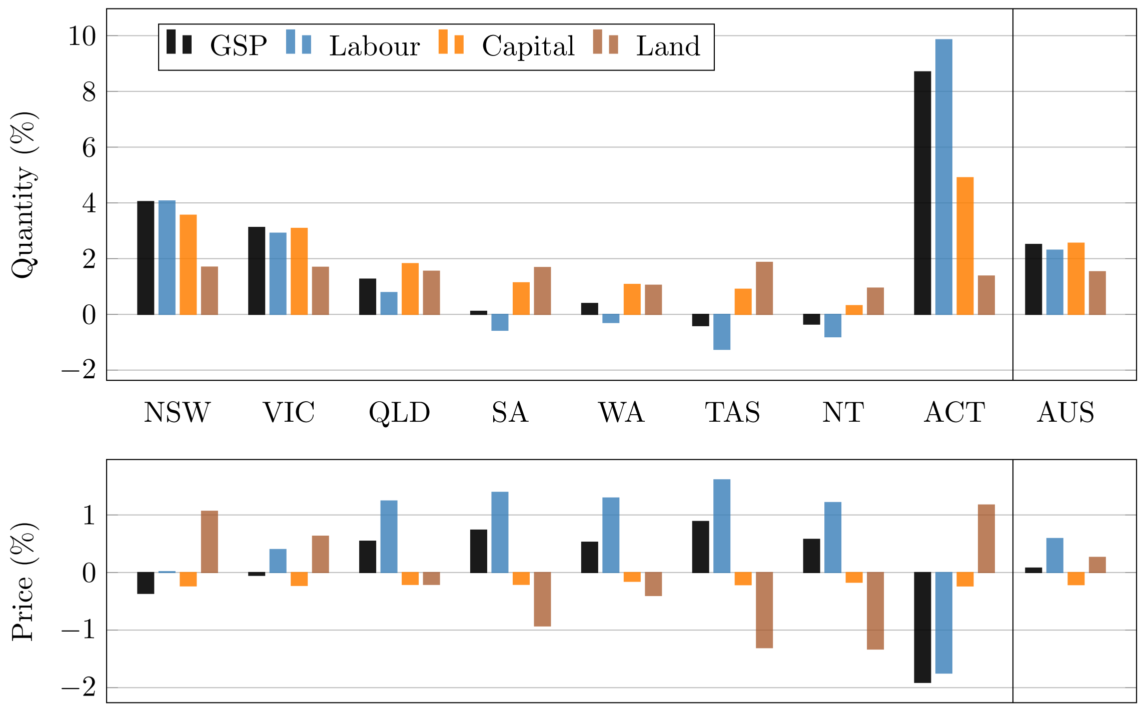

Figure 10: GSP and factor input quantity (upper panel) and price (lower panel) indices

The upper panel of figure 10 shows changes in gross state product (GSP) and quantity indices for primary factor inputs: labour, capital and land. The lower panel shows corresponding price indices.[15] In the right-hand section of each panel, results for Australia as a whole are shown. Gross domestic product (GDP) increases 2.5%, while changes in GSP range from a 8.7% increase in the ACT to a 0.40% decrease in Tasmania. The two largest states, New South

[15]Price changes are relative to a national index of consumer prices.

Wales and Victoria, see their GSP increase 4.0% and 3.1% respectively. The GDP factor price index increases by 0.08% (relative to CPI) and to maintain the balance of trade, there is a real appreciation of 0.7%.

Changes in the measure of effective labour input are much larger than the changes in headcount of figure 9. This is firstly the result mainly of the changing workforce composition: workers in the WFH occupations are, on average, much more productive than those in the WFH occupations. Secondly, even in states the lose workers, the greater concentration of jobs within cities generates productivity effects from agglomeration. The aggregate price index for labour actually increases slightly in NSW and Victoria, despite increased labour supply to those states. It rises much more strongly in those states that see their labour supply decrease, while falling strongly in the ACT.

Similarly, although the total physical hectares of land are fixed in the model, the effective quantity of land increases in all states. This is firstly because land is converted from rural to urban uses, where it is more productive, and secondly, because a greater ability to WFH decreases effective commuting costs and thus tends to increase accessibility to employment. The aggregate land price index, however, rise in states where labour supply increases and falls in those where it decreases, as land becomes relatively more abundant.

5 Discussion

Our simulation results appear broadly in line with previous modelling studies. Our main findings align with those of Delventhal, Kwon, and Parkhomenko (2020), which is reassuring given that they model several phenomena that we have omitted here: (i) increased housing demand of those working from home; (ii) decreased floorspace demand of firms employing those workers; (iii) effective job densities (which generate spillovers) that discount days worked from home; (iv) congestion effects and (v) effects of and interactions with density-suppressing regulations.

We do not omit the first three of these phenomena because we consider them unimportant, but because they are poorly understood. There may be substantial heterogeneity across occupations and industries. For example, requirements of home office space may differ because some types of task are more prone to disturb, or alternatively, to disturbance by other activities in the household. Effects on commercial floorspace demand and spillovers are likely to depend on what sorts tasks are still performed in the office environment and when. For example, do productivity spillovers depend more on formal interactions that can be scheduled in advance, or on serendipitous meetings?[16]

Congestion effects, on the other hand, are well understood. However, the treatment of congestion in Delventhal, Kwon, and Parkhomenko (2020) is extremely simplified, being a uniform function of total commuting vehicle kilometres. More insight into congestion effects of WFH can probably be gleaned from the stylised urban economic models in Larson and Zhao (2017); Rhee (2009), where congestion has an explicit spatial dimension. We argue that a large-scale SCGE model is better paired with a large-scale strategic transport model that can account for the multi-purpose, multi-modal, network structure of real transportation networks. We hope to do this in future work. For example, considering only car travel ignores the possibility that WFH commuters may prefer outer suburban and peri-urban locations along commuter and regional rail lines, which provide easy access to the CBDs of Australia's largest cities. Similarly, considering only commuting trips ignores effects of (de)congestion on road freight, business-to-business trips and private trips for non-work purposes.

Finally, land use regulations are recognised as major constraints on housing supply in the inner and middle suburbs of Australia's largest cities Keaton and Tulip (2020); Kendall and Tulip (2018). We do not attempt to model such regulations here, mainly because of data limitations at SA2 level. Qualitatively, the costs of existing regulations will fall in areas where

[16] For reviews, see (e.g. Duranton and Puga, 2020; Puga, 2010; Combes and Gobillon, 2015).

housing demand falls. The extent to which these gains would be offset by increasing costs of regulation in areas where housing demand rises is unclear. The fact that densities in most of these areas are currently low is not necessarily reassuring. In many areas, current regulations may not allow them to increase significantly. For example, large swathes of suburban Sydney are zoned as 'Low Density Residential'[17] and significant peri-urban areas are zoned for 'Large Lot Residential'. These examples are from New South Wales, but similar planning practices can be found in other jurisdictions.

Our modelling has focussed on the private costs and benefits of WFH. Demands on transport infrastructure may be tempered by less frequent commuting, but demands on telecommunications infrastructure are likely to increase. Both transportation and urbanisation are also associated with significant environmental externalities. In the literature on WFH, the potential to reduce vehicle emissions has been the main focus of environmental concern. Larson and Zhao (2017) argues that emissions associated with construction and operation of housing should also be considered. However, as vehicle fleets are electrified and electricity generation is decarbonised, the potential emissions savings will decline. We suggest that a more important long-term consequence of WFH may be the accelerated loss of biodiversity and native species.[18] The unprecedented 2019/20 bushfire season in Australia also highlighted exposure to worsening natural hazards in outer suburban and peri-urban areas (Bell, 2019).

6 Conclusions

Our counter-factual simulation of a higher propensity to WFH in a subset of occupations shows that a shift in labour supply towards these occupations advantages some industries (notably, various types of business services) relative to others. Residential sprawl is driven by the willingness of workers choosing WFH occupations to live further from their jobs to access cheaper housing and/or better local amenities. Workers choosing non-WFH occupations and non-working households partially offset the outward shift in housing demand by choosing to live in more central locations. Jobs in WFH occupations agglomerate further, as firms in the most productive locations can more easily attract workers and residential demands for land in these locations decline. These effects operate both within and between cities. The largest and most productive cities gain jobs at the expense of practically all other cities, towns and rural areas of Australia. Smaller cities and towns close to large employment centres attract more residents who commute out, but the majority of Australian cities and towns shrink, relative to the baseline.

At a regional level, WFH seems likely to reinforce pre-COVID-19 trends of spatially disparate growth rates and job agglomeration within cities. However, residential density gradients in the largest cities had been gradually steepening. More WFH could potentially slow or reverse that trend. Building either upward or outward could reduce the cost of housing. However, building outward is likely to require much more of governments than building upward as it is liable to increase infrastructure and environmental costs and exposure of people and physical capital to natural hazards. While our model has enables some potential economic benefits of WFH to be quantified, these potential costs warrant further research. Effects of WFH on individual transport choices and on transportation systems also need to be accounted for.

[17] Guidance suggests that dwellings will typically be detached, but that it 'may be appropriate' to include some multi-dwelling housing. See https://www.planning.nsw.gov.au/-/media/Files/DPE/Practice-notes/preparing-LEPs-using-the-standard-instrument-standard-zones-2011-03-10.pdf.

[18] For example, Silcock and Fensham (2019) identify urbanisation as one of six main threatening processes for Endangered and Critically Endangered plant species in Australia. More relatable to the lay person, past and ongoing urbanisation is a major cause of declining koala populations along Australia's eastern coast where loss and fragmentation of habitat due to urbanisation have been compounded by vehicle collisions and dog attacks(McAlpine et al., 2015). Using admissions data from the Australian Zoo Wildlife Hospital in South-East Queensland, Taylor-Brown et al. (2019) show increasing losses of many different species of wildlife in urbanising regions from direct and indirect human impacts.

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A Significant Urban areas

SUA Name	2016 Population	Number of SA2s
Adelaide	1 305 526	106
Albany	33 784	4
Albury–Wodonga	90 836	6
Alice Springs	26 518	6
Armidale	24 114	1
Bacchus Marsh	20 989	1
Bairnsdale	14 899	1
Ballarat	101 678	7
Ballina	25 643	2
Batemans Bay	16 381	2
Bathurst	35 878	2
Bendigo	95 934	8
Bowral–Mittagong	38 653	4
Brisbane	2 282 759	227
Broken Hill	18 114	1
Broome	14 535	1
Bunbury	73 678	9
Bundaberg	70 179	9
Burnie–Wynyard	26 978	6
Busselton	37 690	2
Cairns	149 182	18
Camden Haven	17 001	1
Canberra–Queanbeyan	439 971	116
Central Coast	328 330	28
Coffs Harbour	70 106	5
Colac	12 450	1
Darwin	133 098	40
Devonport	29 900	5
Dubbo	37 118	3
Echuca–Moama	20 848	2
Emerald	13 867	1
Esperance	12 355	1
Forster–Tuncurry	20 855	2
Geelong	254 296	15
Geraldton	38 369	4
Gisborne–Macedon	21 011	3
Gladstone–Tannum Sands	44 954	8
Gold Coast–Tweed Heads	645 711	52
Goulburn	23 415	1
Grafton	19 037	1
Griffith	19 709	1
Gympie	21 315	2
Hervey Bay	53 016	5
Hobart	207 396	31
Horsham	16 462	1
Kalgoorlie–Boulder	30 652	4
Karratha	16 363	1
Kempsey	15 125	1
Kingaroy	10 464	1
Launceston	85 732	18
Lismore	29 016	2
Lithgow	13 040	1
Mackay	80 411	12
Maryborough	27 240	3
Melbourne	4 546 593	294
Melton	61 960	3
Mildura–Wentworth	51 051	5

Continued on next page

SUA Name	2016 Population	Number of SA2s
Moe–Newborough	16 840	1
Morisset–Cooranbong	24 207	2
Mount Gambier	29 532	2
Mount Isa	19 271	1
Mudgee	12 019	1
Murray Bridge	18 196	1
Muswellbrook	12 376	1
Nelson Bay	27 459	2
Newcastle–Maitland	475 716	36
Nowra–Bomaderry	36 790	2
Orange	39 586	2
Parkes	11 251	1
Perth	1 982 270	159
Port Augusta	14 053	1
Port Hedland	14 411	2
Port Lincoln	16 198	1
Port Macquarie	46 376	2
Port Pirie	14 347	1
Portland	10 943	1
Rockhampton	78 598	11
Sale	14 891	1
Shepparton–Mooroopna	50 708	3
Singleton	16 517	1
St Georges Basin–Sanctuary Point	18 545	2
Sunshine Coast	316 905	28
Swan Hill	11 079	1
Sydney	4 637 436	272
Tamworth	41 986	3
Taree	26 385	2
Toowoomba	133 654	13
Townsville	178 244	22
Traralgon–Morwell	41 385	2
Ulladulla	15 618	1
Ulverstone	14 402	3
Victor Harbor–Goolwa	26 154	2
Wagga Wagga	55 800	4
Wangaratta	18 940	1
Warragul–Drouin	35 523	2
Warrnambool	34 615	2
Warwick	15 395	1
Whyalla	22 432	1
Wollongong	294 784	22
Yanchep	12 169	2
Yeppoon	18 539	1
Rural (ACT)	948	8
Rural (NSW)	1 013 035	143
Rural (NT)	86 062	22
Rural (Qld)	760 124	111
Rural (SA)	266 405	57
Rural (Tas.)	153 106	34
Rural (Vic.)	692 021	105
Rural (WA)	289 671	56