

# How the rise of teleworking will reshape labor markets and cities?

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## IDE DISCUSSION PAPER No. 868

### How the rise of teleworking will reshape labor markets and cities?

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#### Abstract

Motivated by empirical evidence, we propose a model of the monocentric city with heterogeneous workers and teleworking. We show that increased teleworking flattens the land-rent gradient and eventually moves skilled workers from the city center to the city's periphery. Unskilled workers move from the local services sector into final goods and wage inequality between skilled and unskilled workers increases. Extending the model to two cities, teleworking increases housing prices in the less productive city relative to the more productive city, with implications for unskilled workers in both cities. Empirical evidence from housing prices in England are consistent with this result.

**Keywords:** telecommuting, working from home, gentrified cities, doughnut cities, inter-city commuting

**JEL classification:** J60, R00

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# 1 Introduction

More than two years after the start of the Covid-19 pandemic, while many parts of life are returning to the pre-pandemic normal, the shift towards a larger proportion of work being done away from the office appears to be truly becoming a new normal. As a result, we are beginning to see more and more anecdotal evidence that this rise in teleworking is requiring major cities to adapt. San Francisco’s once vibrant central business district (CBD) has struggled to bring workers back to the offices (Holder, 2022), leading to the commissioning of a major revitalization plan to attract old, and new, footfall back to the CBD (Imbault *et al.*, 2022). Across the ocean, there are reports that the city of London is experiencing an exodus of high-skilled workers, seeking less expensive housing and better lifestyles in more residential-friendly towns and cities (Sidders, 2022). This coincides with up to 14% of restaurants in central London closing since 2020 (Barnes, 2022); blamed on the increase in teleworking. We see similar stories across many major cities including Manhattan, Toronto, and Paris. What are the mechanisms through which a large-scale shift in teleworking has such an impact on our cities? How will this affect labor market opportunities and urban inequality? What might happen if teleworking continues to rise?

The goal of this paper is to study how the intensity of telecommuting affects the residential and labor force organization of cities. We set the stage by documenting new empirical evidence for London, England. We find that the gradient describing the change in land-rent across distance from the central business district (CBD) has flattened, dropping in magnitude 17.1 percentage points (37%), between 2021 and 2019. We also find that the flattening of the gradient is greater—up to 19.5 percentage points—in neighborhoods in which, pre-pandemic, a greater proportion of residents hold jobs that are possible to do from home. This finding complements evidence reported for American and Chinese cities (Gupta *et al.*, 2022; Brueckner *et al.*, 2021; Huang *et al.*, 2022), and is consistent with a structural change in the spatial organization of major cities. Further, over this same period we find a 24 percentage point (400%) increase in working from home by skilled workers, while unskilled workers report a much smaller increase. This evidence is consistent with the observation by Gupta *et al.* (2022) for U.S. metropolitan areas of a flattening of the bid-rent curve due to greater working from home.

Motivated the empirical evidence we develop a theoretical setting that accounts for three important features of the urban economy: 1) Local labor markets are made up of

both skilled and unskilled workers. 2) With a few exceptions (think of call-centers), telework characterizes predominantly the skilled workers (Adams-Prassl *et al.*, 2020; Dingel and Neiman, 2020; Mattana *et al.*, 2020). 3) Unskilled labor may provide local consumption services (LCS), such as food, retail and haircuts. The demand for these services is determined by the density of skilled workers in the CBD during the working day. We use this setting to analysis the effect of a change in the intensity of telecommuting on the city’s labor market and residential structure, first the case of one city and then in a system of two cities where individuals can reside in one city and work in the other.

We develop a monocentric city model that takes into account the above features. There are three primary production factors—land, skilled, and unskilled labor—and two sectors—the first sector produces the consumption good (costlessly tradable) using skilled and unskilled labor, while the second sector supplies LCS, using unskilled labor. Skilled workers provide both home and office labor, combined through a general transformation function that yields the input used to produce the consumption good. All work takes place in the city’s CBD, and workers chose where to live given land rents and commuting costs. Commuting costs are increasing with income, consistent with well-documented evidence (Small, 2012; Koster and Koster, 2015). Using this model we study how an increase in the skilled homeworking share affects all workers. Specifically we consider wage inequality between the two worker types, spatial sorting within the city, and housing and commuting costs.

Our main findings from the monocentric city may be summarized as follows. First, teleworking affects the spatial structure of the city. In the absence of telecommuting, the city is *gentrified*—costly commuting means that skilled workers favor proximity to the city center (Edlund *et al.*, 2015). For a small increase in the WFH share, the social structure of the city remains the same, but when the WFH share goes beyond a certain threshold, the skilled find it desirable to reside in the periphery where land is cheaper. We refer to this urban structure as the *doughnut city* because the city center gets less and less vibrant; consumption of LCS falls and a growing proportion of unskilled, now living near the CBD, move to work in the final sector for a lower pay. In sum, *a wide-spreading of telecommuting is likely to trigger a hyper-suburbanization of the skilled at the expense of the unskilled workers*. This agrees with the recent trend toward a new and extensive suburbanization, as we show for London, and documented for several US and Chinese metropolitan areas (Gupta *et al.*, 2022; Liu and Su, 2021; Ramani and Bloom, 2021; Huang *et al.*, 2022).

Clearly, unlike what our model predicts, the change in residential structure will not arise at once but will instead follow a gradual process. Our setting can easily be extended to such a mobility pattern by assuming that skilled workers have heterogeneous attitudes toward commuting or the city centre (see, e.g., Tabuchi and Thisse, 2002).

Second, telework has important redistributive effects. Regardless of the city's social structure a higher WFH share exacerbates wage disparities between the skilled and the unskilled. This happens because unskilled jobs are destroyed in the LCS sector, leading unskilled workers to move to the final sector. This boosts the skilled wage and depresses the unskilled wage. Further, we show that wages of both types of workers are bell-shaped in the WFH share; *a low WFH share allows all workers to earn more while a high share lowers the income of both types of workers*. However, unskilled workers realize the top of the bell at a lower value of the WFH share than do skilled workers. These results are unexpected because the unskilled are *a priori* unaffected by telecommuting.

Third, despite the popular belief that telecommuting leads to lower commuting and housing costs, we show that, while this is true for a doughnut city, the aggregate urban cost to workers of greater teleworking is ambiguous in the gentrified city. This is because, when WFH shares are sufficiently small, skilled and unskilled wages will both increase. The increased WFH share increases unskilled workers' commuting costs, and this could offset the decrease in commuting costs realized by the skilled workers (through less commuting). In contrast, in a doughnut city an increased WFH share lowers land rents everywhere in the city and depresses wages for the unskilled. Average land expenditure for skilled workers is lower in a doughnut city than in a gentrified city, highlighting one of the main gains that the skilled expect from WFH.

We next expand the model to an urban system formed by two cities that differ in their total factor productivity. In this context, it is well known that urban costs are higher in the more productive city because competition for land is tougher. Consequently, some skilled may choose to reside in the less productive city while keeping their job in the more productive one. Such a commuting pattern gives rise to a completely new type of suburbanization in which the residential population of the more productive city shrinks while the residential population of the less productive city grows. Between-city commuting leads to lower urban costs in the more productive city but raises them in the less productive one. Therefore, the departure of inhabitants—but not of workers—from the more productive city makes those who stay better-off, whereas the arrival of new

residents in the less productive city—who do not work therein—makes the incumbents worse-off though higher housing and commuting costs.

Our main result from this model is that *the mass of between-city commuters is bell-shaped in the WFH share*. For low values of the WFH share, the skilled who reside in the more productive city commute to CBD frequently, and thus bear relatively high commuting costs. As WFH grows, more skilled find it optimal to move to the less productive city, residing close to its CBD, pushing the resident skilled who work there toward an intermediate area situated between the between-city commuters and the local low-skilled workers. In other words, there is gentrification of the less productive city, but its CBD does not attract more skilled workers. This shows how inter-city commuting differs from inter-city migration studied in standard models of urban systems, and generates redistributive effects that need not be innocuous.

When the WFH share rises further, the difference between urban costs in the two cities shrinks, which leads between-city commuters to save the cost of travelling between cities by moving back to their original city where they reside in the suburbs. Simultaneously, those who remain between-city commuters will locate in the intermediate area of the less productive city where housing is less expensive. The central areas of both cities are now inhabited by the unskilled because the skilled need to commute less and, therefore, prefer to live in the suburbs where land is cheap. Last, when the WFH share is sufficiently high, low land rent and almost costless commuting, due to its low frequency, leads between-city commuters to return to their city of origin. In this case, the more productive city regains residents, but LCS establishments patronized by commuters suffer.

We again turn to the English data to test predictions of our model with empirical evidence. Specifically, we look at the relationship between productivity and housing price growth, between 2019 and 2021, across different cities in England and Wales. We find that housing price growth is higher in less productive cities. Consistent with skilled workers moving out of high productivity cities in search of more affordable housing, we also find strong and statistically significant negative relationship between average house prices in 2018 and the growth in housing prices between 2019 and 2021. These results support our theoretical result that increased teleworking may lead to a shift in residential demand towards lower-productivity, less expensive, cities.

**Related literature.** While the management and psychological literature on telecommuting is mounting—the survey by Allen *et al.* (2015) includes about 200 references—the

economic theory literature on telecommuting and cities is meager. Safirova (2002) provides numerical solutions to extend the monocentric city model, accounting for telecommuting when home workers and office workers are imperfect substitutes. However, Safirova remains within standard urban economics frameworks, considering a land market and a single production sector. Rhee (2008) studies the trade-off between working time and leisure and shows that most of the commute time saved by teleworking is allocated to work rather than leisure. Recent papers, such as Althoff *et al.* (2020), Behrens *et al.* (2021), De Fraja *et al.* (2021), and Koren and Peto (2020), study different relationships between telecommuting and the spatial organization of activities.

There are two papers close in spirit to ours. Delventhal *et al.* (2022) calibrate a quantitative model in which WFH impacts where different types of workers reside in an urban area. Brueckner and Sayantani (2022) explore the case of between-city commuting with workers who can, and workers who cannot, work from home. We make an important contribution over these papers. First, our model accounts for different types of unskilled labor. This is important for thinking about how teleworking will shape the composition of labor markets and wages. Second, our model focuses on the externalities that the teleworking of skilled workers has on urban costs and wages borne by unskilled workers. This has important implications and provides structure for thinking about welfare effects of the rise in teleworking, and the channels through which we may experience what Nick Bloom has referred to as a “time-bomb for inequality” (Wong, 2020).

The remainder of the paper is organized as follows. In Section 2 we motivate our modelling with evidence on recent changes in housing prices and working for the city of London in recent years. In Section 3 we set up the one-city model. In Section 4, we determine the skilled and unskilled wages. Section 5 characterizes the equilibrium city structure for different values of the WFH share. In Section 6, we extend the one-city model to study the commuting patterns between two cities under WFH, and test predictions of the model with additional empirical evidence. Section 7 concludes.

## 2 London since the pandemic

In this section we provide some new empirical evidence on how cities have changed since the Covid-19 pandemic. Specifically, we look at the case of London,<sup>1</sup> which has a number

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<sup>1</sup>In this analysis we specifically focus on the 53 *local authorities* in England that make up the central London travel to work area. For simplicity we refer to this area as London. The local authority is the



of features that make it an interesting city. First, London stands out in the UK as the labor market with the highest productivity (and wages) and a strong, negative, relationship between housing prices and distance to CBD. A simple bi-variate regression of log-price on log-CBD distance shows that a one percent increase in distance is associated with a 0.347% decrease in price<sup>2</sup>. To illustrate, in 2019, the average price for a flat within one kilometer of central London was £1,006,735 (£2,994 per month to rent), within one to ten kilometers is £683,056 (£2,420 per month to rent), and within ten to twenty kilometers is £349,106 (£1,908 per month to rent). This steep decline in prices also holds when we adjust for property size.<sup>3</sup>

A second interesting feature of London is that economic activity is centrally concentrated. An eight kilometer radius around the center of London makes up 6.5% of the total land area and 24.0% of the residential population, but 31.3% and 73.2% of the total retail and office floorspace for London (see Appendix Figure A.4 for an illustration.) Further, 45% of all employees in London work within this eight kilometer radius.<sup>4</sup>

Finally, prior to 2020, as we get closer to the center of London we see a higher concentration of skilled workers in the residential population. Of the working residents within five kilometers of the CBD, 56.9% work in skilled occupations. This proportion falls to 44.0% and 40.0% as we move out ten to twenty and more than twenty kilometers away from the CBD.

## 2.1 Data

The primary outcomes that we will be interested in are sale and rental prices for residential properties. For sales prices we use information from *HM Land Registry Open Data*. These data contain the universe of housing sales taking place between 2017 and 2022. Each observation reflects a unique sale, and contains information on the price paid for the property, the street address, the property type, and the date that the property changed ownership. Our main analysis (see Table 1) focuses on the change in prices between 2019 and 2021–22. We exclude from this analysis sales for which the property type is

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smallest unit of governing authority for the England and Wales, similar to a city or town.

<sup>2</sup>Based on 2019 sales.

<sup>3</sup>We can adjust for floorspace of a property using the rental data. The monthly rental price per square meter of property is £46.1, £33.2, and £26.9 for one, ten and twenty kilometers from London's center.

<sup>4</sup>Retail and office floor space based on data provided by the Valuation Office Agency. Distribution of the residential and working population are based on information from the 2011 population census. Skilled occupations, as measured here, make 46% of the total London residential population.

listed as *other*, and property sales in excess of £50 million.<sup>5</sup> This leaves us with 231,293 observations for the London area.

Rental prices data are provided by *Rightmove*, an on-line property website. These data contain all properties advertised on the website between 2017 and 2022, and include information on monthly rental price (actual paid), the street address, the property type, and the date that the property was advertised. For London, these data capture between 400,000 and 500,000 rental postings per-year between 2017–2021, and an additional 200,145 postings for 2022.

Control variables are based on data collected from a number of different sources. In Appendix A we outline all data sources and the derivation of any control variables included in the regression. This includes, a Bartick-style instrument at both the level of the city and the neighborhood, reflecting pre-Covid employment growth, a neighborhood level deprivation index, a count of endogenous amenities in the neighborhood (restaurants, pubs, cafes, theaters, etc.), distance of neighborhood from the coastline, trains and large parks.

We compare price changes within different neighborhoods, defined by a geographic area with a population of approximately 900 households.<sup>6</sup> We refer to the CBD as the geographic centroid for the City of London. See Appendix A for further details and summary statistics for the data.

## 2.2 London housing prices since 2019

We estimate the average percent change in price given a percent change in distance (the *gradient* henceforth) between 2019 and 2021, using the following equation:

$$p_{ijt} = \zeta_1 d(z_{ij}, z_{CBD}) + \zeta_2 D_t^{2021} \times d(z_{ij}, z_{CBD}) + X'_{ij} \Gamma + \phi_j + \theta_t + \bar{\omega}_{jt} + e_{ijt}, \quad (1)$$

where  $p_{ijt}$  is the log of average (sale or rental) price in neighborhood  $i$  of local authority  $j$  at time  $t$ ,  $d(z_{ij}, z_{CBD})$  is the distance between the centroid of neighborhood  $i$  and the London CBD,  $D_t^{2021}$  is a dummy variable equal to 1 after the year 2021 and 0 otherwise, and  $X_{ij}$  is a vector of observable neighborhood and local authority characteristics which may influence price. The parameters  $\phi_j$ ,  $\theta_t$ , and  $\bar{\omega}_{jt}$  control for local authority, time and

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<sup>5</sup>These sales appear to reflect purchases of multi-residential units, such as an apartment building. Our focus is on sales intended for single family occupancy.

<sup>6</sup>Formally, neighborhoods are identified by *lower super output area* (LSOA), as defined by the Office for National Statistics. The LSOA is a geographic area containing between 400 and 1,200 households.

Table 1: Distance to central London and residential property prices

	Residential property sales			Residential property rentals		
	(1)	(2)	(3)	(4)	(5)	(6)
Distance to center	-0.347*** (0.058)	-0.373*** (0.033)	-0.462*** (0.046)	-0.394*** (0.060)	-0.345*** (0.038)	-0.379*** (0.041)
Year2021	-0.028 (0.043)	-0.080** (0.038)	-0.344*** (0.065)	-0.212*** (0.027)	-0.200*** (0.020)	-0.242*** (0.031)
Year2021 $\times$ Distance	0.051*** (0.015)	0.059*** (0.013)	0.171*** (0.039)	0.087*** (0.010)	0.084*** (0.008)	0.098*** (0.019)
Endogenous amenities		0.024 (0.023)	-0.016* (0.008)		0.031 (0.021)	-0.004 (0.014)
Endogenous amenities <sup>2</sup>		-0.001 (0.002)	0.002* (0.001)		-0.001 (0.002)	0.001 (0.001)
Distance to coast		0.049* (0.026)	-0.026 (0.026)		0.054* (0.027)	-0.073 (0.058)
Distance to park		-0.012** (0.005)	-0.013*** (0.004)		-0.029*** (0.010)	-0.015** (0.007)
Distance to train		0.038*** (0.014)	0.038*** (0.011)		0.006 (0.017)	0.025* (0.015)
Local authority fixed effects			Yes			Yes
Local authority $\times$ Year2021 fixed effects			Yes			Yes
$N$	231,961	231,293	231,293	1,111,380	1,105,739	1,105,739
$R^2$	0.111	0.315	0.353	0.185	0.290	0.340

Notes: Outcome is the log-price (sale and monthly rental). Data include years 2019, 2021 and 2022 for housing in the London Travel to Work Area. Dummy variable Year2021, equal to 1 if year  $\geq$  2021, and 0 otherwise. All distance measures are transformed to  $\log(1 + distance)$ . In addition the the reported variables, column (1) includes month-of-year dummies, columns 2 and 5 additionally includes Bartick instrument (for city and neighborhood), city productivity growth, average neighborhood income, and dummy variables for deciles of deprivation, and columns 3 and 6 additionally includes local authority and local authority  $\times$  time fixed effects. Robust standard errors clustered at the city level (53 clusters); \*, \*\*, and \*\*\* denote statistical significance at 10%, 5% and 1%.

local authority  $\times$  time fixed effects. Therefore the parameter of interest,  $\zeta_2$  is estimated using variation in the within-local authority distance of neighborhoods from the London CBD. Residual unobserved characteristics which influence housing prices are reflected in the error term,  $e_{ijt}$ . The parameter of interest  $\zeta_2$ , reflects the difference in the gradient after 2021 relative to the 2019 gradient, estimated by  $\zeta_1$ .

In Table 1 we report the estimated values for Equation (1), using (log) housing sale prices (columns 1–3) and (log) monthly rent prices (columns 4–6) as outcomes. Columns 1 and 3 report the coefficients for distance and time (including month-of-year dummy variables) without additional control variables. We examine the sensitivity of these estimates by, adding in neighborhood and city characteristics (columns 2 and 5), and adding in local authority fixed effects (columns 3 and 6). In our preferred specification of columns 3 and 6, estimates are based on entirely variation in the location of neighborhoods *within*

local authorities. In all regressions standard errors are clustered by local authority (53 clusters in total).

Since 2019, the land gradient has reduced by between 5.1 and 17.1 percentage points for property sales and between 8.7 and 9.8 percentage points for property rentals. These point estimates are large, up to a 37% reduction in the gradient for sales and a 26% reduction in the gradient for rental, relative to the 2019 gradient. Further, estimates of this relationship are stable across different specifications, despite the additional control variables being correlated with the outcome—notice that in Table 1 the  $R^2$  more than triples in size between columns 1 and 3. In Figure 1 we provide a visualization of this change in the gradient across the price-distance relationship (binscatter regressions include the full controls from columns 3 and 6, Table 1).<sup>7</sup>

In Appendix A, Table A.2, we provide additional analysis in which we allow the coefficient on the time $\times$ distance term to vary according to the proportion of residents who, pre-2020, were employed in an occupation that could be done from home.<sup>8</sup> In the sales data the decrease in the gradient is larger for neighborhoods with a higher proportion of jobs that can be performed remotely; there is almost a two percentage point difference in the magnitude of the decrease between the highest WFH neighborhoods and the lowest. The difference in these gradients is statistically significant ( $p = 0.004$ ). However, we do not observe a similar pattern for the rental prices, for which the estimated coefficient is relatively stable across quartiles.

It is possible that this flattening of the gradient reflects a trend that started before the pandemic. We perform a placebo test by estimating Equation (1) using alternative year pairs (Table 2)—2017 versus 2019, 2016 versus 2018, and 2015 versus 2017 for sales data and 2017 versus 2019 for rental data.<sup>9</sup> For sale prices, these estimates are small in magnitude, statistically insignificant, and of the opposite sign. The largest magnitude for sales, -2.5 percentage points in 2015 versus 2017, is less than 15% of the magnitude for the 2019 versus 2021 decrease. The corresponding coefficient for the 2017 versus 2019 regression for rental prices is significant ( $p=0.011$ ), but corresponds to a 5.4 percentage point increase in the magnitude of the distance gradient, contrary to the estimates of Table 1.

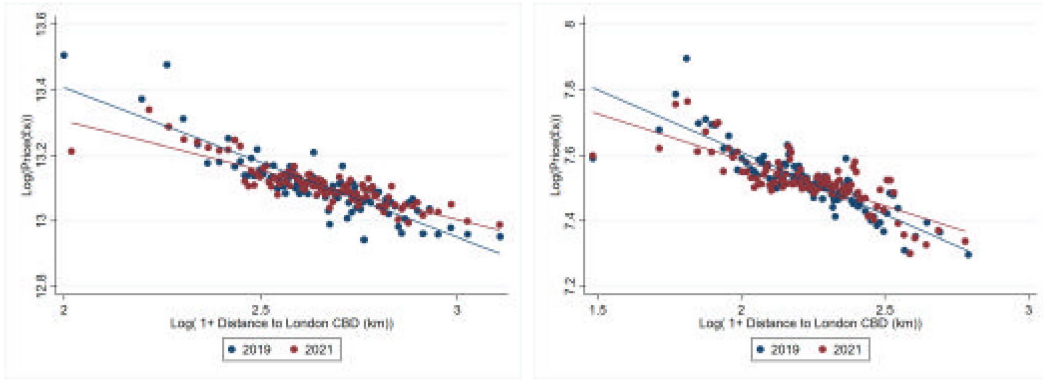
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<sup>7</sup>We provide an additional visual analysis of the change in the bivariate relationship between housing prices and distance to the CBD, by quarter of the year since 2017, in appendix Figure A.2.

<sup>8</sup>Neighborhood specific work-from-home rates are based on estimates from De Fraja *et al.* (2021).

<sup>9</sup>This reflects the fact that we only have rental data going back to 2017.

Figure 1: Distance to central London and property prices, 2019 versus 2021



(a) Residential property sales.

(b) Residential property rentals.

Notes: This figure plots a binscatter of the regression of log-prices on distance to central London for the Greater London in 2019 and 2021/22. Control variables include Bartick instrument (for city and neighborhood), city growth in productivity, average neighborhood income (2019), and dummy variables for deciles of deprivation and city fixed effects.

Table 2: Distance to central London and property prices, placebo years

	Sales			Rental
	2017 vs. 2019 (1)	2016 vs. 2018 (2)	2015 vs. 2017 (3)	2017 vs. 2019 (4)
Distance to center	-0.447*** (0.066)	-0.441*** (0.057)	-0.427*** (0.050)	-0.327*** (0.031)
Year	-0.043 (0.062)	0.005 (0.040)	0.174*** (0.056)	0.205*** (0.033)
Year $\times$ Distance	-0.008 (0.038)	-0.005 (0.024)	-0.025 (0.035)	-0.054** (0.021)
$N$	252,761	267,025	284,837	933,913
$R^2$	0.382	0.392	0.422	0.376

Notes: Outcome is log-price; columns 1–3 reflect residential property sale prices and column 4 reflects residential property rental prices. Year corresponds to a dummy variable equal to 1 for the latest year listed in each column, and 0 otherwise. All regression include controls as specified in columns 3 and 6 of Table 1. \*, \*\*, and \*\*\* denote statistical significance at 10%, 5% and 1%.

Taken together, we interpret these results as providing strong evidence of a flattening of the price-distance gradient for the Greater London area. This complements evidence of a flattening of the price-distance gradient been found for cities in the US (Gupta *et al.*, 2022; Brueckner *et al.*, 2021), and points to a structural change in our cities that has taken place since the 2020 pandemic.

### 2.3 Recent change in how(where) work is done

The pandemic has led to a dramatic increase in the amount of work done from home in many countries. In the UK, data from a number of surveys is consistent with the change in working from home being permanent. In an analysis of UK Labour Force Survey data, we find that the proportion of employees who state that they *normally work from home in their main job* not only increased dramatically in 2020, but has further increased since mid-2021 (we provide an example in appendix Figure A.1). This likely reflects a changes to formal working arrangements between employer and employees. Further, we see that these changes are much larger for employees in skilled occupations. In 2022, between 32% and 35% of skilled workers report primarily working from home, compared to about 6% in 2019. In contrast, in 2022 unskilled workers report a work from home share below 16% for occupations not in local consumer services (LCS) and just over 5% for LCS occupations.

The Labour Force Survey data are in line with survey evidence on increases in working from home since 2019. Using information from the Work From Home Survey, De Fraja *et al.* (2022) find that workers in business and finance plan to do 39.7 percentage points more of their work from home relative to pre-pandemic. In contrast, those working in food preparation and service occupations only plan to do 3.42 percentage points more of their work from home relative to pre-pandemic. In a 2022 survey of employers, an average of 29.7% of work was done in using a hybrid or a work from home model, with proportions as high as 67.4% in professional, scientific and technical industries and 81.2% in information and communication, compared to 6.3% in accommodation and food services.<sup>10</sup>

In what follows we develop a model which links these observed changes in how (and where) work is done in urban centers and the cost of housing.

## 3 Model set up

We consider a linear city  $X$  with a dimensionless central business district (CBD) located at  $0 \in X$ , and denote by  $x \in X$  a location and its distance to the CBD. The land density at each location is one and the opportunity cost of land is zero. There are three primary goods: land, skilled labor ( $s$ ) and unskilled labor ( $\ell$ ). The mass of  $k$ -workers is given by  $L_k$  for  $k = \ell, s$  with  $L_\ell > L_s$ . Each  $k$ -worker supplies inelastically one unit of her type of labor. Both types of workers consume one unit of housing (land) and work at the CBD.

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<sup>10</sup>Information taken from the *Business insights and impact on the UK economy* survey, wage 59.

The economy is formed by two sectors. The first sector produces a costlessly tradable consumption good ( $c$ ), which is chosen as the numéraire. The second sector supplies local consumption services (LCS), which are non-tradable, and include restaurants, bars and other leisure facilities, as well as personal services consumed near the workplace.

We make the standard fixed-lot size assumption, that is, each worker uses  $l = 1$  unit of land for housing and pays the land  $R(x)$  when she resides at  $x \in X$ .<sup>11</sup> Hence, the city size is given by  $L_s + L_\ell$ . In line with standard urban economics, we assume absentee landowners.

### 3.1 Working and commuting

Skilled workers split their working time between home,  $\rho \in [0, 1]$ , and office,  $1 - \rho$ . In contrast, we assume that unskilled work is not teleworkable, so the unskilled workers work entirely in the CBD.

Commuting costs are linear in the distance  $x$  to the CBD. Let  $w_k$  be the wage paid to a  $k$ -worker ( $k = \ell, s$ ). Following the well documented positive correlation between commuting costs and labor incomes (Koster and Koster, 2015; Su, 2022), we make the reasonable assumption that commuting costs are proportional to wages. Denoting a worker's unit commuting cost by  $\xi \in (0, 1)$ , the cost per-commute of a  $k$ -worker located at  $x$  is equal to  $\xi w_k x$  for  $k = \ell, s$ . Workers pay the commuting cost when they work from the office, but not when they work from home. Therefore, the unskilled worker located at  $x$  pays  $\xi w_\ell x$  for commuting, while the skilled worker located at  $x$  pays  $(1 - \rho)\xi w_s x$

### 3.2 Consumption

Although it is reasonable to expect some establishments providing LCS will drift from the CBD to the suburbs when the WFH share rises, we believe that a substantial proportion of such services will no longer be provided. Indeed, consumers who are located in sparsely populated areas have to travel to the establishments that provide LCS. As a result, these establishments will have access to significantly smaller markets than when they are located in the CBD. This in turn should deter entry. We therefore assume that LCS are supplied and consumed at the CBD only.

When working at the office, skilled workers spend a fixed share,  $\delta$ , of their income on LCS provided at the CBD. A skilled worker spends  $(1 - \rho)\delta w_s$  on LCS and consumes

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<sup>11</sup>This simplifying assumption is easily relaxed. We provide a detailed discussion in Section 5.3.

$\eta \equiv (1 - \rho)\delta w_s/p$  units, where  $p$  the price of a unit of LCS. Total LCS consumption in the CBD is given by  $\eta L_s$ . Therefore, the supply of urban amenities is endogenously determined through the number of skilled working at the CBD, but also through their wage. We may consider  $\eta$  as an index of the cultural and social vibrance associated with the gentrification of city centers (Couture and Handbury, 2020; Diamond and Gaubert, 2022).

Each skilled worker consumes  $c_s$  units of the numéraire final good and realizes preferences of  $U(c_s, \eta)$ . Therefore, given the work arrangement  $\rho$ , skilled worker's program may then be written as follows:

$$\max_x U(c_s, \eta), \quad \text{s.t. } w_s = c_s + p\eta + R(x) + (1 - \rho)\xi w_s x,$$

while the program of an unskilled worker is given by

$$\max_x U = c_\ell, \quad \text{s.t. } w_\ell = c_\ell + R(x) + \xi w_\ell x,$$

where  $R(x)$  the land rent at  $x$ .

### 3.3 Production

**Local consumer services.** LCS are produced under constant returns and perfect competition, using unskilled labor. We scale the production output such that one unit of unskilled labor is required to produce one unit of LCS, so that  $p = w_\ell$ . Assuming that the unskilled workers are perfectly mobile between the LCS sector and the consumption sector, they are paid the same wage  $w_\ell$  in the two sectors.

For any given  $\rho$ , LCS market clearing requires that  $\eta L_s$  unskilled workers are employed in the LCS sector while

$$\lambda = L_\ell - \eta L_s \tag{2}$$

unskilled are hired by the final sector.

**Final consumption good.** In line with the monocentric city model, the final sector is located at the CBD. It operates under constant returns to scale and perfect competition, using skilled and unskilled labor as production inputs. The skilled workers allocate proportion  $\rho$  of work from home and proportion  $1 - \rho$  of their work in the CBD. We will



remain as general as possible about the productivity effects of WFH; combining  $\rho$  units of home labor and  $1 - \rho$  units of office labor translates into  $A(\rho)$  efficiency units of skilled labor, where  $A(\rho)$  is strictly positive and continuous over the interval  $[0, 1]$ . This function may be interpreted as the total factor productivity of a skilled worker under the labor arrangement  $\rho$ . Since the skilled workers are homogeneous, it is reasonable to assume that, when the WFH share is  $\rho$ , the total mass of skilled workers produces  $A(\rho)L_s$  efficiency units of skilled labor. Therefore, for a given WFH arrangement  $\rho \in [0, 1]$ , the production function of the final sector is given by  $F(L_s, \lambda) = (A(\rho)L_s)^\beta \lambda^{1-\beta}$ .

Using (2), we obtain

$$F(L_s, \lambda) = (A(\rho)L_s)^\beta (L_\ell - \eta L_s)^{1-\beta}. \quad (3)$$

There are currently no clear conclusions on how WFH affects workers' productivity, and therefore the specific functional form of  $A(\rho)$ . Following the pioneering work of Bloom *et al.* (2015), the economics literature leans towards the existence of positive productivity effects of WFH because it allows workers to save time on commute and to better organize their various business and home tasks. Yet, Morikawa (2020) finds that the productivity during the June 2020 lock-down was about 60 to 70% of what it was at the workplace in 2017. The productivity effects of WFH likely depend on the individual characteristics of teleworkers, as well as on the specificities of occupations and industries (Adams-Prassl *et al.*, 2020; Bartik *et al.*, 2020). That said, we make the following assumption, imposing a non-monotonic structure on  $A(\rho)$ .

**Assumption A.**  $A(\rho)$  is single-peaked over  $[0, 1]$  and maximized at  $\rho_A \in (0, 1)$ .

If  $A(\rho)$  increases at  $\rho = 0$ , perhaps because the teleworkers spend more time on working, it is reasonable to suppose that  $A(\rho)$  increases over some interval  $[0, \rho_A]$  with  $\rho_A < 1$ . Indeed,  $\rho_A = 1$  is inconsistent with the fact that the WFH share was very low prior to the COVID-19. When  $\rho$  exceeds  $\rho_A$ , the advantages associated with telework are depleted. Hence, the deficiencies of telework start dominating so that it is reasonable to assume that  $A(\rho)$  decreases over  $(\rho_A, 1]$ . By contrast, if  $A(\rho)$  decreases at  $\rho = 0$ , this is likely because home working is a poor alternative to office working, which therefore suggests that  $A(\rho)$  is decreasing over the whole interval  $[0, 1]$ . In this case, we fall back on the standard setting in which the skilled work full-time at the CBD. The latter does not

seem plausible as empirical evidence shows that even before the pandemic the WFH share significantly differs from zero (see Introduction). Hence, Assumption A seems reasonable.

In this paper, WFH shares are treated as exogenous. This is informative for considering how changes in the WFH share shape the wage and city structures. We expect the share to be chosen endogenously through agents' decisions, but do not know (yet) whether this share will be determined by firms or workers, or through negotiations between employers and employees (*Bloomberg*, 6/12/2021). In Section 5.4, we complement our analysis with a numerical analysis of the WFH share chosen by the skilled workers in the one-city case. This value depends crucially on the marginal rate of substitution between consumption of the final good and the LCS good, which must be given up when they work from home. When the two goods are poor (good) substitutes, skilled workers in a gentrified city such as London choose a WFH share that is relatively low (high).

## 4 The equilibrium conditions and preliminary results

In this section we work through the basic results which are independent of worker location.

In equilibrium, wages in the final goods sector, for each of skilled and unskilled workers, are equal to the marginal product of the workers. Using equation (3),  $\beta F(L_s, \lambda) = w_s L_s$  and  $(1 - \beta)F(L_s, \lambda) = w_\ell \lambda$ , we obtain the following system of two equations for the skilled and unskilled wages:

$$w_s = \beta A^\beta (\rho) (\mathbf{L} - \eta)^{1-\beta}, \quad w_\ell = \frac{1 - \beta}{\beta} \frac{1}{\mathbf{L} - \eta} w_s, \quad (4)$$

where  $\mathbf{L} \equiv L_\ell/L_s$  is the city's skill ratio. Using (4), the wage ratio is  $w_s/w_\ell = \beta(\mathbf{L} - \eta)/(1 - \beta)$ . Combining it with  $\eta = (1 - \rho)\delta w_s/w_\ell$ , we obtain

$$\eta = \frac{(1 - \rho)\beta\delta}{1 - \beta + (1 - \rho)\beta\delta} \mathbf{L} > 0, \quad \frac{w_s}{w_\ell} = \frac{\beta}{1 - \beta + (1 - \rho)\beta\delta} \mathbf{L}. \quad (5)$$

Equation (5) shows that  $\eta$  decreases with  $\rho$ . Thus, *increasing the WFH share leads to the exit of suppliers of LCS* (De Fraja *et al.*, 2021). Note also that the individual consumption  $\eta$  increases with the ratio  $\mathbf{L}$  because the price  $w_\ell$  of LCS decreases;  $\eta$  also increases with  $\beta$  because the skilled wage rises while the price of LCS decreases.

Furthermore, the wage ratio  $w_s/w_\ell$  increases with  $\rho$  because the concomitant drop in the consumption of LCS implies that the final sector uses more unskilled labor. In other

words, *income inequality between skilled and unskilled workers widens as the WFH share increases*. This result holds regardless of the properties of the function  $A(\rho)$ .

Empirical evidence finds an urban skilled wage premium (Autor, 2019). Consistent with this, we assume that  $w_s/w_\ell > 1$  for all  $\rho$ . Using (5), we obtain the condition for the skilled wage to be higher than the unskilled wage for all  $\rho$ :

$$\mathbf{L} > \frac{1-\beta}{\beta} + \delta, \quad (6)$$

which we assume to hold throughout the paper.

Using (5), wages take the form:

$$w_s = \beta A^\beta(\rho) \left[ \frac{1-\beta}{1-\beta+(1-\rho)\delta\beta} \right]^{1-\beta} \mathbf{L}^{1-\beta}, \quad w_\ell = (1-\beta)^{1-\beta} [(1-\beta+(1-\rho)\delta\beta)A(\rho)]^\beta \mathbf{L}^{-\beta}. \quad (7)$$

Since the bracketed term increases with  $\rho$  and  $A(\rho)$  is single-peaked,  $\rho_s > \rho_A$  exists such that  $w_s$  increases over  $(0, \rho_s)$ . As for  $w_\ell$ , the bracketed term decreases with  $\rho$ ,  $w_\ell$  increases over  $(\rho_\ell, \rho_A)$  where  $\rho_\ell < \rho_A$ . In what follows, we assume that  $A(\rho)$  is such that  $w_s$  and  $w_\ell$  decrease, respectively over  $(\rho_s, 1)$  and  $(\rho_\ell, 1)$ .

Summarizing yields the following proposition.

**Proposition 1.** *For any given city structure, a higher WFH share exacerbates wage inequality between the skilled and the unskilled. Furthermore, under Assumption A the skilled and unskilled wages are bell-shaped in the WFH share.*

In other words, telecommuting has implications for economic inequality on top of its effects on wages, an aspect that is often absent from the debate about its costs and benefits.

## Numerical analysis

Here we conduct a numerical analysis to gain insights about the values of the thresholds  $\rho_s > \rho_\ell$  under specification of  $A(\rho)$ , and empirically plausible parameter values. We set  $\beta = 0.4$ , meaning a skilled labor share of 40% in the final sector production.

We assume that the share  $\delta$  varies between 0.05 and 0.15. This corresponds to the evidence from empirical studies; De Fraja *et al.* (2021) find that in 2019 the average UK worker earned £29,570 and spent £1467 (£28.22 per week) on LCS near their work. This implies that the average worker spends approximately 5% of her total employment income

on LCS in the CBD. Similar calculations from Barrero *et al.* (2021) for US workers in 2019, find the average worker earned \$63,100 and spent \$7,904 on LCS near their work. This implies that LCS spending is 12.5% of total income. From Barrero *et al.* (2021) we can also calculate LCS spending proportions by percentiles of the income distribution. A worker at the 25th percentile earns \$35,000 and spends \$1,820 on LCS, or 5.2% of total income. A worker in the 75th percentile earns \$75,000 and spends \$10,400 on LCS, or 13.9% of total income.

In choosing a functional form for  $A(\rho)$ , we follow Davis *et al.* (2021) and assume that  $A(\rho)$  is given by a CES function:

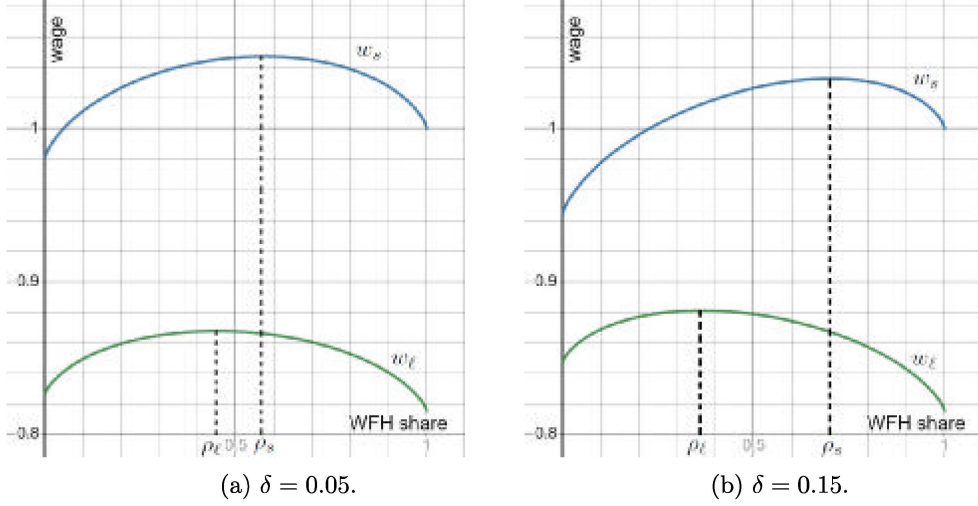
$$A(\rho) = \left[ \phi \rho^{\frac{\sigma-1}{\sigma}} + (1-\rho)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \quad (8)$$

where  $\sigma > 1$  is the elasticity of substitution between home and office labor while the parameter  $\phi > 0$  measures the efficiency of ICT relative to the efficiency of face-to-face communication within firms. More efficient ICT ( $\phi \uparrow$ ) shifts the function  $A(\rho)$  upward and increases  $\rho_A$ . Under (8),  $A(\rho)$  is strictly concave while both  $A(0)$  and  $A(1)$  are positive.

We impose that  $\phi$  is smaller than 1, suggesting that WFH is less productive than office work. This is consistent with evidence that, although home workers devote more time to work than office workers (Bloom *et al.*, 2015; Barrero *et al.*, 2021), exchanges via Internet are less efficient than face-to-face communication (De la Roca and Puga, 2017; Battiston *et al.*, 2021). Likewise, a study on the spatial organization of MIT demonstrates “the significant role that spatial proximity still plays in collaborative knowledge creation process *despite the abundance of tools for digital communication and virtual collaboration*” (Claudel *et al.*, 2017, p.2, our emphasis). It is, therefore, not surprising that Davis *et al.* (2021) find that ICT are not (yet) very efficient.

Using the above parametric values, we can find the values of  $\rho$  which maximise the wage equations in (7), yielding the threshold values  $\rho_A$ ,  $\rho_s$ , and  $\rho_\ell$ . Of course, this will depend on the productivity of WFH,  $\phi$ . Since  $\phi < 1$  and  $\rho_A$  increases with  $\phi$ , by setting  $\phi = 1$  we find the upper bound for  $\rho_A$ , which is equal to 0.5. Likewise, both  $\rho_s$  and  $\rho_\ell$  increase with  $\phi$ . Therefore, using  $\phi = 1$  also provides us with their upper bounds. Using the above numbers show that the unskilled wage increases up to  $\rho_\ell = 0.45$  while  $\rho_s = 0.57$  when  $\delta = 0.05$ . As the share  $\delta$  gets larger, the peak for the unskilled wage  $\rho_\ell$  shifts to the left while the skilled wage increases for a wider range of WFH shares. For instance,

Figure 2: Wages and WFH shares



Notes: In these figures we plot wages for skilled and unskilled workers across the WFH share,  $\rho$ . The figure to the left is plotted for  $\delta = 0.05$ , the figure to the right is plotted for  $\delta = 0.15$ . Wage maximums are shown at  $\rho_s$  for skilled workers and  $\rho_\ell$  for unskilled workers.

when  $\delta = 0.15$ , we find  $\rho_\ell = 0.36$  while  $\rho_s = 0.70$ . We provide a visual reference for this in Figure 2.

## 5 The city structure

We now turn our attention to the workers' decision of where to live in the city. A *spatial equilibrium* is defined by a distribution of workers over the interval  $[0, L_s + L_\ell]$  and a consumption pair  $(c_s, c_\ell)$  such that no worker can be made better off by changing location and markets clear.

The bid rent of a skilled worker at  $x \in X$  is defined by  $\Psi_s(x) = w_s - c_s - w_\ell \eta - (1 - \rho)\xi w_s x$ , while the bid rent function of an unskilled is given by  $\Psi_\ell(x) = w_\ell - c_\ell - \xi w_\ell x$ ; notice they are both linear in  $x$ . As the two bid rent curves must intersect for the two groups of workers to live in the city, the skilled workers secure the locations over which  $\Psi_s$  is steeper than  $\Psi_\ell$ . Comparing the slopes of two bid rent functions shows that the skilled outbid the unskilled over the area  $(0, L_s)$  if

$$\left| \frac{\partial \Psi_s(x, U_s)}{\partial x} \right|_{x=L_s} > \left| \frac{\partial \Psi_\ell(x, U_\ell)}{\partial x} \right|_{x=L_s} \Leftrightarrow \frac{w_s}{w_\ell} > \frac{1}{1 - \rho} \geq 1, \quad (9)$$

where the equality holds if and only if  $\rho = 0$ . On the other hand, the unskilled set up near

the CBD in the area  $(0, L_\ell)$  if  $w_s/w_\ell < 1/(1 - \rho)$ . Thus, either of two urban structures may emerge as an equilibrium (Fujita, 1989). We say that the city is *gentrified* when the skilled workers choose to set up in the vicinity of the CBD. Otherwise, we have a *doughnut* city in which the city's central area is occupied by the unskilled. Since  $1/(1 - \rho)$  increases with  $\rho$ , a higher WFH share may shift the city from the former to the latter.

Plugging (5) into (9) shows that the city is gentrified if and only if

$$\rho < \bar{\rho} \equiv 1 - \frac{1 - \beta}{\beta(\mathbf{L} - \delta)}. \quad (10)$$

From the assumption that (6) holds, it follows that  $\bar{\rho}$  belongs to interval  $(0, 1)$ . Consequently, *the city is gentrified if and only if the WFH share is not too high.*

We will discuss in Section 5.3 the robustness of the city structure when several of our main assumptions are relaxed.

## Numerical analysis

We again rely on a numerical analysis to gain insights about the relationship between  $\bar{\rho}$  and the thresholds  $\rho_s > \rho_\ell$ . In particular, do the skilled/unskilled wages start decreasing with  $\rho$  before or after the city switches from a gentrified to a doughnut structure? For  $\mathbf{L} = 3$ , which corresponds to a share of college educated workers equal to 25% of the population, and a LCS share  $\delta = 0.05$ , we obtain  $\bar{\rho} = 0.49$  while  $\rho_\ell = 0.45$  and  $\rho_s = 0.57$ . Since  $\rho_\ell < \bar{\rho} < \rho_s$ , in a gentrified city the skilled wage always increases while the unskilled wage first increases and, then decreases with  $\rho$ . In this case, the skilled wage keeps rising until  $\rho_s$  even when the periphery is inhabited by the skilled ( $\rho > \bar{\rho}$ ).

For a smaller skill share,  $\mathbf{L} = 4$ , we obtain  $\bar{\rho} = 0.62$ , which is now larger than the upper-bound of  $\rho_s$ . For  $\delta = 0.15$ ,  $\bar{\rho}$  slightly falls to 0.61, which is now lower than  $\rho_s = 0.70$ . We may then conclude that *unskilled wage starts decreasing with the WFH share when the city is gentrified.* Regarding the skilled wage, depending on the parameter values, it may increase for any  $\rho < \bar{\rho}$  but it may also start decreasing when the city is gentrified.

### 5.1 The gentrified city

Each worker realizes an urban cost, equal to the sum of the land rent paid and commuting costs: for unskilled  $UC_\ell = R_\ell(x) + \xi w_\ell x$ ; for skilled  $UC_s = R_s(x) + (1 - \rho)\xi w_s x$ . We start by considering these costs in the outer-city suburbs,  $x \in (L_s, L_s + L_\ell]$ . Because the

opportunity cost of land is zero, land rent at the limit is  $R(L_s + L_\ell) = 0$ . Therefore, when the city is gentrified, the worker at the city limit is an unskilled who bears the urban cost  $UC_\ell = \xi w_\ell(L_s + L_\ell)$ . Since the spatial equilibrium requires that all the unskilled reach the same utility level at the spatial equilibrium, it must be the case that  $c_\ell$  is the same for all  $x \in (L_s, L_s + L_\ell]$ . Therefore,  $R_\ell(x) = \xi w_\ell(L_s + L_\ell - x)$  for  $\forall x \in (L_s, L_s + L_\ell]$ . Since  $R_\ell(x)$  is linear and downward-sloping in  $x$ , at a rate of  $\xi w_\ell$ , Proposition 1 implies that *for  $\rho < \rho_\ell$  an increase in telecommuting leads to an increase in the unskilled spending on housing* because they earn more. For  $\rho \in [\rho_\ell, \bar{\rho})$ , unskilled spend less on housing with larger WFH share. By the same argument, unskilled commuting costs,  $\xi w_\ell x$ , and urban costs,  $UC_\ell$ , increase with WFH share for  $\rho \in (0, \rho_\ell)$  and decrease for  $\rho \in [\rho_\ell, \bar{\rho})$ .

We now turn our attention to urban costs for the skilled located at  $x \in (0, L_s]$ . Notice that at  $x = L_s$ , the spatial equilibrium requires that  $R_\ell(L_s) = R_s(L_s) = \xi w_\ell L_\ell$ . Further, equilibrium requires that the skilled workers receive the same utility at all locations. This implies that  $c_s$  be invariant to location, so the skilled have the same level of urban costs independently of their location  $x \in [0, L_s]$ :

$$UC_s(x) = \xi w_\ell L_\ell + (1 - \rho)\xi w_s L_s \equiv UC_s. \quad (11)$$

As skilled urban costs behavior involves a complex mix of wages and direct WFH effect, we use our preferable parameter values to show that  $UC_s$  decreases for  $\rho > 0.035$ , considerably smaller than those observed prior to 2020 in the US and the UK (Barrero *et al.*, 2021; De Fraja *et al.*, 2022). We use (11) to solve for the equilibrium land rent over  $[0, L_s]$ , given by  $R_s(x) = \xi w_\ell L_\ell + (1 - \rho)\xi w_s(L_s - x)$ . Clearly, skilled land rent increases at the locations close to geographical boarder between skilled and unskilled,  $x = L_s$ , for  $\rho < \rho_\ell$ , and decreases otherwise. Land rent, however, decreases in the locations close to the CBD,  $x = 0$ , as shown by our simulations.

In a gentrified city, the skilled land gradient is equal to  $-(1 - \rho)\xi w_s$  while the unskilled land gradient is  $-\xi w_\ell$ . As  $(1 - \rho)w_s > w_\ell$ , the land rent is steeper over  $[0, L_s]$  than over  $(L_s, L_s + L_\ell]$ . This is because the WFH share is still low enough for the skilled commuting costs to be higher than the unskilled commuting costs. Hence, the land rent is convex and has an outward kink at  $x = L_s$ . Furthermore, we use the parameterized numerical analysis above and find that skilled land gradient increase only for  $\rho < 0.01$ , which is below reported pre-pandemic levels of WFH shares. This result is robust to reasonable

variations in the parameter values. We can conclude that the direct effect of WFH—fewer commuting trips—dominates the indirect effect generated by a hike in the skilled wage. Thus, since the skilled land gradient decreases with  $\rho$  while the unskilled land gradient increases for  $\rho < \rho_\ell$ , the land gradient gets flatter over the whole gentrified city. These findings concur with our empirical results for London in Section 2. For  $\rho > \rho_\ell$ , both skilled and unskilled land gradients decrease. As skilled commuting costs are given by  $(1 - \rho)\xi w_s x$ , it follows the same pattern as skilled land rent gradient.

The next proposition provides a summary.

**Proposition 2.** *If  $\rho < \bar{\rho}$ , then the city is gentrified. In a gentrified city, the urban and commuting costs, as well as housing expenditure of the unskilled are increasing in WFH for low values and decreasing when WFH goes beyond some threshold. By contrast, urban and commuting costs of skilled decrease with the WFH while the housing expenditure of the skilled increases only for small values of WFH at locations further from CBD.*

It is noteworthy that a higher/lower housing expenditure is not caused here by a larger/smaller land consumption or by a social reorganization of the city. It is due to the interplay between the WFH share, wages and commuting costs. This is to be contrasted with the case of having income-independent commuting costs because the land rent always becomes flatter when  $\rho$  rises. The same holds when wages are not (yet) adjusted to a substantial hike in the WFH share, like during the COVID lockdowns.

## 5.2 The doughnut city

If the WFH share is sufficiently large,  $\rho > \bar{\rho}$ , there is a reversal in the city's social structure: the skilled choose to reside in the city periphery while the unskilled live in the central area. Due to home working, the proximity to the CBD ceases to be a concern to the skilled who choose instead to consume more of the final good by residing in the periphery,  $x \in (L_\ell, L_\ell + L_s]$ , where land rents are cheaper.

As before land rent is zero at the city limit,  $R_s(L_s + L_\ell) = 0$  and the spatial equilibrium requires that the skilled urban costs are constant over  $x \in (L_\ell, L_\ell + L_s]$ . Therefore, skilled urban costs must be equal to costs at the periphery:

$$UC_s(x) = R_s(x) + (1 - \rho)\xi w_s x = (1 - \rho)\xi w_s (L_s + L_\ell) \equiv UC_s.$$



Land rents must vary to exactly offset reduced commuting expenses as we move towards the CBD, therefore  $R_s(x) = (1 - \rho)\xi w_s(L_s + L_\ell - x)$ . Thus, in the doughnut city, urban costs, commuting costs and land rents decrease for the suburban skilled workers over  $\rho \in (\rho_s, 1]$ . Moreover, given our preferred parameters values, they also decrease over  $\rho \in [\bar{\rho}, \rho_s)$ . Further, the land rent gradient for the outer city,  $-(1 - \rho)\xi w_s$ , becomes flatter because less commuting means that skilled workers place less value on proximity to the CBD. The skilled land gradient,  $-(1 - \rho)\xi w_s$ , is always flatter than the unskilled land gradient,  $-\xi w_\ell$ . Hence, like in a gentrified city, (i) the land rent is convex and has an outward kink at the border between the two groups of workers, and (ii) the land gradient is flattening over the whole city. This again matches our empirical findings in Section 2.

The land rent at the boundary between the skilled and unskilled areas is such that,  $R_\ell(L_\ell) = R_s(L_\ell) = (1 - \rho)\xi w_s L_s$ , so that urban costs of the unskilled located in the central area are given by

$$UC_\ell(x) = R_\ell(x) + \xi w_\ell x = \xi w_\ell L_\ell + (1 - \rho)\xi w_s L_s = UC_\ell,$$

which are common for all unskilled workers in the central area  $[0, L_\ell)$ . It therefore follows that the land rent across the central area in the doughnut city is given by  $R_\ell(x) = (1 - \rho)\xi w_s L_s + \xi w_\ell(L_\ell - x)$ . Thus, unskilled land rents, commuting costs, and urban costs are always decreasing in the WFH share. This is in contrast to the gentrified city, where the unskilled land rents and commuting costs increase in the WFH share for  $\rho < \rho_\ell$ . In other words, the land market may respond differently to an increase in the WFH share in a gentrified or doughnut city.

We compare the average expenditure on housing for the skilled and unskilled workers in the doughnut city versus the gentrified city. To get a better sense of the land expenditure difference, we resort to numerical simulations using our preferred parameter values. First, average skilled land rent is significantly lower in a doughnut city compared to gentrified city as they move to the outskirts of the city. Contrast to that, skilled commuting costs are larger in the doughnut city because longer distance effect dominates drop in the frequency of trips. However, skilled urban costs are lower in the doughnut city as an increase in commuting costs is more than compensated by the drop in the land rent.

Second, we find that *the average urban costs for the unskilled are lower, but the average land rent paid is higher in a doughnut city compared to a gentrified city*. This is plausible;

unskilled workers, who commute daily, are now closer to the CBD. This allows them to significantly save on commuting costs, and the drop in commuting costs exceeds the hike in land rent. In other words, *the housing benefits associated with telecommuting always arise for the skilled, but this need not be so for the unskilled*. In this way telecommuting affects the unskilled through a variety of channels.

We summarize our findings for the doughnut city in the following proposition:

**Proposition 3.** *If  $\rho > \bar{\rho}$ , then the central urban area is inhabited by the unskilled while the skilled move to the city periphery. As the WFH share increases, urban costs decrease for both skilled and unskilled workers. Furthermore, the average housing expenditure by the skilled is lower in a doughnut city than that in a gentrified city while the opposite holds for the unskilled.*

We close the analysis of the monocentric city by looking at the behavior of the land rent-distance gradient across each of our city structures. The average land rent gradient, corresponding to the empirical point estimates reported in Table 1, is given by:

$$\Delta R(x) = -(1 - \rho)\xi w_s \frac{L_s}{L_s + L_\ell} - \xi w_\ell \frac{L_\ell}{L_s + L_\ell}.$$

In the doughnut city the land rent-distance gradient is always becoming flatter as  $\rho$  increases. In the gentrified city, the land rent-distance gradient may increase with  $\rho$  when the WFH share is sufficiently low, driven by an increase in unskilled commuting costs. Using our preferred simulation specification, we find that the urban rent gradient for the gentrified city is flattening with  $\rho$  for values of  $\rho > 0.035$ , below reported pre-pandemic levels. This fits with our empirical results, reported in Section 2, showing a flattening of the distance gradient.

### 5.3 Robustness of the gentrified city

We can use the model to identify different ways through which a gentrified city will be more or less robust to changes in the WFH share. By robust we mean when does a city change from being gentrified to being a doughnut city, the value of  $\bar{\rho}$ .

First, higher values of  $\beta$  make the city more robust to changes in the WFH share. Raising  $\beta$  shifts upward the right-hand side of (10), which leads to an increase in  $\bar{\rho}$ . Indeed, as shown by (7), a higher  $\beta$  widens the wage gap, which makes it easier for the

skilled to outbid the unskilled.

Second, for the same reason,  $\bar{\rho}$  increases with  $\mathbf{L}$ . While both  $1/\mathbf{L}$  and  $\beta$  can be used to assess the degree of skillfulness of a city, they have the opposite impact on the city structure. On the one hand, the skilled share  $\beta$  in the final sector raises  $\bar{\rho}$ , which renders the gentrified city more robust to changes in telework by widening the range of WFH shares that sustain a gentrified city. On the other, a higher share of skilled in the city shrinks the interval over which a gentrified city is an equilibrium, which makes the gentrified city more fragile to changes in WFH. The intuition for this result is as follows. A higher share of skilled makes unskilled labor a relatively scarce resource. This drives upward the unskilled wage and diminishes wage gap for any WFH share. This allows unskilled to outbid skilled near CBD for smaller values of WFH share.

Third, (10) shows that  $\bar{\rho}$  decreases with the spending share  $\delta$  on LCS. Put differently, cities with a more vibrant night life (higher  $\delta$ ) are less sustainable to WFH shocks. The intuition is very similar to the one above. Since a higher  $\delta$  means that more unskilled are employed in the LCS sector, unskilled labor is a relatively scarce resource in the final sector. The latter again leads to a lower wage gap.

Therefore, for any WFH share, the wage gap between the two groups gets narrower for a higher  $\delta$ , as shown by (7). Since commuting costs are proportional to wages, the lower wage gap allows the unskilled to outbid the skilled in the central area for lower values of the WFH share. Hence, even a vibrant downtown office district in which highways and parking lots have replaced residents and retail is likely to be *less robust to an expansion in home-working*.

For analytical simplicity, we have made several simplifying assumptions. In what follows, we relax one by one each of the main assumptions and determine how they affect the value of  $\bar{\rho}$ .

**Agglomeration economies.** It is well documented that the productivity of on-site skilled workers increases with the employment density (Duranton and Puga, 2020). Here, this means that the function  $A(\rho)$  may be extended to take into account agglomeration economies. Let  $a[(1 - \rho)L_s]$  be the agglomeration economy factor generated by  $(1 - \rho)L_s$  skilled workers at the office; the function  $a(\cdot)$  is strictly increasing and concave. For example, if  $\mathbb{A}$  is homogenous of degree  $r > 0$ , combining all the labor units of the skilled workers translates into  $\mathbb{A}(\rho) = a^r[(1 - \rho)L_s]A(\rho)L$  efficiency units of skilled

labor. Since the function  $a^r[(1-\rho)L_s]$  decreases with  $\rho$ , the presence of agglomeration economies weakens the impact of the WFH share at  $\hat{\rho}$  when  $A(\rho)$  is increasing at  $\hat{\rho}$  while it amplifies its impact when this function is decreasing at  $\hat{\rho}$ . Hence, accounting for agglomeration economies has an unambiguous effect on the total factor productivity of the skilled labor force. Although our model suffices to show that *the presence of agglomeration economies slows down the dispersion of skilled workers*, it would be interesting to study how different types of agglomeration economies may affect the city structure when they are combined with telecommuting. For example, location-dependent knowledge spillovers or the sharing of local public goods such as transit are likely to interact in different ways with telecommuting.

**Teleworkers need more home-space.** Following a well-established tradition in applied urban economics, we have assumed that workers consume a fixed lot size. This clashes with Stanton and Tiwari (2021) who find that prior to the pandemic, wired workers spend 7% more on housing than similar non-remote households in the same commuting zone. Our model can easily be extended for the teleworkers to acquire  $h < 1$  additional units of land. In a gentrified city, the new boundary between the skilled and the unskilled is now given  $y(L_s) > L_s$ . Hence, the commuting cost of the skilled at  $y$  is equal to  $(1-\rho)\xi w_s y$  while she spends  $hR(y) > 0$  to increase her home-space. Since  $R(y) = \Psi_s(y)$ , the bid rent function of the skilled worker at  $y$  becomes  $\Psi_s(y) = [w_s - c_s - \eta w_s - (1-\rho)\xi w_s y]/(1+h)$ . Recomputing (9), we obtain

$$\bar{\rho}_h = 1 - \frac{1-\beta}{\beta \left( \frac{L}{1+h} - \delta \right)} < \bar{\rho}.$$

In other words, *as teleworkers need more space to work home, a gentrified city becomes more vulnerable*, the reason being that the additional cost of  $hR(y)$  for housing makes the skilled less willing to outbid the unskilled, and more likely to move to the city periphery.

At the other extreme of the spectrum, we consider a dimensionless CBD while telecommuters allow firms to use less office space, thus reducing real-estate costs which are high in cities where land and housing are very expensive. When land is an additional input of the final sector, we expect the land rent to decrease when the WFH share rises and more firms established in secondary urban centers to be attracted by the CBD (Delventhal *et al.*, 2021).

**The attractiveness of the city center.** If the city center is endowed with various types of amenities, there are reasons for visitors to spend time and money there during non-working periods, which shifts upward the demand for LCS (Couture and Handbury, 2020). In this case, as shown in Appendix B, a higher non-working-day spending raises the value of the threshold  $\bar{\rho}$  because the skilled commute more to the CBD. Thus, cities whose centers have increasingly come to be more than offices are likely to be more resilient to the expansion of teleworking. It is worth pointing out that a higher skilled spending share on LCS during workdays and non-working days have opposite impacts on  $\bar{\rho}$ . Indeed, visiting the city center during non-working days requires additional commuting, thus raising the value of proximity to the CBD.

#### 5.4 Equilibrium WFH share

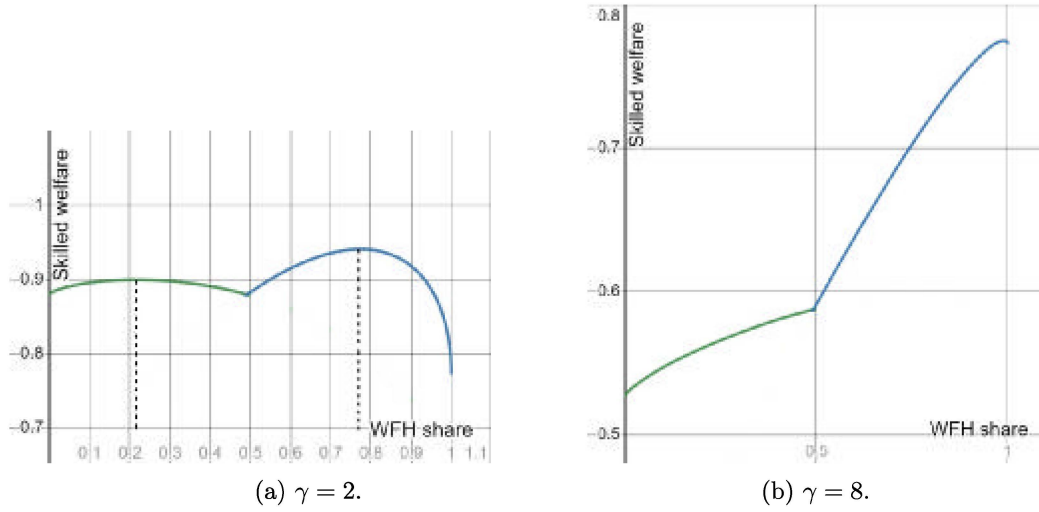
So far, we have treated the WFH share as exogenous. In this section, we determine the share that the skilled would choose if they were free to do so. In other words, the skilled choose  $\rho$  non-cooperatively in order to maximize their utility. Since  $\rho$  affects the consumption of LCS, the solution depends on the marginal rate of substitution between the consumption good and the LCS. To keep things simple, we assume that both goods are combined in CES preferences. Therefore, the skilled choose  $\rho$  to solve the following program

$$\begin{aligned} \max_{\rho} U(c_s, \eta) &= (c_s^{(\gamma-1)/\gamma} + \eta^{(\gamma-1)/\gamma})^{\gamma/(\gamma-1)}, \\ \text{s.t. } w_s &= c_s + (1 - \rho)\delta w_s + UC_s(x), \end{aligned}$$

where  $\gamma > 1$  is the elasticity of substitution between LCS and home consumption. A low value of  $\gamma$  means that home consumption and LCS are poor substitutes.

When WFH increases, we have seen that for  $\rho < \rho_\ell$  both the wage  $w_s$  and the price of LCS increase, while they both decrease when  $\rho > \rho_s$ . Since the price of LCS is equal to the wage  $w_\ell$ , this makes it hard to predict how  $\rho$  affects the skilled welfare. Therefore, we use a numerical analysis to evaluate. It should be clear that the value of  $\gamma$  and  $\delta$  are critical for the equilibrium value of the WFH share because both a low elasticity of substitution between the consumption good and LCS and a high consumption of LCS make the CBD more attractive for reasons that are not related to commuting. We perform a numerical analysis using our preferred set of parameter values and  $\delta = 0.05$  for two polar values of

Figure 3: Skilled welfare across WFH shares



Notes: In these figures we plot welfare, based on the CES utility specified in the main text, for skilled workers across different WFH shares,  $\rho$ . The two figures differ in elasticity of substitution,  $\gamma$ . The figure to the left is plotted for  $\gamma = 2$ , the figure to the right is plotted for  $\gamma = 8$ .

$\gamma$ , i.e.,  $\gamma = 2$  and  $\gamma = 8$ . The results are very contrasted.

First, the welfare levels vary in different ways in a gentrified or doughnut city. Second, the choices made by the skilled vastly differ according to the value of the elasticity of substitution  $\gamma$ . Figure 3a shows the pattern when the two types of consumption are very differentiated ( $\gamma = 2$ ). In a gentrified city, the skilled choose  $\rho = 0.22$  while they choose  $\rho = 0.77$  under a doughnut city. This is intuitively plausible. As LCS and home consumption are bad substitutes, a high WFH share has a strong and negative impact on the well-being derived from consumption. The latter explains a sharp drop in welfare beyond  $\rho = 0.85$ . Nevertheless, they may enjoy some of the WFH benefits by working, say one day per week, something that many university professors do. By contrast, Figure 3b shows that the skilled choose to work home full time because they can easily substitute LCS with home consumption ( $\gamma = 8$ ).

Assuming  $\delta = 0.15$ , we find that the skilled prefer a gentrified city for a wider range of  $\gamma$ . In particular, in contrast to Figure 3b, the skilled reach a higher welfare level in a gentrified city rather than in a doughnut city when  $\gamma = 2$ . Thus, a lively CBD endowed with a wide range of consumption amenities is more likely to retain its gentrified structure than a CBD that hosts predominantly offices.

## 6 Inter-city commuting: From WFH to WFA(nywhere)

In this section we consider an economy with two cities  $i = 1, 2$  which differ only in their total factor productivity. Since urban costs in the more productive city are higher than urban costs in the less productive city, skilled workers of the former city may wish to reside in the latter city. This in turn implies that the mass of skilled workers in a city differs from the mass of skilled residents. Likewise, the gross product of the more (resp., less) productive city may be higher (resp., lower) than the total income of its residents. Our goal is to study how different intensities of WFH affect the internal structure of the two cities, the inter-city commuting pattern, and the wage ratios.

Each city is defined by a one-dimensional space  $X_i$  with a dimensionless CBD located at  $0 \in X_i$ . We denote a location and its distance to the CBD by  $x_i \in X_i$ . The two CBDs are connected by a transportation link that allows people to travel from any center to the other. To focus the analysis on the role of productivity and WFH, we assume that the two cities accommodate the same masses of skilled and unskilled workers,  $L_{s1} = L_{s2} \equiv L_s$  and  $L_{\ell 1} = L_{\ell 2} \equiv L_\ell$ . However, cities differ in their total factor productivity. The production function of the final sector in city  $i$  is given by

$$F_i(L_s, \lambda_i) = \epsilon_i (A(\rho)L_s)^\beta \lambda_i^{1-\beta},$$

where  $\epsilon_i > 0$  is city  $i$ 's TFP. We assume that city 1 is more productive than city 2, i.e.,  $\epsilon_1 > \epsilon_2$ . Consequently, wages are higher in city 1 than in city 2.

We assume that skilled workers are mobile between cities, they can reside in one city and work in another, while the unskilled cannot. Since wages are higher in city 1 than in city 2, absent inter-city commuting, urban costs are also higher in city 1. Thus, skilled workers of city 1 may find it desirable to relocate in city 2 while remaining employed in city 1 (Brueckner *et al.*, 2021). This raises urban costs in city 2 and lowers those in city 1. We call these workers *between-city commuters* who reside in city 2 only. Note that wages are unaffected by the residential shift because the labor pools do not change. The skilled who live and work in the same city are referred to as *within-city commuters*.

In order to pin down the pure effect of teleworking, in the next two sections we focus on the case where cities are such that no skilled wants to change her residence or workplace from one city to the other in the absence of telecommuting. In this case, inter-city commuting (if any) arises because there is telecommuting.

## 6.1 Residential migration to the less productive city

Let  $\alpha \geq 0$  be the share of city 1's skilled workers who choose to reside in city 2, i.e., they live in city 2 and work in city 1. In this case, the masses of skilled workers living in cities 1 and 2 are, respectively, equal to  $(1 - \alpha)L_s$  and  $(1 + \alpha)L_s$ . The commuting cost between the two CBDs is denoted  $\xi_c w_{s1} > 0$ .

As two CBDs are connected by a transportation link (for example a train connecting CBDs), between-city commuters must go to the CBD of city 2 and then go to the CBD of city 1. The between-city commuter who lives at  $x_2$  in city 2 pays the intra-city commuting cost  $(1 - \rho)\xi w_{s1}x_2$  and the between-city commuting cost  $(1 - \rho)\xi_c w_{s1}$ . The skilled who work and reside in city 2 bear a unit commuting cost equal to  $\xi w_{s2}$  while the unskilled have a unit commuting cost equal to  $\xi w_{\ell 2}$ .

Wages in city  $i = 1, 2$  are as follows:

$$w_{si} = \epsilon_i \beta A^\beta (\rho) (\mathbf{L} - \eta)^{1-\beta}, \quad w_{\ell i} = \frac{1 - \beta}{\beta} \frac{w_{si}}{\mathbf{L} - \eta}, \quad (12)$$

where  $\eta$  is defined by (5). Since the labor force in city 1 remains the same, between-city commuting does not affect how this city is organized. That is, the social structure of city 1 (gentrified versus doughnut) is still determined by the condition  $\rho \leq \bar{\rho}$  where  $\bar{\rho}$  is defined by (10).

In contrast, the social organization of city 2 is affected by inter-city commuting. Since  $w_{s1} > w_{s2}$  for all  $\rho \in [0, 1]$ , *between-city commuters always outbid within-city commuters*, so that the former locate closer to the CBD than the latter regardless of the internal structure of city 2. However, the unskilled may set up either at the outskirts of city 2, or between the in-between and within-city commuters or near the CBD. City 2 may then display three different social structures according to the WFH share.

(i) When  $\rho < \bar{\rho}$ , the two cities are gentrified. As the between-city commuters are always closer to the CBD than the within-city commuters, the social structure of city 2 is as follows: the between-city commuters locate in  $[0, \alpha L_s)$ , the within-city commuters in  $(\alpha L_s, (1 + \alpha)L_s)$ , whereas the unskilled set up in the periphery  $((1 + \alpha)L_s, (1 + \alpha)L_s + L_\ell]$ .

(ii) The social structure of cities changes when  $\rho$  is larger than  $\bar{\rho}$ . Indeed, Proposition 3 implies that the unskilled outbid the within-city commuters in both cities, so that the former are now closer to the CBD than the latter in both cities. Furthermore, it follows from (9) that the between-city commuters outbid the unskilled in city 2 if and only if



$w_{s1}/w_{\ell 2} > 1/(1 - \rho)$ . Using (12) and plugging (5), between-city commuters locate next to the CBD if and only if

$$\rho < \hat{\rho} \equiv 1 - \frac{1 - \beta}{\beta} \frac{1}{(\epsilon_1/\epsilon_2)\mathbf{L} - \delta}. \quad (13)$$

Observe that the only difference with (10) is that  $\mathbf{L}$  is multiplied by  $\epsilon_1/\epsilon_2 > 1$ , hence,  $\hat{\rho} > \bar{\rho}$ . When  $\rho \in (\bar{\rho}, \hat{\rho})$ , in city 2, the within-city commuters reside in city periphery, the unskilled locate between within-city and between-city commuters, while the between-city commuters are still next to CBD because the WFH share is not sufficiently high for them to choose remote locations. As raising  $\epsilon_1/\epsilon_2$  increases  $\hat{\rho}$ , a larger productivity gap between cities sustains the coexistence of a less productive gentrified city with a more productive doughnut city for a wider range of WFH shares.

(iii) Last, for  $\rho > \hat{\rho}$ , the two cities have a doughnut structure because the unskilled outbid the between-city commuters who remain closer to city 2's CBD than the local within-city commuters because they have higher wage.

Since the level of urban costs in city 2 varies with its internal structure, we must study separately these three configurations to determine the share of city 1's skilled who choose to live in city 2.

### Small WFH shares ( $0 \leq \rho < \bar{\rho}$ )

We show in Appendix C that between-city commuting arises ( $\alpha > 0$ ) for  $\rho < \bar{\rho}$  if and only if the following inequalities hold:

$$\frac{\epsilon_1 - \epsilon_2}{\epsilon_1} \left( 1 + \delta + \frac{1 - \beta}{\beta} \right) < \frac{\xi_c}{\xi L_s} < \frac{\epsilon_1 - \epsilon_2}{\epsilon_1} (1 + \mathbf{L}), \quad (14)$$

which yields a non-degenerated interval if and only if (6) is satisfied.

The first inequality in (14) holds when the difference in city productivities is small, the between-city commuting is relatively expensive, or both. This implies that no city 1's skilled worker wants to reside in city 2 when there is no telecommuting ( $\rho = 0$ ). The second inequality in (14) holds if the difference in city productivities is not too small, the between-city commuting is not too expensive, or both. In sum, by assuming that (14) holds, we rule out the extreme cases in which city productivities are very similar or very different. Likewise, between-city commuting is assumed to be neither very cheap nor very expensive.

The equilibrium value  $\alpha^*$  is such that the difference between urban costs in the two cities is equal to the cost of traveling between the two city centers, that is,  $UC_{s1} - UC_{c2} = (1 - \rho)\xi_c w_{s1}$ . We show in Appendix C that:

$$\alpha^*(\rho) = \frac{\epsilon_1 - \epsilon_2}{2\epsilon_1} \left( 1 + \delta + \frac{1 - \beta}{\beta} \frac{1}{1 - \rho} \right) - \frac{\xi_c}{2\xi L_s}. \quad (15)$$

Hence, *the share of between-city commuters increases with the WFH share*. As expected, if between-city commuting becomes cheaper ( $\xi_c \downarrow$ ), perhaps because a high-speed railway is built between the two cities, the equilibrium share  $\alpha^*$  increases. A higher within-city commuting rate  $\xi$  also raises  $\alpha^*$  because it widens the gap between cities' urban costs. For the same reason,  $\alpha^*$  increases with the productivity difference  $\epsilon_1/\epsilon_2$  between cities. The share  $\alpha^*$  also rises with the mass of skilled workers in both cities ( $L_s \uparrow$ ) because the average within-city commuting rate grows faster in city 1 than in city 2, which exacerbates the urban costs difference between cities. Last,  $\alpha^*$  increases with the share  $\delta$  of spending on LCS because a higher consumption of CBD services raises urban costs in city 1 more than in city 2, which incentivizes more skilled to shift to city 2.

We now use consensus values of the parameters to obtain quantitative approximations for the share of inter-city commuters. We use urban costs estimations by Combes *et al.* (2019) who report that within-city commuting costs account for almost 13% of their expenditure and housing for about 33%.<sup>12</sup> We find that for  $\epsilon_1/\epsilon_2 = 1.1$  and  $\xi_c = 0.045$  (between-city commuting accounts for 4.5% of skilled wage), between-city commuting arises together with WFH. For  $\mathbf{L} = 3$ , the share of between-city commuters  $\alpha^*$  rises to 0.065 when  $\rho$  approaches  $\bar{\rho} = 0.49$ . In other words, 6.5% of the skilled population of city 1 relocate to city 2 when the skilled work about half of working days from home. This number increases with larger productivity difference  $\epsilon_1/\epsilon_2$  and/or higher share of unskilled (larger  $\mathbf{L}$ ).

### Intermediate WFH shares ( $\bar{\rho} < \rho < \hat{\rho}$ )

We now study what happens when  $\bar{\rho} < \rho < \hat{\rho}$ . The equilibrium share  $\alpha^*$  of between-city commuters is pinned down by  $(UC_{s1} - UC_{b2})/(1 - \rho) = \xi_c w_{s1}$ . We show in Appendix D

<sup>12</sup>Thus, urban costs stand for about 45% of their income which is similar to numbers reported in the US (Bureau of Transportation Statistics, 2013).

that  $\alpha^*$  for  $\bar{\rho} < \rho < \hat{\rho}$  is given by:

$$\alpha^*(\rho) = \frac{1+L}{2} - \left(1 + \delta + \frac{1-\beta}{\beta} \frac{1}{1-\rho}\right) \frac{\epsilon_2}{2\epsilon_1} - \frac{\xi_c}{2\xi L_s}. \quad (16)$$

Hence, *the share of between-city commuters now decreases with the WFH share*. The same holds when  $\delta$  rises. These two results differ from what we obtained in the case where  $\rho < \bar{\rho}$ . On the other hand, the effects of a change in  $\xi_c$ ,  $\xi$ ,  $\epsilon_1/\epsilon_2$ , and  $L_s$  are the same as in the case of low WFH shares.

Substituting  $\bar{\rho}$  into (15) and (16) yields the same value given by

$$\alpha^*|_{\rho=\bar{\rho}} = \frac{\epsilon_1 - \epsilon_2}{2\epsilon_1} (1+L) - \frac{\xi_c}{2\xi L_s}. \quad (17)$$

Consequently,  $\alpha^*$  is continuous at  $\bar{\rho}$ . Since  $\alpha^*$  now decreases over  $(\bar{\rho}, \hat{\rho})$ , the highest share  $\alpha^*$  of between-city commuters is reached at  $\rho = \bar{\rho}$  and given by (17).<sup>13</sup>

The share of inter-city commuters takes its lowest value over this domain at  $\rho = \hat{\rho}$ :  $\alpha^*|_{\rho=\hat{\rho}} = (\epsilon_1 - \epsilon_2)/2\epsilon_1 - \xi_c/2\xi L_s$ . Two cases may arise: (i) if  $\alpha^*|_{\rho=\hat{\rho}} < 0$ , then there exists a value of  $\rho_1 \in (\bar{\rho}, \hat{\rho})$  beyond which  $\alpha^*$  is equal to 0, (ii) if  $\alpha^*|_{\rho=\hat{\rho}} > 0$ , then  $\alpha^* > 0$  over  $(\bar{\rho}, \hat{\rho})$ .

### High WFH shares

When  $\rho > \hat{\rho}$ , the within-city commuters locate in the suburbs of city 2, the unskilled locate next to the CBD, while the between-city commuters set up between these two groups. We show in Appendix E that

$$\alpha^* = \frac{\epsilon_1 - \epsilon_2}{2\epsilon_1} - \frac{\xi_c}{2\xi L_s}. \quad (18)$$

Thus, when  $\rho$  takes on high values, *the share of between-city commuters is independent of the WFH share*. Clearly,  $\alpha^* > 0$  if productivity difference is high enough, or inter-city commuting is fairly inexpensive relative to within-city commuting, or both.

## 6.2 The bell-shaped curve of between-city commuting

We are now equipped to describe how the pattern of between-city commuting varies with the WFH share.

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<sup>13</sup>Inequality (14) implies that (17) is positive.

If the second inequality in (14) does not hold,  $\alpha^*$  is always equal to zero. There is no between-city commuting for all WFH shares because between-city commuting is expensive, the productivity difference between cities is small, or both. Contrast to that, if (14) holds, there are between-city commuters for some values of the WFH share.

The following proposition provides a summary.

**Proposition 4.** *Under (14), the equilibrium mass of between-city commuters first increases and, then, decreases with the WFH share.*

As the size of the labor pools in cities do not change with WFH share, the presence of between-city commuters does not affect wages in both cities. Furthermore, between-city commuters lower (resp., raise) urban costs of both skilled and unskilled workers in the more (resp., less) productive city. As wages are unaffected by between-city commuting, the new residential pattern makes the inhabitants of the less productive city worse-off. For our preferred set of parameter values, the welfare loss incurred by the unskilled in city 2 varies from 1.5 to 3.3 percent. As for the skilled, the range is [1.5, 3.4]. By contrast, the between-city commuters, as well as those who stay in the more productive city, are better-off. In particular, the relative gains made by the between-city commuters are comparable to the relative losses made by city 2's inhabitants: they vary from 1.7 to 3.9 percent.

Unexpectedly (at least to us), *the impact of the WFH share on the urban system is bell-shaped*. This is not due to (8) but to  $\epsilon_1 > \epsilon_2$ . The top of the bell occurs when the social structure of the more productive city changes. Furthermore, the mass of between-city commuters is equal to 0 for small or large values of  $\rho$ . Though  $\alpha^* = 0$  for low  $\rho$  seems natural, that the mass of between-city commuters is also equal to 0 when the WFH share is high is more surprising. The reason for this result is that the skilled reside in the periphery of city 1 where the land rent they pay is very low, whereas they have to pay a higher land rent in city 2 because they do not set up in this city's periphery.

Prior to the establishment of home working, the population was evenly distributed between cities. The appearance of between-city commuters generates an asymmetric pattern in which the less productive city hosts a larger population. As between-city commuters bring back their income in city 2, this city imports the consumption good from the more productive city.

Two more remarks are in order. First, a few companies, e.g., Google, announced their plans to cut their workers' salaries by up to 25% if they choose to leave in remote and

cheaper areas (*Vox*, 4/10/2021). This policy will reduce the flow of supercommuters but not the incentives to move away from the city center. Second, if the transportation link can be used by local residents to commute within each city as in the case of an urban highway in car cities, all workers face a lower commuting rate  $\xi$ . Consequently, since (15), (16) and (18) increases with  $\xi$ , the bell-shaped curve is shifted downward. Hence, fewer workers will choose to reside in the cheaper city as the urban cost differential shrinks. For the same reason, between-city commuting will arise for a higher WFH share.

### 6.3 Empirical evidence of WFH and the productivity of cities

The two-city model predicts that, starting with small WFH values, an increase in the adoption of teleworking for high-skilled workers will lead (some of) them to move from the productive (and relatively expensive) city to the less-productive (and relatively affordable) city. Given that pre-Covid levels of working from home are relatively low, we should expect to see skilled workers seeking out more affordable residential property outside of the highly productive cities in which they live. This shift in housing demand will put upwards pressure on housing prices in low-productivity (affordable) cities relative to high-productivity (expensive) cities. We follow an empirical strategy similar to Brueckner *et al.* (2021) to test this prediction of the model.

We estimate the following regression equation:

$$\Delta p_j = a_0 + \tau PROD_j \times WFH_j + a_1 PROD_j + a_2 WFH_j + \beta X_j + u_j \quad (19)$$

where the outcome,  $\Delta p_j$  is the change, between 2019 and 2021, in the (log of) average prices for city  $j$ .  $PROD_j$  and  $WFH_j$  are the pre-Covid values for city  $j$ 's productivity (measured as the log of gross value added per hour worked) and the proportion of residents who have jobs that can be done from home, measured using the strategy of Dingle and Neiman (2020) and De Fraja *et al.* (2021). The vector  $X_j$  includes characteristics of city  $j$  which may influence the change in housing prices. We include variables for natural amenities (located near a major park or coastal location) and endogenous amenities (cafes, restaurants, pubs, cinemas and other locally consumed services). This specification reflects the expectation that workers will change their weighting of a locations amenity value when the link between residential and work location is weakened (Brueckner *et al.*, 1999).

Table 3: The change in residential property prices, 2019–2021

	Residential property sales				Residential property rentals			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Productivity $\times$	-0.342	-0.001			-0.662***	-0.290		
WFH	(0.311)	(0.285)			(0.243)	(0.272)		
Productivity	0.064	-0.047			0.202**	0.100		
	(0.119)	(0.108)			(0.100)	(0.110)		
Price <sub>2018</sub> $\times$			-0.342***	-0.262**			-0.358***	-0.293***
WFH			(0.104)	(0.124)			(0.064)	(0.071)
Price <sub>2018</sub>			0.124***	0.132***			0.028	0.066*
			(0.040)	(0.047)			(0.034)	(0.037)
WFH share	1.119	0.079	4.209***	3.469**	1.674*	0.909	2.384***	2.150***
	(1.087)	(1.000)	(1.329)	(1.573)	(0.891)	(0.968)	(0.462)	(0.538)
$N$	329	306	336	313	328	306	335	313
$R^2$	0.120	0.231	0.157	0.260	0.698	0.803	0.774	0.823

Notes: Outcomes are the difference in the log of the average sale and rental prices for 2021 and later versus 2019. Productivity is measured by the city’s gross value added per hour worked. Price<sub>2018</sub> is the log of average prices for the year 2018. WFH is the estimated proportion of jobs which can be done from home. Regressions in columns 1, 3, 5 and 7 do not include additional control variables. Regressions in columns 2, 4, 6 and 8 include controls for log of average income, log of population, log of total land size, log of the number of endogenous amenities, coastal dummy, dummy for access to a train, average deprivation index score, and Bartick instrument. See Appendix A for data sources and details. Robust standard errors reported in parenthesis; \*, \*\*, and \*\*\* denote statistical significance at 10%, 5% and 1%.

A negative estimate of  $\tau$  is consistent with an increase in working from home will leading to a greater increase in housing prices in less productive cities compared to their more productivity counterparts. This is consistent with workers who can work from home seeking out homes in cities that are less expensive, but continuing to maintain their employment in the high-productivity center.

The results of this regression are reported in Table 3 for sales and rental prices. In columns 1 and 5 we report regressions of price changes on productivity without controlling for amenities and other city characteristics; in columns 2 and 6 we add in the full set of controls. As an alternative specification, rather than productivity, we use average housing prices in 2018 (columns 3–4 and 7–8). If teleworkers are moving to a new city in pursuit of less expensive housing, then we expect to see a negative relationship between pre-pandemic housing prices and the growth in housing prices.

The results from the sales and rental data largely agree with one another. The estimated coefficient corresponding to  $\tau$  in (19), for the interaction of productivity (2018 prices) and working from home rates, is negative, although the productivity specification is sensitive to the addition of controls. Using 2018 prices instead of productivity returns estimates similar in magnitude, but much more precise and less sensitive to controls. Consider the association between 2018 housing prices and the 2019–2021 change

in housing prices (columns 3–4). When no one can work from home (i.e.  $WFH = 0$ ) a percent change in the average 2018 price is associated with a 0.132 percent increase in the 2019–2021 sale price change. For every 10 percentage point increase in the proportion of workers who can work from home, the productivity-price change is reduced by -0.026 percentage points.

It is worth noting that the magnitudes of the 2018 price specification and the productivity specification are very similar. Further, estimates for the parameter of interest are quite similar across both sales and rental data.

#### **6.4 Job migration to the more productive city**

Telecommuting allows workers to enjoy a wider range of job opportunities. Indeed, when city 1 is more productive than city 2, city 2’s skilled workers may want to take a job in city 1 where wages are higher while keeping their residence in city 2 where urban costs are lower. We show in Appendix F that the share of between-city workers increases with the WFH share.

Note that the two types of inter-city commuters shape the urban and wage structures in very different ways. Between-city commuters lead to lower urban costs for all within-city commuters in the more productive city whose size shrinks. The opposite holds in the less productive city. Wages and output of the final sector remain the same in both cities. Contrast to that, between-city workers diminishes the skilled wage and rises the unskilled wage in the more productive city. The opposite holds in the less productive city. Thus, although the city sizes do not change, urban costs borne by the skilled fall and increase for the unskilled in the more productive city. The opposite holds in the other city.

### **7 Concluding remarks**

We have shown that telecommuting has consequences that go way beyond productivity gains or losses for firms and workers. Telecommuting has implications for the unskilled who do not work home, for the social structure of cities and for housing expenditures. For example, the renewal of urban centers observed in several big cities is likely to be negatively affected by a growing adoption of teleworking. As adopting WFH represents a fundamental shift in how firms do business, it is premature to predict that telework will trigger the great dispersion of skilled labor. Yet, unless firms choose the strategy “return

to the office,” telework should foster some dispersion of the skilled who also face a wider range of residential opportunities. In addition, WFH raises income inequality between the skilled and the unskilled, which may give rise to very contrasted city structures. All of this shows that WFH has social and spatial effects that do not occupy center stage in the on-going debates about the good and the bad of home working.

Inter-city commuting is likely to have an impact on cities’ finances. Fewer commuters – or workers who commute less often – could translate into a shrinking of the local revenue base. For example, Philadelphia, PA, expects a permanent loss of 15% of the non-resident wage tax base in its projections for the coming years (*Bloomberg*, 28/02/2022). Cities will be affected differently according to their specialization and the institutional environment in which they operate. Furthermore, towns and cities might get embarked into a subsidy war in which local governments aim to attract skilled workers. For example, inspired by the Tulsa Remote work program in Oklahoma, leaders in Venice plan to bring in young professionals who want to live and work there, instead of visiting during vacation (*Bloomberg*, 18/01/2022).

Note finally that how the WFH share will be chosen should have an impact on cities. However, it is far from being obvious that agents involved in the decision process will take this impact into account in their final decision.

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For Online Publication

Appendices to accompany “How the rise of teleworking will reshape labor markets and cities”

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## Appendix A

Our analysis is based on housing sales for England and Wales.

**Neighborhood definition.** We define a neighborhood as the lower super output area. This is an official geographic area in England and Wales, set by Office for National Statistics, which is defined by a geographic area in which approximately 1,500 residential live. There are 34,753 neighborhoods in England and Wales (34,741 in our data). In 2019 neighborhoods had an average of 1700 residents, or 750 residential properties, and an average of 29 residential property sales took place. The average land area of a neighborhood is four squared kilometers. Details are reported in Table A.1.

For our purposes central London is defined as the centroid of an LSOA in the City of London, E01032740.

**House price data.** We use data reflecting housing prices for the universe of sales (3,598,411 in total) between 2018 and 2021, provided by the UK land registry. These data provide information on the final price of sale, the date the sale was completed (i.e. when the property officially transferred ownership), street address location, and the type of house (detached, semi-detached, terrace or flat/apartment). While the data do not provide a measure of house size, type of house will provide a reasonable proxy.

Rental price data are provided by *Rightmove*, an on-line property website. Data include information on the monthly rental price, street address, property type (and size) and the date of the listing. *Rightmove* is one of the two dominant property websites in the UK.

**Other data.** Our measure of productivity is the gross value added per hour worked (in pounds) by city. These are taken from reference tables published by the Office for National Statistics and reflect 2019 values.

We measure the proportion of employed residents in occupations that can be done from home using neighborhood work from home rates from De Fraja *et al.* (2020). These rates are calculated by assigning an index, reflecting the proportion of work that can be done from home, to four-digit UK standard occupational classification codes—following the work of Dingel and Neiman (2020)—and then calculating the average index for each neighborhood weighted by the number of residents in the corresponding occupations.

Information on neighborhood amenities come from Open Street Map data. We calculate the endogenous amenities as the count of pubs, cafes, restaurants, cinemas, and other local services within half a kilometer of the neighborhood centroid. For natural amenities

we calculate the distance from the neighborhood centroid to the closest park of a size in the top 5% (approximately 0.2 kilometers squared). For cities, we calculate the total coverage of park space (in kilometers squared) within a city.

We include data from a number of different sources as control variables, and for the purpose of stratifying out results, in the above regressions. These include, an index of neighborhood deprivation, a Bartick style instrument to control for pre-Covid changes in employment opportunities, average resident income.

Table A.1: Summary statistics by neighborhood and local authority

	Mean	Standard deviation	Minimum	Maximum	10 <sup>th</sup> percentile	90 <sup>th</sup> percentile
	(1)	(2)	(3)	(4)	(5)	(6)
Neighborhoods						
Area ( $km^2$ )	0.52	1.66	0.02	48.11	0.10	0.80
Residential population	1836.60	468.43	810.00	16004.00	1437.00	2302.50
Residential properties	755.05	253.41	310.00	7540.00	540.00	990.00
Sales (annually)	19.06	15.02	1.00	464.67	7.67	29.67
Price (£1000s)	596.97	426.24	163.83	7533.75	324.39	930.72
Rental listings (annually)	76.11	122.13	1.00	2323.00	10.00	174.33
Price (£s per month)	1708.67	715.19	726.00	13044.86	1201.28	2319.48
Distance to CBD (km)	14.87	8.23	0.00	45.49	5.21	25.45
Endogenous amenities	1.50	4.85	0.00	230.00	0.00	4.00
Distance to coast (km)	56.62	17.07	0.00	94.27	33.09	77.41
Distance to park (km)	1.10	0.82	0.01	7.43	0.35	2.08
Distance to train (km)	1.39	1.08	0.00	11.26	0.28	2.69
Bartick instrument (%) <sup>†</sup>	11.26	2.48	4.12	21.67	8.38	14.80
Income (per-week) <sup>‡</sup>	659.32	116.68	450.00	1140.00	520.00	820.00
Local authorities						
Area ( $km^2$ )	449.45	647.00	2.90	5180.40	39.07	1039.27
Residential population (1000s)	176.90	119.96	2.22	1141.82	82.31	324.75
Residential properties (1000s)	77.79	51.03	1.18	448.78	37.10	139.34
Sales (annually)	1864.65	1156.86	107.00	8921.00	911.25	3067.00
Price change (% , 2019–2021)	13.06	6.00	-23.76	32.53	6.26	20.17
Price (2018, £1000s)	307.78	205.09	95.75	2305.93	153.74	495.59
Rental listings (annually)	3039.96	4269.16	35.25	36397.50	557.00	7551.50
Price change (% , 2019–2021)	8.24	8.22	-31.96	87.27	0.11	15.86
Price (2018, £s per month)	899.31	449.96	425.07	3954.84	534.89	1378.78
Productivity <sup>‡</sup>	33.41	7.30	20.30	62.40	26.40	43.50
WFH share (%)	36.34	7.20	21.28	71.03	28.63	45.68
Endogenous amenities	147.76	140.12	0.00	1266.00	33.00	314.00
Access to coast (%)	7.82	15.52	0.00	100.00	0.00	31.65
Access to train (%)	5.65	9.70	0.00	100.00	0.00	12.16
Bartick instrument (%)	10.46	1.45	6.52	16.59	9.01	12.27
Income (per-week)	550.75	89.82	401.91	860.00	452.25	688.92

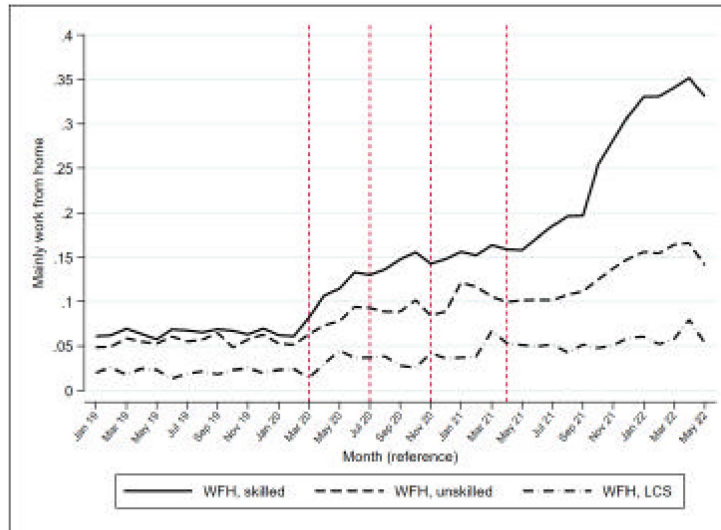
Notes: Neighborhoods are identified as 5,722 *lower super output areas* across the London travel to work area. Local authorities cover 335 local authority districts across England and Wales. <sup>†</sup>Variables calculated at the higher geographic level of the *middle super output area*. <sup>‡</sup>Productivity measured by gross value added per hour worked (reported in £).

Table A.2: Distance to central London and residential property prices, varying by WFH share

	Sales (1)	Rentals (2)
Distance to center	-0.466*** (0.047)	-0.380*** (0.041)
Year2021	-0.381*** (0.065)	-0.234*** (0.034)
Year2021 × Distance Q1	0.169*** (0.037)	0.103*** (0.019)
Year2021 × Distance Q2	0.175*** (0.038)	0.099*** (0.018)
Year2021 × Distance Q3	0.191*** (0.039)	0.097*** (0.020)
Year2021 × Distance Q4	0.195*** (0.039)	0.091*** (0.026)
Endogenous amenities	-0.016* (0.008)	-0.004 (0.014)
Endogenous amenities <sup>2</sup>	0.002** (0.001)	0.001 (0.001)
Distance to coast	-0.027 (0.027)	-0.072 (0.058)
Distance to park	-0.013*** (0.004)	-0.015** (0.007)
Distance to train	0.041*** (0.011)	0.024* (0.014)
City fixed effects	Yes	Yes
City×Year2021 fixed effects	Yes	Yes
<i>N</i>	231,293	1,105,739
<i>R</i> <sup>2</sup>	0.354	0.340

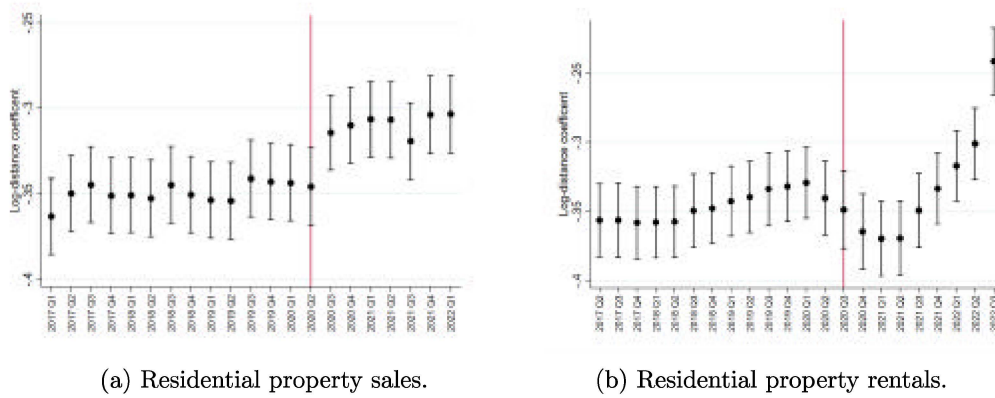
Notes: Outcome is the log-price (sale and monthly rental). Data include years 2019, 2021 and 2022 for housing in the London Travel to Work Area. Dummy variable Year2021, equal to 1 if year  $\geq$  2021, and 0 otherwise. Distance Q1–Q4 is distance from London centre,  $\log(1+distance)$ , according to the pre-2020 concentration of jobs that can be done from home in each neighborhood (Q1 = lowest; Q4 = highest). All distance measures are transformed to  $\log(1+distance)$ . In addition to the reported variables, column 1 includes month-of-year dummies, column 2 additionally includes Bartick instrument (for city and neighborhood), city productivity growth, average neighborhood income (2019), and dummy variables for deciles of deprivation, and column 3 additionally includes local authority and local authority×time fixed effects. Robust standard errors clustered at the city level (53 clusters); \*, \*\*, and \*\*\* denote statistical significance at 10%, 5% and 1%.

Figure A.1: Working from home, before and after 2020



Notes: This figure plots the proportion of employed UK survey respondents, by month, who stated that they are working mainly from home in their main job. For surveys conducted during Jan–Sept 2021, the respondent was asked to answer in relation to usual working pattern if coronavirus restrictions are not in place. Jobs are separated into different skills according to three digit standard occupation classification codes. Red vertical lines show periods in which national public health restrictions were in place (March 2020–July 2020 and November 2020–April 2021). Data from the UK Labour Force Survey.

Figure A.2: Distance to central London and property prices over time

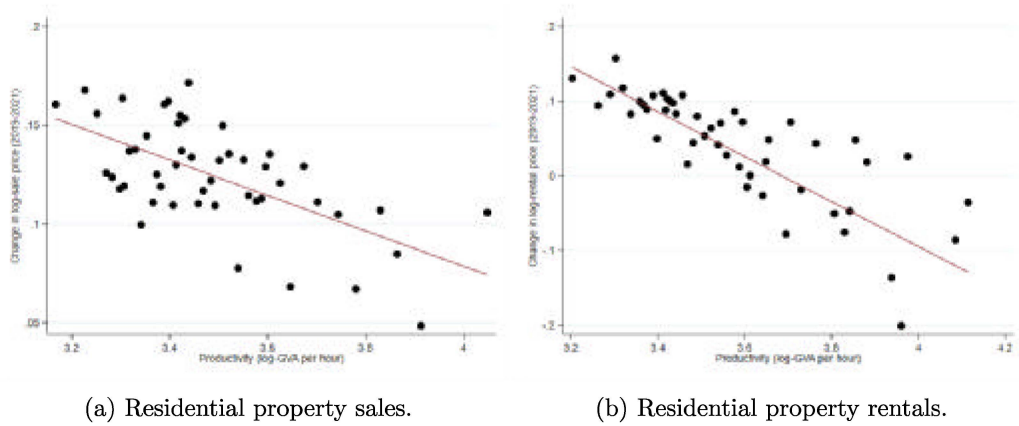


Notes: This figure plots the coefficient of a regression of housing prices on distance to London city center for each quarter from Q1 2017 to Q1 2022 for sales data and Q3 2022 for rental data. Bars indicate 95% confidence interval. Vertical line placed at the quarter in which the first UK nation lockdown began (23 March 2020).

In Figure A.2 we show the correlation between (log) price and (log) distance to CBD, by quarter of year, from 2017 to 2021. For housing sales, there is a very gradual decrease in magnitude the correlation between 2017 to 2020, but in the third quarter of 2020, we see a clear, large, drop in magnitude (Figure A.2a). In 2019 a one percent increase in distance led to a 0.347 percent decrease in housing prices; in 2021 a one percent increase in distance led to a 0.295 percent decrease in house prices. The difference between the pre-and post 2020 the magnitudes is large and statistically significant (difference of 0.054,  $p=0.000$ ). We see a similar picture for rental prices (Figure A.2b), although in this case there is an initial increase in the magnitude of the correlation in the third quarter of 2020, followed by a rapid decrease in magnitude starting in the third quarter of 2021.



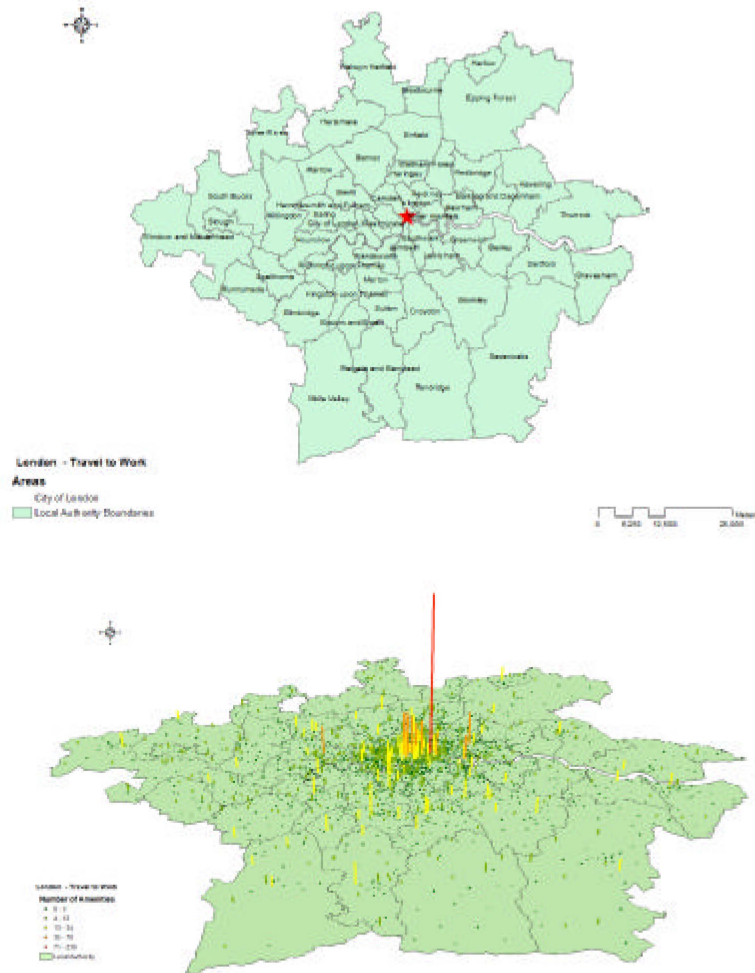
Figure A.3: Productivity and the change in property prices for England and Wales



Notes: This figure shows a binscatter plot of the change in the log-average price for residential property against productivity, by local authority in England and Wales. Productivity is measured as the log of gross value added per work hour in 2019.

In Figure A.2 we show the raw correlation between the change in (log) price, from 2019 to 2021, and (log) productivity, across local authorities in England and Wales. Both figures indicate a negative relationship. The coefficient on a bivariate regression of the change in (log) price on (log) productivity indicates that a 10% increase in productivity is associated with a 0.8% decrease in sales prices ( $p \geq 0.000$ ) and a 1.7% decrease in rental prices ( $p \geq 0.000$ ).

Figure A.4: London travel to work area



Notes: Top map shows the London travel to work area, boundaries correspond to local authorities within. Star denote the central business district from which distances are measured. The bottom map shows the concentration of locally consumed services across the travel to work area. Higher vertical lines indicate a greater concentration of businesses for different neighborhoods.

## Appendix B

In this Appendix we investigate how city structure varies with teleworking under the presence of city center amenities. To this end, we assume that skilled spend a share  $\theta\delta$  of their income on LCS during the weekend at the CBD. Parameter  $\theta$  captures the attractiveness of the urban center. Higher  $\theta$  means that the skilled are willing to visit the CBD more often and/or spend more during their visits. In particular,  $\theta > 1$  reflects the fact that skilled spend more during the weekends than during weekdays on LCS.

In this case, the skilled budget constraint takes the form:

$$w_s = c_s + p\eta + R(x) + (1 - \rho)\xi w_s x + \theta\delta w_s + \theta\xi w_s x.$$

Then, the wage ratio becomes

$$\frac{w_s}{w_\ell} = \frac{\beta\mathbf{L}}{1 - \beta + (1 - \rho + \theta)\beta\delta}.$$

The condition for the gentrified city is

$$\frac{w_s}{w_\ell} = \frac{\beta\mathbf{L}}{1 - \beta + (1 - \rho + \theta)\beta\delta} > \frac{1}{1 - \rho + \theta}.$$

Therefore, a gentrified city emerges when

$$\rho < \bar{\rho} \equiv 1 - \frac{1 - \beta}{\beta(\mathbf{L} - \delta)} + \theta.$$

Thus, a higher spendings  $\theta$  on LCS during weekend makes a gentrified city sustainable over a wider range of WFH shares.

## Appendix C

The urban costs of an unskilled who resides at  $x_2 \in ((1 + \alpha)L_s, (1 + \alpha)L_s + L_\ell)$  in city 2 are given by

$$UC_{\ell 2}(x_2) = R_{\ell 2}(x_2) + \xi w_{\ell 2} x_2 = \xi w_{\ell 2} [(1 + \alpha)L_s + L_\ell] \equiv UC_{\ell 2},$$

which increases with  $\alpha$  because more skilled workers makes the average unskilled commuting distance longer.

Let  $w$  (resp.,  $b$ ) be the index used for the within-city (resp., between-city) commuters who reside in city 2. The urban costs of an unskilled who resides at  $x_2 \in ((1 + \alpha)L_s, (1 + \alpha)L_s + L_\ell)$  in city 2 are given by

$$UC_{\ell 2}(x_2) = R_{\ell 2}(x_2) + \xi w_{\ell 2} x_2 = \xi w_{\ell 2} ((1 + \alpha)L_s + L_\ell) \equiv UC_{\ell 2}.$$

Since  $R_{w 2}((1 + \alpha)L_s) = R_{\ell 2}((1 + \alpha)L_s) = \xi w_{\ell 2} L_\ell$  at the border between the unskilled

and the with-city commuters, the urban costs  $UC_{n2}$  of a within-city commuter is as follows:

$$UC_{w2}((1 + \alpha)L_s) = \xi w_{\ell 2} L_{\ell} + (1 - \rho)\xi w_{s2}(1 + \alpha)L_s = R_{w2}(x_2) + (1 - \rho)\xi w_{s2}x_2 \equiv UC_{n2}.$$

Therefore, the land rent paid by a within-city commuter at  $x_2 \in (\alpha L_s, (1 + \alpha)L_s)$  is equal to

$$R_{w2}(x_2) = R_{w2}((1 + \alpha)L_s) + (1 - \rho)\xi w_{s2}((1 + \alpha)L_s - x_2),$$

so that the land rent at the border  $\alpha L_s$  between within-city and between-city commuters is given by

$$R_{w2}(\alpha L_s) = R_{w2}((1 + \alpha)L_s) + (1 - \rho)\xi w_{s2}L_s = R_{b2}(\alpha L_s).$$

This yields the urban costs borne by a between-city commuter located at  $x_2 \in (0, \alpha L_s)$  in city 2 is given by

$$UC_{b2}(\alpha L_s) = \xi w_{\ell 2} L_{\ell} + (1 - \rho)\xi w_{s2}L_s + (1 - \rho)\xi w_{s1}\alpha L_s \equiv UC_{b2}, \quad (C.1)$$

which increases with  $\alpha$  because the average commuting distance is longer.

Using (11) shows that the urban costs of a skilled in city 1 at any location  $x_1 \in (0, (1 - \alpha)L_s)$  are as follows:

$$UC_{s1} = \xi w_{\ell 1} L_{\ell} + (1 - \rho)\xi w_{s1}(1 - \alpha)L_s. \quad (C.2)$$

Hence, a larger share of between-city commuters decreases the skilled urban costs in city 1 because the average commuting distance is shorter. As expected, the difference between urban costs in the two cities decreases when the mass of between-city commuters increases.

Substituting (C.1) and (C.2) into this expression and using (12), we obtain the equilibrium share  $\alpha^*$  of skilled who move to city 2:

$$\alpha^*(\rho) = \frac{\epsilon_1 - \epsilon_2}{2\epsilon_1} \left( 1 + \delta + \frac{1 - \beta}{\beta} \frac{1}{1 - \rho} \right) - \frac{\xi_c}{2\xi L_s}.$$

In the absence of between-city commuting, urban costs in city 1 are higher than in city 2 due to wage difference between cities. Since the consumption good is costlessly tradable between cities, its price is equal to 1 in both cities. As a result, the cost-of-living difference between two cities arises only due to variation in urban costs. Thus, city 1's skilled workers choose to reside in city 2 and keep working in city 1 if the difference in urban costs exceeds the between-city commuting cost, that is,

$$\frac{1}{1 - \rho} UC_{s1}|_{\alpha=0} - \frac{1}{1 - \rho} UC_{b2}|_{\alpha=0} > \xi_c w_{s1}.$$

Since urban costs are proportional to wage, what matters for between-city commuting

to emerge is whether the share of income spent on between-city commuting per office hour  $\xi_c$  is smaller than the difference between urban costs per office hour. Plugging (12) into (C.1) and (C.2) and setting  $\alpha = 0$ , the latter inequality takes the form

$$\frac{\epsilon_1 - \epsilon_2}{\epsilon_1} \bar{s} > \xi_c,$$

where  $\bar{s}$  is the share of income spent on urban costs per office hour, which is defined by

$$\bar{s} \equiv \xi L_s \left[ \frac{1}{1-\rho} \frac{1-\beta}{\beta} + 1 + \delta \right], \quad (\text{C.3})$$

which increases with  $\rho$ .

The threshold  $\rho_0$  beyond which between-city commuting arises is such that the difference between urban costs is equal to the between-city commuting cost:

$$\frac{\epsilon_1 - \epsilon_2}{\epsilon_1} \bar{s} = \xi_c.$$

Therefore, using (C.3) shows that there is a positive flow of in-between city commuters if and only if the inequalities

$$\frac{\epsilon_1 - \epsilon_2}{\epsilon_1} \left( 1 + \delta + \frac{1-\beta}{\beta} \right) < \frac{\xi_c}{\xi L_s} < \frac{\epsilon_1 - \epsilon_2}{\epsilon_1} (1 + \mathbf{L})$$

hold.

## Appendix D

We know that the within-city commuters reside at city 2's periphery. The urban cost paid by a skilled who resides at  $x_2 \in (\alpha L_s + L_\ell, (1 + \alpha)L_s + L_\ell)$  in city 2 is then given by

$$UC_{s2}(x_2) = R_{s2}(x_2) + (1 - \rho)\xi w_{s2}x_2 = (1 - \rho)\xi w_{s2}[(1 + \alpha)L_s + L_\ell] \equiv UC_{s2},$$

which implies that the land rent paid by within-city commuters is  $R_{s2}(x_2) = (1 - \rho)\xi w_{s2}[(1 + \alpha)L_s + L_\ell - x_2]$ .

Since the land rent at the border between within-city commuters and unskilled is  $R_{s2}(\alpha L_s + L_\ell) = (1 - \rho)\xi w_{s2}L_s = R_{\ell 2}(\alpha L_s + L_\ell)$ , the urban cost paid by an unskilled who resides at  $x_2 \in (\alpha L_s, \alpha L_s + L_\ell)$  in city 2 is equal to

$$UC_{\ell 2}(x_2) = R_{\ell 2}(x_2) + \xi w_{\ell 2}x_2 = (1 - \rho)\xi w_{s2}L_s + \xi w_{\ell 2}(\alpha L_s + L_\ell) \equiv UC_{\ell 2},$$

while the land rent she pays is  $R_{\ell 2}(x_2) = (1 - \rho)\xi w_{s2}L_s + \xi w_{\ell 2}(\alpha L_s + L_\ell - x_2)$ .

The land rent at the border between the between-city commuters and the unskilled is then  $R_{\ell 2}(\alpha L_s) = (1 - \rho)\xi w_{s2}L_s + \xi w_{\ell 2}L_\ell = R_{b2}(\alpha L_s)$ . Therefore, the urban cost paid by

a between-city commuter who resides at  $x_2 \in (0, \alpha L_s)$  in city 2 is equal to

$$UC_{b2}(x_2) = R_{b2}(x_2) + (1 - \rho)\xi w_{s1}x_2 = (1 - \rho)\xi w_{s2}L_s + \xi w_{\ell 2}L_\ell + (1 - \rho)\xi w_{s1}\alpha L_s \equiv UC_{b2}.$$

As shown by (11), the urban costs paid by the skilled in city 1 are as follows:

$$UC_{s1} = (1 - \rho)\xi w_{s1}[(1 - \alpha)L_s + L_\ell].$$

Skilled workers choose to reside in city 2 and to work in city 1 if  $(UC_{s1} - UC_{b2})/(1 - \rho) > \xi_c w_{s1}$  holds. Using (12), urban costs per office hour are now given by

$$\frac{UC_{s1}}{1 - \rho} = \hat{s}_1 w_{s1}, \quad \frac{UC_{b2}}{1 - \rho} = \hat{s}_2 w_{s2}, \quad (\text{D.1})$$

where

$$\hat{s}_1 = \xi L_s(1 - \alpha + \mathbf{L}), \quad \hat{s}_2 = \xi L_s \left[ 1 + \delta + \frac{1 - \beta}{\beta} \frac{1}{1 - \rho} + \alpha \frac{\epsilon_1}{\epsilon_2} \right]$$

are, respectively, the shares of income spent on land and commuting per office hour in city 1 and city 2. While  $\hat{s}_2$  increases with  $\rho$ , the corresponding share  $\hat{s}_1$  in city 1 is independent of  $\rho$  because the skilled in city 1 locate at the periphery of the city. Thus,  $(UC_{s1} - UC_{b2})/(1 - \rho)$  decreases with  $\rho$ .

The equilibrium share of commuters is established by  $\alpha^*$  such that  $(UC_{s1} - UC_{b2})/(1 - \rho) = \xi_c w_{s1}$ . Substituting D.1 into this condition, and solving for  $\alpha^*$ , yields:

$$\alpha^*(\rho) = \frac{1 + \mathbf{L}}{2} - \left( 1 + \delta + \frac{1 - \beta}{\beta} \frac{1}{1 - \rho} \right) \frac{\epsilon_2}{2\epsilon_1} - \frac{\xi_c}{2\xi L_s}.$$

## Appendix E

When  $\rho > \hat{\rho}$ , the urban costs paid by a within-city commuter who resides at  $x_2 \in (\alpha L_s + L_\ell, (1 + \alpha)L_s + L_\ell]$  in city 2 is given by

$$UC_{s2}(x_2) = R_{s2}(x_2) + (1 - \rho)\xi w_{s2}x_2 = (1 - \rho)\xi w_{s2}[(1 + \alpha)L_s + L_\ell] \equiv UC_{s2},$$

so that the land rent that prevails at  $x_2$  is equal to  $R_{s2}(x_2) = (1 - \rho)\xi w_{s2}[(1 + \alpha)L_s + L_\ell - x_2]$ .

At the border between the within-city and between-city commuters, the land rent is equal to  $R_{s2}(\alpha L_s + L_\ell) = (1 - \rho)\xi w_{s2}L_s = R_{b2}(\alpha L_s + L_\ell)$ . Therefore, between-city commuters bear the urban cost

$$UC_{b2}(\alpha L_s + L_\ell) = (1 - \rho)\xi w_{s2}L_s + (1 - \rho)\xi w_{s1}(\alpha L_s + L_\ell) = UC_{b2}.$$

In city 1, the skilled bear urban costs given by

$$UC_{s1} = (1 - \rho)\xi w_{s1}[(1 - \alpha)L_s + L_\ell].$$

Solving  $UC_{s1} = UC_{b2} + (1 - \rho)\xi_c w_{s1}$  for  $\alpha$  yields:

$$\alpha^* = \frac{\epsilon_1 - \epsilon_2}{2\epsilon_1} - \frac{\xi_c}{2\xi L_s}.$$

## Appendix F

Telecommuting allows workers to enjoy a wider range of job opportunities. Indeed, when city 1 is more productive than city 2, city 2's skilled workers may want to take a job in city 1 where wages are higher while keeping their residence in city 2 where urban costs are lower. Let  $\kappa \geq 0$  be the share of between-city workers. When  $\kappa > 0$ , the skilled labor forces in city 1 and 2 change and are, respectively, equal to  $(1 + \kappa)L_s$  and  $(1 - \kappa)L_s$ . Therefore, a positive share  $\kappa$  affects wages in both cities through changes in cities' skilled labor pools, as well as in urban costs through variations in wages. Hence, between-city workers affect the urban system in a deeper way than between-city commuters.

Like the between-city commuters, between-city workers first go to the CBD of city 2 and, then, travel to the CBD of city 1. Since commuting costs are proportional to wages, the between-city workers pay the within-city commuting cost  $(1 - \rho)\xi w_{s1}x_2$  and the between-city commuting cost  $(1 - \rho)\xi_c w_{s1}$ . The skilled who work and reside in the same city bear only the within-city commuting cost  $(1 - \rho)\xi w_{si}$ . All unskilled are within-commuters; their commuting rate is  $\xi w_{\ell i}$ .

As between-city workers affect both wage schedule and consumption of LCS in cities, wages are now given by

$$w_{s1} = \epsilon_1 \beta A^\beta (\rho) \left( \frac{\mathbf{L}}{1 + \kappa} - \eta_1 \right)^{1-\beta}, \quad w_{\ell 1} = \frac{1 - \beta}{\beta} \frac{w_{s1}}{\frac{\mathbf{L}}{1 + \kappa} - \eta_1}, \quad (\text{F.1})$$

and

$$w_{s2} = \epsilon_2 \beta A^\beta (\rho) \left( \frac{\mathbf{L}}{1 - \kappa} - \eta_2 \right)^{1-\beta}, \quad w_{\ell 2} = \frac{1 - \beta}{\beta} \frac{w_{s2}}{\frac{\mathbf{L}}{1 - \kappa} - \eta_2}. \quad (\text{F.2})$$

In the absence of between-city workers,  $\eta_1 = \eta_2$  and the skilled wage ratio is equal to the city productivity ratio  $\epsilon_1/\epsilon_2$ . The presence of between-city workers leads to the following consumptions of LCS

$$\eta_1 = \frac{(1 - \rho)\beta\delta}{(1 + \kappa)(1 - \beta + (1 - \rho)\beta\delta)} \mathbf{L}, \quad \eta_2 = \frac{1 + \kappa}{1 - \kappa} \mathbf{L}.$$

Using these equations, skilled wage ratio takes the following form:

$$\frac{w_{s1}}{w_{s2}} = \frac{\epsilon_1}{\epsilon_2} \left( \frac{1 - \kappa}{1 + \kappa} \right)^{1-\beta}, \quad (\text{F.3})$$

which is lower than the productivity ratio  $\epsilon_1/\epsilon_2$  when  $\kappa > 0$ , while the between-city unskilled wage ratio

$$\frac{w_{\ell 1}}{w_{\ell 2}} = \frac{\epsilon_1}{\epsilon_2} \left( \frac{1 + \kappa}{1 - \kappa} \right)^\beta$$

is higher than the productivity ratio. The wage ratio  $w_{s1}/w_{s2}$  decreases with the share  $\kappa$  of between-city workers, while the opposite holds for the ratio  $w_{\ell 1}/w_{\ell 2}$ .

A positive share  $\kappa$  of city 2's skilled workers will choose to work in city 1 if the initial skilled wage in city 1 net of between-city commuting costs and services consumption exceeds the skilled wage in city 2 net of services consumption, that is,

$$w_{s1} - \eta_1 w_{\ell 1} - (1 - \rho)\xi_c w_{s1} > w_{s2} - \eta_2 w_{\ell 2}.$$

Plugging (F.1) and (F.2) shows that this condition is equivalent to

$$\frac{w_{s1}}{w_{s2}} > X \equiv \frac{1 - (1 - \rho)\delta}{1 - (1 - \rho)\delta - (1 - \rho)\xi_c}. \quad (\text{F.4})$$

Combining (F.3) and (F.4), we obtain an equilibrium flow of between-city workers:

$$\kappa^*(r) = \frac{1 - \left( \frac{\epsilon_2}{\epsilon_1} X \right)^{\frac{1}{1-\beta}}}{1 + \left( \frac{\epsilon_2}{\epsilon_1} X \right)^{\frac{1}{1-\beta}}}.$$

Since  $X$  decreases with  $\rho$ , the right-hand side of this expression is shifted upwards with  $\rho$ . As a result, *the share of between-city workers increases with the WFH share.*

Setting  $Y = (\epsilon_2/\epsilon_1)X$ , it is readily verified that  $\kappa^*$  decreases with  $Y$ . Since  $\partial Y/\partial(\epsilon_2/\epsilon_1) > 0$ ,  $\partial Y/\partial\delta > 0$  and  $\partial Y/\partial\xi_c > 0$ , we may conclude that the share of between-city workers decreases when the productivity gap shrinks, the intercity travel cost increases or the spending share on LCS rises.