The Zoom City:
Working From Home and Urban Land Structure

Efthymia Kyriakopoulou* Pierre M. Picard†

Abstract

How would cities change if working from home (WFH) persisted in the post-pandemic era? This paper investigates the impact of WFH in the internal structure of monocentric cities, where production is characterized by management and employee spillovers. We find that business land rents decrease, while residential land rents fall close to the business center and increase in the suburbs. WFH raises urban productivity and average wages only in large cities. The paper also studies the optimal fraction of WFH from a residents and welfare point of view. Our results suggest that workers-residents have incentives to adopt an inefficiently high WFH scheme. We finally discuss the implementation of remote work in the short run. We show that WFH implies higher benefits for long distance commuters and lower benefits or even losses for firms and short distance commuters.

Keywords: Work from Home, Urban Structure, Commuting, Land Use

JEL Codes: R14, R49, J81.

1 Introduction

Covid-19 has affected the labour and land markets in multiple ways. It has forced many companies to adopt more flexible work routines and facilitated the transition to remote work. Indeed, working from home (WFH) has become a new reality for a lot of employees (mainly office workers) and is

*Department of Economics, Swedish University of Agricultural Sciences and Department of Economics and Management, University of Luxembourg. Email: Efthymia.Kyriakopoulou@slu.se.

†Department of Economics and Management, University of Luxembourg and CORE, Université Catholique de Louvain. Email: pierre.picard@uni.lu

now more popular than ever. The transition to remote working has certainly been challenging for a large number of employees. Creating home office space and finding the right technology are two of the problems that people have encountered.

But is WFH likely to persist in the post-covid era? Preliminary estimations based on survey data show that both employers and employees embrace the flexibility and will permanently adopt new remote work routines, allowing employees to work-from-home multiple days a week (Global Workplace Analytics, 2021; Bartik et al. 2020). It is thus expected that WFH will persist after the end of the pandemic and this can affect the distribution of economic agents in the interior of the cities in multiple ways (Barrero et al, 2020). According to estate agents, people are reassessing their housing needs, which has already increased the demand for larger houses or apartments in many big cities. Less office work and commuting decreases the willingness of workers to locate close to their job. Remote workers want more space and seem willing to locate at the outskirts of big cities, in larger houses or apartment that offer home office space. This trend is observed in many cities around the world. Urban centers in the US had 15 percent more move-outs in 2020 than 2019, which is mainly related to the move of office-based workers.[1] People are moving away from the cities in the UK[2], while European city dwellers are also leaving the big cities as the coronavirus exploded across Europe.[3]

At the same time, firms are considering to vacate some of their buildings. Indeed, if the number of employees being physically present at the office every day is smaller than the total number of employees working for the same firm, firms will need smaller space. The examples of firms, authorities or whole regions that have announced similar plans are numerous. The City of London is converting offices into homes as a response to the Covid crisis.[4] The European Commission plans to vacate half of its office buildings in Brussels in the next 10 years, implementing a new remote work regime,[5] while in New York and San Francisco vacancies have risen significantly.[6] These new needs for housing and office space will probably increase the commuting distance between firms

[1] See https://allwork.space/2021/08/employees-are-leaving-big-cities/

[2] https://www.theguardian.com/business/2021/apr/19/uk-house-prices-surge-as-high-demand-meets-record-shortage-of-homes-for-sale

[3] https://www.nytimes.com/2021/02/11/world/europe/workers-europe-cities-pandemic.html

[4] https://www.bbc.com/news/business-56888615

[5] https://www.vrt.be/vrtnws/en/2021/04/27/european-commission-to-vacate-half-of-its-buildings/

[6] https://www.minnpost.com/metro/2021/06/during-the-pandemic-rents-went-down-in-new-york-and-san-francisco-why-not-the-twin-cities/

and workers. The urban structure is expected to change, with jobs moving to the core of the city and residents moving to the periphery, occupying more space.

In this paper, we use a simple urban economics model of land use where workers and firms compete for space and firms benefit from economies of urban density.[7] Under the latter, firms have incentives to locate close to each other and form business clusters in which they benefit from the interactions with other firms, exchange information and knowledge and increase their productivity (Moretti, 2004; Greenstone et al., 2010). The urban economics literature provides ample empirical evidence on the existence of economies of density in cities (Combes and Gobillon, 2015) and uses it as the main agglomeration factor explaining the existence of cities (e.g. Fujita and Ogawa, 1982; Lucas and Rossi-Hansberg, 2002). In the absence of remote work, workers want to locate close to their workplace to avoid paying high commuting costs. The formation of large business clusters prevents them from locating close to their job location, increases their average commuting distances and leads to higher land rents in the area around the cluster (due to increased competition). The balance between economies of business density, commuting cost and land scarsity determines workers' and firms' location decisions.

How do cities change when people can work remotely and commute to work on a less frequent basis? WFH and low on-site presence offers a lot of flexibility and changes the willingness of workers to offer high rents in order to locate close to the business center. Places closer to the outskirts of the city where rents are lower become more attractive when people do not have to commute to work so often. At the same time, WFH mitigates face-to-face communication between workers not only within each firm but also between neighboring firms, which hampers innovation and productivity within the city. To investigate this effect, we separate the management tasks that require presence in the office and city business district from the employees' tasks that can be partially performed from home.[8] In both cases, production externalities in the form of exchange of information and spillovers are important. Thus, production is characterized by management and employee spillovers. In this setting, the main difference between the two types of spillovers is

[7]See, for example, Fujita and Ogawa (1982), Lucas and Rossi-Hansberg (2002), Kyriakopoulou and Picard (2021).

[8]A similar division of tasks undertaken by more and less skilled agents is assumed in Antràs et al. (2006, 2008). Here we assume that tasks related to the management of the firm take place on-site, while employees can work both on-site and remotely. Antràs et al. (2006, 2008) study the case where more knowledge-intensive tasks are done domestically, while low skill tasks can be offshored and take place in another country.

that WFH has a direct impact only on the employee spillovers.

The objective of this paper is to study how working from home will affect the spatial interdependence of firms and workers and investigate the impact on the land and labour markets, as well as on welfare. We also study how WFH affects the productivity of workers, by considering different scenarios for the fraction of work done at office and home. We investigate the differences between the equilibrium and the optimal WFH level and we discuss long- versus short-run changes in hybrid working schemes. For the sake of conciseness, we focus on spatial equilibria where monocentric city structures emerge. We are not aware of any paper providing any formal theoretical modelling on how WFH will change the structure of cities while accounting for interaction externalities - which is the driving force of city formation - and therefore, we aim to cover this gap in the literature.

Our results indicate that WFH facilitates the emergence of monocentric cities and sustains them for a wider range of population sizes. When the city is large, WFH can be beneficial for productivity. On the contrary, in small cities, WFH leads to productivity losses. Business rents fall when workers partly work remotely, while residential rents decrease close to the business district. When WFH results in the expansion of the city, residential rents increase close to the city edges. Welfare benefits associated with remote work occur only in the case of large cities. We also show that the optimal fraction of WFH is smaller than the equilibrium one when production spillovers related to the physical presence of employees are significant. Finally, switching to remote work in the short run - when rents and wages are fixed - implies higher benefits for the long distance commuters and lower benefits or even losses for firms and short distance commuters.

The paper is organized as follows. Section 2 relates the paper to the literature. Section 3 presents the model while Section 4 discusses the spatial equilibrium of the monocentric city. Section 5 discusses the equilibrium rents and wages. Section 6 is devoted to the welfare analysis and highlights the difference between the optimal and the equilibrium WFH level. Section 7 discusses the implementation of WFH in the short run and Section 8 concludes.

2 Related literature

Hybrid working schemes that combine work from home and work at the office are currently and may remain popular in the decades to come (Barrero, et al., 2021a). The Covid-19 pandemic facilitated the development of high-tech communication tools and online platforms, which enabled the transition to a remote work era. One third of employees switched to WFH during the pandemic, while it is estimated that 37% of the jobs can be performed *entirely* at home (Brynjolfsson et al., 2020; Dingel and Neiman, 2020). Large companies, including Facebook, Amazon, Dropbox, Twitter, Spotify and Microsoft, have announced their plans to offer increased flexibility to their employees by switching to long-term remote work. As far as employees are concerned, some people are keen to return to their normal office life, while other would to like to avoid going back to the office (Barrero, et al., 2021b). Yet according to forecasts, WFH will remain a permanent feature of the future working environment (OECD, 2020; Bartik et al., 2020).

Remote work has attracted the attention of researchers in many different fields, including urban economics. Urban areas have been particularly affected by the changes related to the switch to remote work. In a recent study, Althoff et al. (2021) show that the highest remote work levels are observed in more densely populated cities in the US, which are specialized in high skill jobs. The changes in the work location have also created changes in the places where people spend their money. In particular, the share of spending in retail activity in more residential areas has seen a relative increase compared to the share of retail activity in large business centers (De Fraja et al., 2021). The shift to remote work has also inevitably affected workers' productivity and urban production. There is no consensus though about the direction of this effect. An earlier study by Bloom et al. (2015) found a 13 percent increase in the productivity of remotely working employees at the call-center of a Chinese travel agency. The development and the widespread adoption of technological innovations that facilitated remote working during the pandemic has boosted WFH productivity by 46 percent (Davis et al., 2021). On the other hand, using data from over 10,000 skilled professionals working at a large Asian IT services company, Gibbs et al. (2021) found that the average effect of working from home on productivity was negative.

Our paper is close to the growing literature on the impact of WFH on the demand for housing and office space. Very recent quantitative studies conducted for US cities show that WFH has an impact on the internal structure of cities, with jobs moving to the core of the city and residents moving to the periphery (Delventhal et al. 2021; Delventhal and Parkhomenko, 2021). Lui and Su (2021) study the impact of Covid-19 on the housing demand in the US and show that there is a higher drop in the neighborhoods with higher home values. Brueckner et al. (2021) also show that WFH decreases the house prices and rents in high-productivity counties, while workers who are able to fully work from home relocate to cheaper metro areas. Using US data, Gupta et al. (2021) show that the shift to remote work decreased house prices and rents in city centers and increased them in areas farther away from the center. This decrease in rents in high-density areas and central business districts of America's largest cities has also been confirmed by other recent studies (e.g. Ramani and Bloom, 2021; Lennox, 2020).

The above papers study the impact of WFH on different aspects of the urban environment. Our analysis contributes to this literature by explicitly studying the formation of large monocentric cities which is driven by the benefits to firms of being close to one another. More precisely, we consider the existence of agglomeration externalities stemming from by the exchange of information and knowledge among firms which is facilitated by the geographical proximity among them. Our paper is the first one that studies this type of externalities - which have been proven to be the most important force that promotes the clustering of economic activities - in a theoretical urban framework where employees divide their time between WFH and working at the office. The consideration of these externalities is important since WFH impedes the interaction and exchange of information across firms and can thus be bad for innovation and aggregate productivity. The workhorse model of Fujita and Owaga (1982) allows us to study the effect of WFH on the internal structure of cities, urban productivity, wages, equilibrium utility and welfare and derive closed-form solutions. We are not aware of any WFH-related study in urban economic theory that takes into account this externality.

Our results confirm Behrens et al.'s (2021) findings that WFH is a mixed blessing: small fractions of WFH increase productivity but larger fractions have a negative impact. Their theoretical framework though is different to ours: they discuss a general equilibrium model with three production factors and three sectors. Our model reproduces a similar relationship between aggregate productivity and WFH through the channel of business interactions. However, unlike our paper, there is no land competition between firms and residents and their agglomeration force stems from the product diversity in urban intermediate sector. Our results can also be compared to Brueckner at al. (2021), who briefly discuss the impact of WFH on the internal structure of cities, while focusing more on its impact across cities. In their theoretical model, individuals work only from home, while they live and work in different cities. In our paper, we explicitly study the firms' incentive to change their location and the structure of wages and land rents, while Brueckner at al. (2021) do not consider changes in firms' location. Finally, our paper is close to Delventhal et al. (2021) and Delventhal and Parkhomenko (2021) who use a quantitative urban model to study the changes in the shape of cities after a permanent increase in the fraction of working from home. Our results confirm their finding with respect to the city structure and the rents for housing and office space. Our simple model though allows us to analytically discuss the spatial equilibrium, the optimal city structure, the optimal fraction of remote work, as well as to point out the differences between the short- and the long-run equilibria.

3 Model

We consider a linear city model with homogeneous firms, homogeneous residents-workers and absentee landlords. The city expands on the unit-width segment where firms and workers interact through competitive labor and land markets. There are two forces that promote the formation of business and residential areas: business production externalities and workers' commuting cost. Firms tend to locate closer to each other because geographical proximity increases their productivity. In this paper we follow the literature by considering agglomeration benefits through professional interactions and exchange of information across firms (Fujita and Ogawa, 1982; Lucas and Rossi-Hansberg, 2002; etc.). As in any urban economics model, workers face a trade-off: locating closer to firms relaxes their commuting costs but increases their land rents. In the absence of remote work, the balance between those forces determines the land use. WFH adds several features to the model: on the one hand, workers save commuting cost but must dedicate space at home as a work area. On the other hand, firms save office space but remote work prevents the professional interactions with their business neighbors. Below, we study how these additional features affect the equilibrium urban structure in a monocentric city model.

Firms and workers compete for land at location x and $y \in \mathbb{R}$. We assume a closed city with a mass N of workers who work and reside in the city and an endogenous mass M of firms that produce in the city. The densities of resident and firms are denoted by $n(x)$ and $m(y)$ and satisfy $\int n(x)\mathrm{d}x = N$ and $\int m(y)\mathrm{d}y = M$. Workers consume an (inelastic) unit of land and a quantity c of a composite good, available in the national market at a price normalized to 1.[9] They derive

[9] For simplicity, we assume that the consumption of land is equal to one. Fixed land consumption by both households and firms is assumed in Fujita and Thisse (2002, chapter 6.3), Regnier and Legras (2018) and Kyriakopoulou and Picard (2021).

linear utility from the consumption of the composite good, $U(c) = c$. WFH allows workers to spend a share β of their time at the office and a share $1-\beta$ to work remotely in their homes. A worker residing at x and working at y gets a salary $w(y)$ and incurs a commuting cost given by $\beta t\,|x-y|$, where t is the cost per unit of distance. For simplicity, we assume that each worker uses one unit of space for residential purposes and γ units as a home office space. The total use of space per resident is therefore $1+\gamma$, and the total amount of space used for residential purposes in the interior of the city is $(1+\gamma)N$. Their budget constraint is given by

$$c(x) + (1+\gamma)R(x) + \beta t\,|x-y| \leq w(y) \tag{1}$$

where $R(x)$ is the land rent and the price of the composite good is normalized to one. The density of residents at location x is $n(x)$.

Firms are assumed to have equal sizes and to produce a composite good that is shipped and sold at a unit price in the national market. For the sake of exposition, each firm locating at y uses a unit mass of workers and pays $w(y)$.[10] As result, labor market clearing imposes that $N = M$. We study the case where firms use only a share $\beta < 1$ of office space when workers spend β of their work time on site and work remotely otherwise. For the sake of simplicity, we assume that each firm uses one unit of land when workers have full-time work on site. As a result, firm uses only β units of land under WFH policy. The total use of office land is then βM, while the total amount of space used both for residential and office purposes is $(1+\beta+\gamma)M$ units of land. The firm's profit is given by

$$\pi(y) = A(y) - \beta R(y) - w(y) \tag{2}$$

where $R(y)$ and $w(y)$ denote the land rent and labor costs, respectively. In this expression, $A(y)$ denotes the firm's production of composite good, which is sold in the national market at a price normalized to one. Production is subject to economies of density and is explained in the next paragraphs.

The focus of this paper is to discuss the impact of WFH in the presence of economies of business density, which are related to management and employee spillovers. To explain this, we take the example of Arzaghi and Henderson's (2008) economies of firm density in the New-York advertising industry. Advertising firms tend to locate in close proximity because they often get too big contracts and need to subcontract tasks to other firms. In our framework, we call 'management

[10] The firms' land and labor demands can trivially be extended to any scalars. See Fujita and Ogawa (1982).

spillovers' the production stemming from advertising firms' management to make rapid subcontract deals with other neighboring firms. The management is active on-site and crosses the street to encounter another firm's management, rapidly cut a deal and physically sign subcontracts. By contrast, we call 'employee spillovers' the production capabilities generated by employees who collaborate with or supervise the subcontractors' employees in their firms' neighborhoods. Subcontracting employees need to help and check advertising designs, production and distribution by subcontractors. Physical presence helps this supervision task. The key difference we emphasize in this paper is that employees may work from home whereas management activities are supposed to take place on site. The effect of WFH on agglomeration economics therefore hinges on the balance between the two kinds of activities and business spillovers. In the terms of Dingel and Neiman (2020), employees' tasks here have potential for WFH whereas management's ones do not.

Under management spillovers, the management of the firm located at y contributes to the production of $(\alpha - \tau |z-y|)$ units of goods when it meets the management of another firm at z, where $|z-y|$ is the distance between the two firms.[11] In this expression, α denotes the benefits resulting from an interaction whereas τ measures the cost of this interaction per unit of distance. Assuming that management meets randomly other firms in the office district with an interaction intensity (or frequency) ϕ, its production is given by $\phi \int (\alpha - \tau |z-y|) m(z) \mathrm{d}z$ where $m(z)$ is the density of firms at location z. Hence, the productivity of the firm rises with a higher density of firms in its nearby area, which reflects economies of business density. The role of management spillovers in the productivity of firms is discussed in Greenstone et al. (2010), Bloom et al. (2012), and Bloom et al. (2016). The production function can be interpreted as the benefit of professional networks linking firms' management. For simplicity, we focus on the case of 'global interactions' where every interaction yields a positive benefit: $\alpha - \tau |z-y| > 0$. This sets an upper bound on the distance between businesses and therefore on the city size.[12]

Under employee spillovers, the firm produces $(\alpha - \tau |z-y|)$ goods for each on-site employee who meets another on-site employee in another firm. We further assume that the probability to have an activity with employees outside the firm is given by $\beta^{1/2}$, which is a concave increasing function of the on-site presence. The probability is one when employees are full time on site

[11] Empirical research in urban and regional economics provides ample evidence of such type of agglomeration forces (Ciccone and Hall, 1996; Rosenthal and Strange, 2008).

[12] For analysis of 'local interactions', see Augeraud, Marhenda and Picard (2021).

($\beta = 1$) and decreases more and more rapidly when they work more often from home, which reflects increasing returns in employees' interactions outside of their firms. Supposing independent probability of an outside activity, a successful match between two employees is given by the probability $\beta^{1/2} * \beta^{1/2} = \beta$. In this case, they produces $(\alpha - \tau |z - y|)$ units of goods. This gives a production of $\int \beta (\alpha - \tau |z - y|) m(z) \mathrm{d}z$ where $m(z)$ is the density of firms.[13] Then, the production function becomes

$$A(y) = (\beta + \phi) \int (\alpha - \tau |z - y|) m(z) \mathrm{d}z \tag{3}$$

The production function (3) captures the benefit of business proximity for management and employees in a linear way. Although this is a strong simplification of actual production schemes, its exact shape is not reported by the empirical literature and cannot be used as guidance. As in Fujita and Ogawa (1982) and followers, the linear structure with respect to location x drastically helps the analytical discussion of city structure below. The linear structure with respect to outside professional interactions of management and employees, ϕ and β, is novel and helps to disentangle the economies of density that are linked to the activities with potential for WFH or not.

In this model, WFH is driven by two parameters β and γ. While γ expresses the use of home work space, β simultaneously captures four features of WFH: the fraction of on-site worktime, the fraction of commuting travels, the fraction of firm's land and finally the fraction of economies of density accrued to teleworkers' professional interactions. In reality, those features may move in different proportions and non-linear ways. Although interesting, relaxing the relationships between those features requires knowledge about their exact (quantitative) shape and lies beyond the scope of the current analysis.

Residents and firms individually choose location in the city. In theory, they may locate in the same area or in different districts. In this paper we focus on spatial equilibria sustaining monocentric cities.

4 Monocentric-city spatial equilibrium

A monocentric city includes a central business district (CBD) on the interval $[-b_1, b_1]$, and is surrounded by two symmetric residential areas of equal size on the intervals $[-b_2, -b_1)$ and $(b_1, b_2]$,

[13] For a discussion on how the spatial concentration of firms affects productivity, see Rosenthal and Strange (2020).

with $0 < b_1 < b_2$. In the presence of WFH, each firm and resident respectively use β and $1+\gamma$ units of lands so that the total size of the business area is equal to βM and the total size of the residential areas to $(1+\gamma) M$. Because of symmetry we can restrict our attention to the RHS of the city, i.e. $x, y \in [0, b_2]$. The district border between firms and residents is given by $b_1 = \beta M/2$ and the one between residents and farmers by $b_2 = (1+\beta+\gamma) M/2$. The length of residential area is equal to $b_2 - b_1 = (1+\gamma) M/2$. The firm density in the CBD is $m(y) = 1/\beta$ while the residential density is $n(x) = 1/(1+\gamma)$. Maintaining global interaction in the office center implies so that $\alpha/\tau > 2b_1 = \beta M$. This restricts our study to cities with sizes lower than $\overline{M} \equiv \alpha/(\tau\beta)$, which we assume in the following.

4.1 Urban production

In a monocentric city, the impact of WFH on urban production combines its effects on business spillovers and city geography. As the firm's production function is given by $A(y) = (\beta+\phi)\int_{-b_1}^{b_1}(\alpha - \tau|z-y|)m(z)\mathrm{d}z$ with $m(z) = 1/\beta$ and $b_1 = \beta M/2$. WFH has two effects on the productivity of a firm located at y. On the one hand, a lower β decreases this productivity because employees match fewer employees from other firms (fall in $(\beta+\phi)$). On the other hand, it increases productivity because the business district becomes more dense and more compact (rise in $m(z)$ and fall in b_1). We can indeed write the productivity as

$$A(y) = \begin{cases} \left(\frac{\beta+\phi}{\beta}\right)\left[\beta M\alpha - \tau\left(\frac{1}{4}\beta^2 M^2 + y^2\right)\right] & \text{if} \quad y \in [0, \beta M/2] \\ (\beta+\phi) M (\alpha - y\tau) & \text{if} \quad y \in [\beta M/2, (1+\beta+\gamma) M/2] \end{cases}$$

It is a concave and quadratic function of y in the city business district and linearly decreasing function of y in the residential area. Within the business district, WFH decreases productivity if and only if

$$\frac{\mathrm{d}A(y)}{\mathrm{d}\beta} = \frac{M}{4}(4\alpha - M\tau(2\beta+\phi)) + \frac{\tau}{\beta^2}\phi y^2 > 0$$

This condition holds true in the absence of management spillovers where $\phi = 0$. In this case, WFH reduces productivity of all firms. The worsening of employee spillovers dominates the effect of stronger business density and compactness. For $\phi > 0$, WFH induces productivity losses in all firms if $M \leq 4\alpha/[\tau(2\beta+\phi)]$; that is, for small enough cities. Otherwise, it induces productivity gains in central firms ($y = 0$) and productivity losses for peripheral firms ($y = b_1$). Because of their closer distances to other firms, central firms gain more from stronger density and compactness than they lose from worsened employee spillovers.[14]

The above effect is reflected in the total urban production given by $TP = \int_{-b_1}^{b_1} A(y)m(y)\mathrm{d}y = (\beta+\phi)(\alpha - \beta\tau M/3) M^2$, which increases with larger β if and only $M \leq 3\alpha/[\tau(2\beta+\phi)]$. So, *WFH induces the fall of total urban production in small cities and its rise in large cities.* Also, it can be seen that total urban production is a concave function of β with a maximum when $\beta = \beta^{TP} \equiv 3\alpha/(2\tau M) - \phi/2$. Hence, *WFH induces a non-monotonic relationship with total urban productivity.* When β^{TP} lies between 0 and 1 and as on-site worktime β decreases from 1 to 0, total production firstly increases, reaches a maximum production at β^{TP} and finally decreases. In this sequence, the benefits from more dense and compact business district firstly outweigh the loss of employees' spillovers, then equate them and finally are dominated by them. By the same argument, the same conclusions hold for the average urban productivity TP/M. This property replicates Behrens et al.' (2021) "mixed blessing of WFH" whereby the economy benefits only from lower intensities of WFH. While these authors base this property on the existence of product diversity in an urban intermediate sector, the present model generates it from the existence of economies of business spillovers and business district compactness.

4.2 Spatial equilibrium

In a spatial equilibrium, land is assigned to its highest value. Since workers are able to relocate at no cost within the city, they must reach the same utility level U^*, independently of their workplaces and residences. If it were not the case, they would have incentives to move to the urban location that offers the highest utility. The maximum land rent that they can offer in order to locate at a location x is given by the following residential bid-rent function:

$$\Psi(x, U^*) = \max_y \frac{w(y) - \beta t\,|x-y| - U^*}{1+\gamma} \tag{4}$$

Under free entry, profits are pushed to zero: $\pi(y) = 0$. Therefore, the maximum land rent that a firm can offer is given by the following business bid-rent function:

$$\Phi(y) = \frac{A(y) - w(y)}{\beta} \tag{5}$$

[14] It can be shown that $\mathrm{d}A(y)/\mathrm{d}\beta$ is never negative for $y \in [0, \beta M/2]$ under global interactions. So, WFH cannot induce productivity gains in all firms.

For simplicity, we approximate the value of alternative use of land (farming) to zero. In the monocentric city, the land market equilibrium satisfies the following conditions:

$$\Phi(y) \geq \max\{\Psi(y), 0\}, \qquad y \in [0, b_1] \tag{6}$$

$$\Psi(x) > \max\{\Phi(x), 0\}, \qquad x \in [b_1, b_2] \tag{7}$$

That is, residents must offer the highest bid rents in the residential district and firms must do so in the business district.

Necessary conditions At the district borders b_1 and b_2, land rent arbitrage imposes the following necessary equilibrium conditions:

$$\Phi(b_1) = \Psi(b_1) \tag{8}$$

$$\Psi(b_2) = 0 \tag{9}$$

Condition (9) expresses the land market competition between residents and farmers. Importantly, condition (8) expresses the land market competition between firms and residents.[15] Furthermore, firms and residents are also active in the labor market.

As discussed in Fujita and Thisse (2002), residents must obtain the same equilibrium utility wherever they work: $U^* = w(y) - \beta t\,(x - y) - (1 + \gamma)\,R(x)$. Taking the wage at $y = b_1$ as the reference point, this imposes following labor-commuting arbitrage conditions for residents at x:

$$w(y) + \beta t y = w(b_1) + \beta t b_1, \qquad y \in [0, b_1] \tag{10}$$

That is, in equilibrium, workers should be compensated by higher wages when they work further away from their residences (smaller y). Otherwise they would offer their work force in firms closer to their homes. This simplifies the residential and firm bid rents as

$$\Psi(x, U^*) = \frac{w(b_1) + \beta t b_1 - \beta t x - U^*}{1 + \gamma} \quad \text{and} \quad \Phi(y) = \frac{A(y) + \beta t y - w(b_1) - \beta t b_1}{\beta} \tag{11}$$

The identities (8) and (9) solve for the equilibrium utility U^* and wage $w(b_1)$ (see Appendix A) that will help characterizing the effect of WFH below. Before this discussion, it is important to establish the sufficient condition for which the monocentric city is a spatial equilibrium.

[15] This condition is absent in most monocentric city analyses where the CBD is assumed to offer an unlimited amount of land to firms (e.g. Brueckner et al. 2021).

Existence We here check the existence of the spatial equilibrium. As pointed earlier, firms and residents may locate in the same area rather than separate districts. To show that conditions (6) and (7) hold, we here show that the bid rents do not cross twice on the interval $[0, b_2]$. Indeed, the above analysis shows that the residential bid rent function Ψ is linear on $[0, b_2]$. Also, being a linear function of the productivity A, the business bid rent function Φ inheritates from the properties of A: it has a concave and quadratic piece on $[0, b_1]$ and a linear decreasing piece on $[b_1, b_2]$, is continuous and has continuous derivative at b_1. As a consequence, it can readily be shown that the bid rents cross only at one location b_1 on the interval $[0, b_2]$ if and only if $\Phi(0) > \Psi(0)$. Using the above definitions and conditions, the latter condition holds and the monocentric city is a spatial equilibrium if and only if

$$M > M_m \equiv \frac{2}{\tau} \frac{t\beta}{\beta + \phi} \frac{1 + \beta + \gamma}{1 + \gamma} \tag{12}$$

As shown in the literature, monocentric cities are spatial equilibria under low enough commuting cost t and high enough economies of density measured by τ. Otherwise, residents have incentives to locate to the city center, which breaks the monocentric configuration and leads to the formation of a mixed area at the geographical center of the city (see Fujita and Ogawa 1982). It can readily be shown that M_m falls with smaller β and larger γ. Hence, monocentric cities are sustained for a larger range of population sizes when WFH is adopted. Finally, stronger management spillovers ϕ reduce M_m and improve the sustainability of smaller cities. This is because they unequivocally strengthen the economies of business density and entice firms to bid higher rents in the business center.

Proposition 1 *Monocentric cities are spatial equilibria if $M > M_m$. WFH facilitates the formation of monocentric cities for a wider range of population sizes.*

The effect of WFH on the existence of a monocentric city equilibrium goes through three channels. First, WFH mitigates the sustainability of monocentric cities because it reduces business spillovers (lower $(\beta+\phi)$), which reduces economies of business density and prohibits firms to sustain high land rents in the urban geographical center. Second, WFH improves their sustainability because it reduces the effective commuting cost (lower $t\beta$) and - as will will see below - reduces the residents bid rents in the center of the business district. Finally, WFH also improves sustainability because larger home office space γ reduces the ratio $(1 + \beta + \gamma) / (1 + \gamma)$ in the above expression.

Intuitively, residents can more hardly bid a large land rent if they need additional space for their remote work.

We now study the properties of land rents and wages.

5 Equilibrium rents and wages

Given the equilibrium existence conditions, we can now discuss the determinants of the equilibrium prices for land and labor.

5.1 Residential land rents

After plugging the equilibrium wage and utility in $\Psi(x, U^*)$, the residential land rent is given by

$$R(x) = \frac{\beta t}{1+\gamma}\left[(1+\beta+\gamma)\,\frac{M}{2} - x\right] \tag{13}$$

(see Appendix A). By the land market arbitrage with farmers, this land rent is zero at the city border $b_2 = (1+\beta+\gamma)\,M/2$. It is equal to the commuting cost savings that residents get when they dwell closer to the business center. Since residents have same net salary across firms $(w(y) + \beta t y)$, they differ only in their commuting patterns to the business center. Knowing the residence location, landlords capture those commuting cost savings.

WFH decreases the gradient of residential land rent $t\beta/(1+\gamma) < 1$, because it falls with lower β and higher γ. Smaller on-site presence β reduces commuting costs while bigger home office space γ spreads the commuting cost savings over larger land plots. Brueckner et al. (2021) empirically show this relationship between land rent gradient and WFH. This is shown in Figure 1 where the black curve represents the land rents without WFH ($\gamma = 0$, $\beta = 1$) while gray curves have WFH with $\beta = 0.75$. The solid gray curve has $\gamma = 0.15$ and the dashed gray one has $\gamma = 0.40$. Residential land rent is presented at the right hand of each curve (above $x = 2.5$).

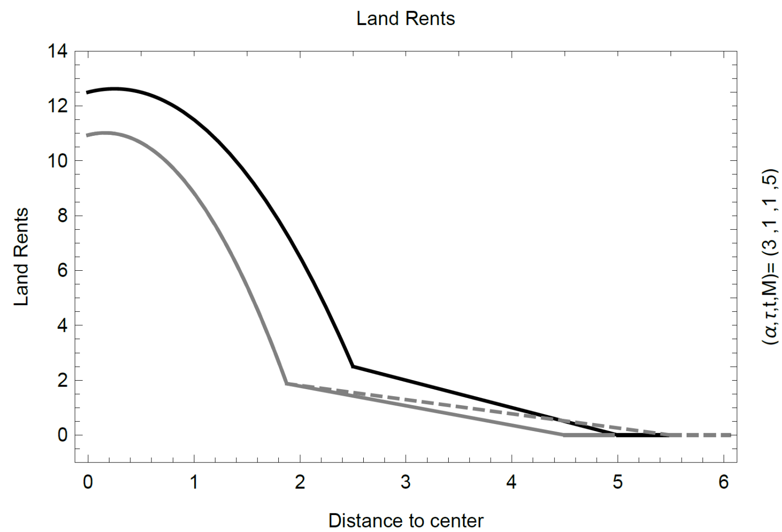

Figure 1: Effect of teleworking on land rents

From this, it can be deduced that if WFH also reduces the city border $b_2 = (1 + \beta + \gamma) M/2$, it decreases the value of residential land rent everywhere. In this case, the land rent rotates counterclockwise and shifts to the left. This happens if $\gamma < 1 - \beta$; that is, if the land used for home office space is smaller than the land savings by firms. Otherwise, if $\gamma > 1 - \beta$, the city expands and residential district spreads over the farming land, which raises land rent above zero around the city border. So, the land rent may rise in some sections of the residential district and fall in others. To solve this ambiguity, we define $R^0(x) = t (M - x)$ as the land rent in the absence of remote working ($\beta = 1$ and $\gamma = 0$). Then, it can be shown that there exists a location $x_a \in (b_1, b_2)$ such $R(x) \geq R^0(x)$ if and only if $x \geq x_a$ (see Appendix A). In this case, WFH reduces the residential land rent on $[b_1, x_a)$ and raises it on $(x_a, b_2]$. On the former interval, land rents fall because landlords are restrained to reap lower savings in commuting cost while they increase in the latter interval because residents demand more space.

The total residential land rent is given by $TR = 2 \int_{b_1}^{b_2} R(x)\mathrm{d}x = \frac{1}{4}\beta t (1 + \gamma) M^2$, which falls with lower β, rises with larger γ and therefore implies an ambiguous effect of WFH. It can be shown that this is smaller than the total rent in the absence of WFH (say TR^0 where $\beta = 1$ and $\gamma = 0$) if and only if $\gamma < (1 - \beta) / \beta$. WFH hence reduces total residential land rent if the land used for extra home office space is not too large compared to firms land savings, which concurs with our discussion above. By contrast, the average residential land rent, given by $AR = TR/(2 (b_2 - b_1)) = TR/((1 + \gamma) M) = \frac{1}{4}\beta t M$, increases in β. As a consequence, *WFH reduces the average residential land rent.*

Finally, we turn to the impact of WFH on the house prices. Under WFH, residents use more space and pay a house rent $(1+\gamma) R(x)$. WFH raises house rents if and only if $(1+\gamma) R(x) > R^0(x)$ where the RHS is the house rent in the absence of remote work. It can be shown that there exists a location x_b such that WFH decreases house rents on $[b_1, x_b)$ and increases them on $(x_b, b_2]$ (see Appendix A). Because the location x_b is not the same as x_a, WFH may thus induce opposite changes in land and house rents. In particular, WFH increases land rent but decreases house rents in the interval $[x_a, x_b]$ when $\gamma > (1-\beta)$ and leads to the opposite change in the interval $[x_b, x_a]$ otherwise.

Proposition 2 *WFH decreases the residential land rent everywhere if $\gamma < 1-\beta$. Otherwise, it decreases it near the city center and increases it near the city edges. House rents follow a similar pattern. WFH reduces the average residential land rent.*

5.2 Business land rent

The business land rent is given by $R(y) = \Phi(y)$ and simplifies to

$$R(y) = \frac{\beta+\phi}{\beta^2}\tau \left[\left(\frac{\beta M}{2} \right)^2 - y^2 \right] + ty \tag{14}$$

for $y \in [0, \beta M/2]$ (see Appendix A). It includes the production surplus created at location y in excess to the output at the business district border and a compensation for commuting cost inside the business district. The first term is indeed equal to $[A(y) - A(b_1)] / \beta$ so that landlords extract a rent only from the production in excess to that at the business district border. If they were extracting more, firms would relocate just beyond this border. Finally, stronger management spillovers ϕ raise this rent as landlords can reap firms' profit from stronger economics from business density.

What is the impact of WFH? It is apparent that the business land rent does not depend on the resident land size, $1+\gamma$. It can be shown that it increases with on-site presence β everywhere in the district ($\mathrm{d}R(y)/\mathrm{d}\beta > 0$ for $y \in [0, \beta M/2]$). Hence, *WFH decreases business land rents.* This is depicted in Figure 1. As a result, WFH also decreases the average business land rent. Also, because the business district shrinks with WFH, the total business land rent falls with it. Finally, the land rent paid by a firm is equal to $\beta R(y)$, which also falls with remote working. So, by adopting a WFH scheme, *firms save on office costs not only because they reduce their office space but also because rents fall in the business district land market.*

Proposition 3 *WFH decreases business land rents everywhere and therefore decreases the total and average rents on business land.*

Summarizing our results, we find that WFH pushes land rents downward in the business district and in the residential areas close to the border with the firms. Moreover, average land rents fall in both of the districts. This leads to the following corollary:

Corollary 4 *On average, landlords lose from the implementation of remote working schemes. Only landlords owning plots at the city edges gain from such schemes.*

5.3 Wages

According to the land-labor arbitrage condition (10), the equilibrium wage is equal to $w(y) = w(b_1) + \beta t(b_1 - y)$, so that firms must pay workers a reference wage $w(b_1)$ and compensate for the commuting costs within the business district. Plugging the equilibrium wage and district borders in this expression gives the equilibrium wage

$$w(y) = A(b_1) - t\beta y = (\beta + \phi)\, M \left(\alpha - \tau\beta \frac{M}{2} \right) - t\beta y$$

(see Appendix A). This wage includes the full value of production at the border of the business district, $A(b_1)$. As explained above, landlords extract only the production surplus above the one realized at the business district border. Since firms are unable to make profit under free entry, workers extract the rest of the production value. Workers therefore reap the economies of density created by management and employee spillovers.

WFH impacts wages through a fall in β and a rise in γ. On the one hand, note that the wage does not compensate for extra residential land required for home office, γ. Although firms save office space by relocating work tasks in less expensive residential areas, there is no market force that pushes them to compensate workers for their additional expenditure. On the other hand, the wage is a concave function of on-the-job physical presence β. This comes from the non-monotone relationship between β and A explained in Section 4.1. The same conclusion applies: WFH induces the fall of wages in small cities and their rise in large cities.

The average wage is defined as $\frac{1}{M}\int w(y)m(y)\mathrm{d}y$. It can be successively written as $\frac{2}{M}\int_0^{b_1} w(y)\frac{1}{\beta}\mathrm{d}y = A(b_1) - \frac{2}{M}t\int_0^{b_1} y\mathrm{d}y$. It includes the (lowest) productivity in the business district and the average commuting cost in this district. As seen in Section 4.1, the former is a non-monotone function of β. The latter increases with β as larger β pushes up the business district border b_1. So, WFH inherits the properties of productivity: it induces the fall of wages in small cities and their rise in large cities while the relationship between home worktime $(1-\beta)$ and average wage is bell-shaped.

Proposition 5 *WFH reduces the average wages in small cities and raises them in large cities. Higher worktime share at home has a bell-shaped impact on average wages.*

6 Equilibrium and optimal WFH

The above analysis shows that WFH has different impacts on prices for land and labor within the urban space and across cities. We now discuss how citizens are affected by WFH, what their best level of WFH is and how the latter differs from the urban planner's choice.

6.1 Equilibrium utility

The spatial equilibrium conditions (8) and (9) yield the residents' equilibrium utility

$$U^* = (\beta + \phi)\, M \left(\alpha - \tau\beta\frac{M}{2}\right) - \beta\,(1 + \beta + \gamma)\, t\frac{M}{2} \tag{15}$$

(see Appendix A). The first term reflects the positive effect of economies of business density and the second term the negative effect of commuting costs. WFH implies lower on-site presence but also additional home office space. As in the literature, it increases with larger firm productivity α and lower commuting cost t and lower business travel cost τ. In (15), larger home office space γ has a negative impact on equilibrium utility but the impact of physical work presence β has an ambiguous effect.

We compare the equilibrium utility with the utility U^0 obtained in the absence of remote work ($\beta = 1$ and $\gamma = 0$). We get

$$U^* - U^0 = -M\,(1-\beta)\left(\alpha - (1+\beta)\,\tau\frac{M}{2}\right) + (1-\beta)\,\phi\tau\frac{M^2}{2} + (2 - \beta\,(1+\beta+\gamma))\, t\frac{M}{2} \tag{16}$$

The first term expresses a utility loss from lower employee spillovers while the second term reflects a utility gain accrued to management spillovers. So, the nature of the business spillovers matters for urban equilibrium utility. The third term expresses a gain or loss due to commuting costs: there are losses if home office space is large enough $\gamma > 2/\beta - (1+\beta) \geq 0$. This is because the extra land used for home office space implies a city expansion and therefore increases commuting distances. Note that a very small amount of remote work ($\beta \to 1$) makes this expression negative because economies of business density are not altered but the additional home office space γ increases the size of residential land, which implies longer commutes.

Expression (16) is positive for population sizes $M < M_1$ where M_1 is its unique positive root. Therefore, WFH has a negative impact on utility for cities with population lower than M_1 and a positive effect for larger urban populations. As a result, *WFH benefits residents-workers only in large enough cities.* This reflects the properties of productivity under business spillovers and WFH.

From the residents' viewpoint, the best living conditions are obtained when her equilibrium utility (16) is maximized. The residents' best office worktime is then obtained for

$$\beta^* = \frac{(2\alpha - M\tau\phi) - t(1+\gamma)}{2(t + M\tau)}$$

This decreases with larger extra land used for home office work γ. Intuitively, the latter expands the residential area and commuting costs, which must be compensated by lower commuting time and therefore lower worktime at the office. It also decreases with the strength of management spillovers, ϕ. In contrast to employee's spillovers, management spillovers unambiguously strengthen from the increased compactness of the business district caused by WFH. As firms break even under free entry, this gain is shifted to workers-residents. Finally, residents' best office worktime decreases with larger urban populations, M. If $\beta^* \leq 0$, residents prefer no on-site presence and therefore full WFH. If $\beta^* \geq 1$, they prefer no WFH.

Proposition 6 *Small fractions of remote work worsen workers' utility. Remote work decreases equilibrium utility in small cities and increases it in large cities.*

6.2 First best

We here consider the welfare from a utilitarian urban planner's viewpoint. The city welfare includes the firms' production minus workers' commuting cost:

$$W = 2\int_0^{b_1} A(y)m(y)\mathrm{d}y - 2\int_{b_1}^{b_2} t\beta \left|x - y(x)\right| n(x)\mathrm{d}x$$

where again the land opportunity cost is assumed to be nil. After substitution, this gives

$$W = (\beta + \phi) \left(\alpha - \beta\tau\frac{M}{3} \right) M^2 - t\beta \left(1 + \beta + \gamma\right) \frac{M^2}{4}$$

The welfare has the same properties as the above equilibrium utility: it increases with larger α and lower t, τ and γ. It is a bell-shaped function of M and β. As above, it can be shown that, for a given $\gamma > 0$, very small WFH time ($\beta \to 1$) is not beneficial.

The welfare-maximizing on-site presence is obtained for

$$\beta^{**} = \frac{4\left(3\alpha - M\tau\phi\right) - 3t\left(1 + \gamma\right)}{2\left(3t + 4M\tau\right)}$$

This falls with prevalence of management spillovers ϕ, commuting cost t, home office space γ and impact of proximity in spillovers τ while it rises with the benefit from interactions α. It also falls with population size M. In that case, bigger city have more remote working. We can compare this outcome with the one chosen by the residents:

$$\beta^{**} \geq \beta^{*} \iff 2M\alpha\left(3t + 2M\tau\right) + \tau M^2 t\left(1 + \gamma - \phi\right) \geq 0$$

This holds true if management spillovers are not too strong, i.e. $\phi < 1 + \gamma$. In such a case, the welfare-maximizing on-site presence is higher than the one that maximizes residents' utility.

Residents have therefore an incentive to promote too much remote working. This result stems from the following balance: First, the planner internalizes the positive externality that firms impose on each other through business spillovers when they choose to locate in the business district. The planner therefore wants to settle firms in a more compact business district, which is possible through more WFH. Second, the planner internalizes the negative effect of economies on business density implied by the reduction in employees' spillovers. This entices the planner to require less WFH. Third, the planner considers the whole value created by the city, which includes both utility and land value. Given that landlords lose from WFH in the land market equilibrium, the planner has incentives to reduce WFH. Overall, the first and third effect dominate. Note also that the above constraint is more likely to be satisfied for large city size for $\phi < 1 + \gamma$.

Proposition 7 *Residents desire more WFH than the social optimum if management spillovers are not too strong.*

Finally, note that the above result is obtained with an inelastic land use of home office space γ. However, home office space may increase in proportion to the time of office worktime such that

$\gamma = \gamma(\beta)$. To check the robustness of our above results to this issue, consider for instance that the home office space is proportional to remote work time such that $\gamma(\beta) = 1 - \beta$.[16] In this case, the use of space by the pair of firm and its mass of workers-residents is unchanged so that city border does not change because of WFH. The optimal utility and welfare WFH levels simplify to

$$\widehat{\beta}^{*} = \frac{2\alpha - M\tau\,(\phi + 1) - t}{2M\tau} \quad \text{and} \quad \widehat{\beta}^{**} = \frac{6\alpha - 2M\tau\phi - 3t}{4M\tau}$$

Those thresholds have the same properties as above. Residents want more remote work than the planner ($\widehat{\beta}^{**} > \widehat{\beta}^{*}$) if and only if $\alpha + M\tau > t/2$. This simplifies the trade-off between production (α), business spillovers (τ) and commuting cost (t).

7 Short run choice of WFH

The above analysis holds in the long run when the land market has cleared and firms and residents have restructured their uses of space. However, in the short run firms and residents may not have a common be agreement about generalized WFH at the market prices of land and labor. In this case, the land market may be locked in an equilibrium where WFH does not catch up. An external event like the Covid pandemic may push firms and workers to remote working and, after adaptation of land use and land market, may lead to another equilibrium with wide spread WFH. We explain this phenomenon is this section.

Suppose the absence of WFH in the short run. Firms and residents do not change location and take the prices of land and labor $R^0(x)$ and $w^0(x)$ as givens (the superscript ^{0} denotes the situation where $\beta = 1$ and $\gamma = 0$). The labor-commuting arbitrage condition imposes that residents at any location $x \in [M/2, M]$ are indifferent to work in any firm located at $y \in [0, M/2]$.

On the one hand, residents balance the commuting cost savings with land rents associated to home work space. The utility gain from WFH is given by $\Delta U^0(x, y) = t\,(1 - \beta)\,(x - y) - \gamma R^0(x)$ where $R^0(x) = t(M - x)$. There are gainers and losers. The highest gain, $\max \Delta U^0(x, y) = t\,(1 - \beta)\,M > 0$, is obtained for the longest commuting distance $x - y = M$ when $x = M$ and

[16] Then, we compute the welfare as

$$W = (\beta + \phi)\,(\alpha - \beta\tau M/3)\,M^2 - \frac{t\beta}{4} 2M^2$$

$y = 0$. The lowest gain, $\min \Delta U^0(x, y) = -\gamma t M/2 < 0$, is obtained for the shortest commuting distance $x - y = 0$ when $x = y = M/2$. There obviously are conflicts of interest amongst residents about the adoption of WFH.

On the other hand, firms balance productivity changes with land rent savings. They indeed lose the production value

$$\Delta A^0(y) \equiv \left(\beta^{1/2} - 1\right) \int_{-M/2}^{M/2} (\alpha - \tau |z - y|)\, m^0(y) \mathrm{d}z < 0.$$

where $m^0(y) = 1$ and where the last integral is a convex increasing function of y. Therefore, the most central firms lose the largest production value. A firm embraces remote working only if it restructures its land and saves the rent $(1 - \beta) R^0(y)$. Its net gain is equal to $\Delta\pi^0(y) = \Delta A^0(y) + (1 - \beta) R^0(y)$, or after substitution of business land rents (14),

$$\Delta\pi^0(y) = -\left(1 - \beta^{1/2}\right) \left[M\alpha - (B + 2)\,\tau \left(\frac{M}{2}\right)^2 + B\tau y^2\right] + (1 - \beta)\, t y$$

where $B = \left(1 + \beta^{1/2}\right)(1 + \phi) - 1 > 0$. This is a quadratic, concave function of $y \in [0, M/2]$ with positive slope at the city center $y = 0$. Firms at the very center of the city do not have the highest incentives to implement WFH because they pay high land rents and lose much of their productivity by allowing remote working. Several cases occur according to the sign of $\Delta\pi^0(0)$ and $\Delta\pi^0(M/2)$ and the discriminant of this quadratic function. First, if $\Delta\pi^0(0) \geq 0$ and $\Delta\pi^0(M/2) \geq 0$, the net gain $\Delta\pi^0(y)$ is positive for all locations $y \in [0, M/2]$ so that all firms want to implement WFH. Second, if $\Delta\pi^0(0) < 0$ and $\Delta\pi^0(M/2) \geq 0$, the net gain is negative for firms close enough to the center and positive for the others. Firms active at the business district geographical center are opposed to WFH while others promote it. Third, if $\Delta\pi^0(0) < 0$, $\Delta\pi^0(M/2) < 0$ and the discriminant is negative, all firms have a net loss and do not want to implement WFH. Finally, if $\Delta\pi^0(0) < 0$, $\Delta\pi^0(M/2) < 0$ and the discriminant is positive, there exists a subset of locations for which firms gains and outside which they lose. To sum up, firms have divergent or convergent incentives according to the parameter values and city sizes.

This paper follows the literature where the implementation of WFH is uniform across workers and firms (e.g. Behrens et al. 2021, Brueckner et al. 2021). Although this view may depart from the reality, it strongly simplifies the analysis as it avoids to study the spatial assignment between residents and firms with differentiated levels of WFH. We therefore view WFH as a social norm or a collective decision where its implementation is organized through some consensus amongst residents and firms. In the practice, in many countries, governments, unions and firms' representatives negotiate the WFH implementation conditions and their framing in legislatory setup.[17] This requires the agreement of the whole society. To make things simple, we here assume that the implementation of WFH results for the agreement of the majority of residents and firms in the city.

Consider the residents distributed on the interval $[M/2, M]$. In equilibrium, any equilibrium assignment function $y(x)$ between home and work locations is possible. Yet, given the unit demands and supplies of labor and land by firms and residents, this assignment function must satisfy $y'(x) \in \{-1, 1\}$. Then, the resident's net gain from WFH becomes $\Delta U^0(x) = t\,(1-\beta)\,(x - y(x)) - \gamma t(M - x)$, which is a strictly increasing function of x. Residents' preferences for WFH are therefore ranked according to the distance to the city center whatever work-home assignment function. It implies that the swing resident is located at $x = 3M/4$ and incurs a short run utility gain if and only if $\Delta U^0(3M/4) \geq 0$. It can be shown that this is always true if $1 - \beta \geq \gamma$ and always false if $1 - \beta \leq \gamma/3$. Very intuitively, the swing resident prefers WFH if it reduces more her commuting trips than it increases her land use. For $1 - \beta \in (\gamma/3, \gamma)$, the swing individual's choice depends on her job place assignment.

Consider then the firms distributed on the interval $[0, M/2]$. Since firms' gain from WFH is given by $\Delta\pi^0(y)$. The claim by the majority of firms depends on each of the four cases discussed above. In the first and third cases, there is unanimity amongst firms either to implement or reject WFH. In the second and fourth ones, the outcome depends on the roots of $\Delta\pi^0(y)$. To ease the exposition we have recourse to a numerical analysis.

Figure 2 displays an example of the short-run collective decisions in favor of WFH by workers (pink) and firms (blue) for various values of on-site work share β and city sizes M. It also shows the parameters supporting a long-run workers' utility gain (gray). The lower black area shows the set of parameters that do not support monocentric cities as imposed by the equilibrium condition (12). The upper black area shows the set of parameters that cannot be studied because they

[17] Employee and company collective agreements that will regulate remote work in a post-Covid-19 Europe are discussed in EU-OSHA (2021).

Such agreements are also negotiated in Canada. by the Canadian Union of Public Employees: https://cupe.ca/negotiating-work-home-language-bargaining-table.

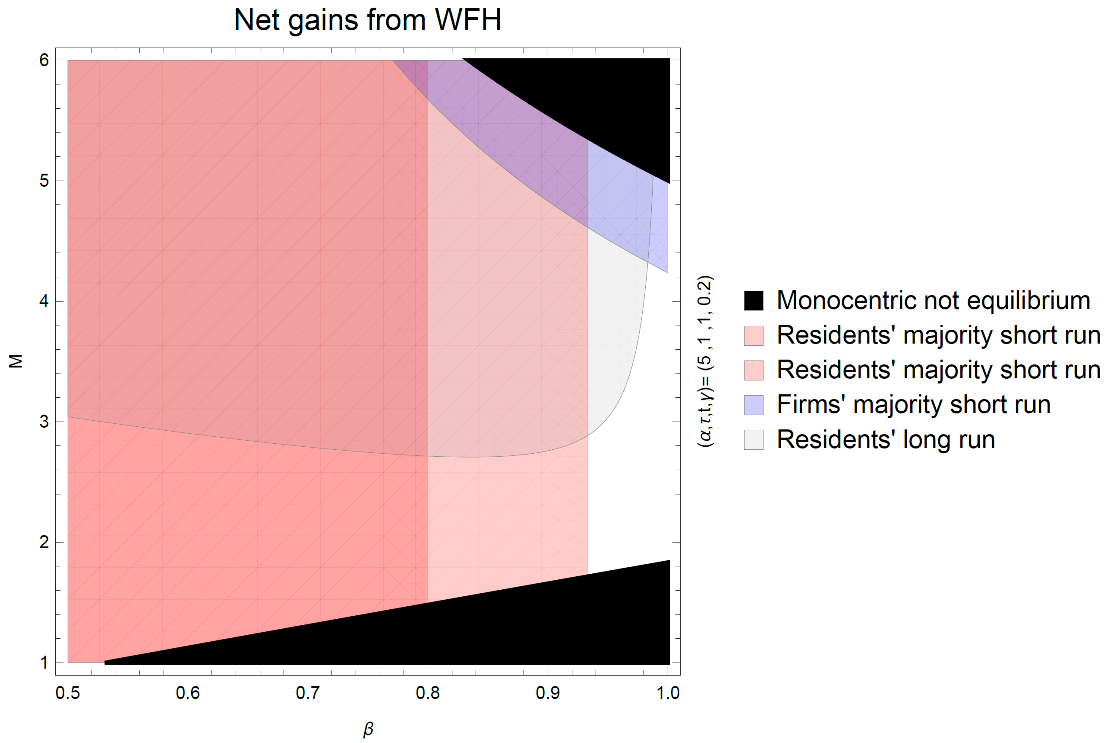

Figure 1: Figure 2: Short vs long run choices of WFH

break the global interaction assumption. As it can be seen, increasing fractions of WFH (lower β) support the formation of equilibrium monocentric cities for a larger set of urban population sizes. In this example, the majority of workers agrees to telework as soon as on-site job presence is lower than $\beta = 0.8$ (dark pink). The majority of workers disagrees (blank) as soon as on-site job presence is higher than $\beta = 0.93$. The agreement on WFH is easier to obtain for larger time working from home. For $\beta \in (0.8, 0.93)$, the majority's agreement depends on residents' effective commuting distances. Similarly, the majority of firms (blue) supports hybrid working schemes only in the case of large cities ($M > 4.5$) and when employees do not spend more than one-fourth of their time working from home ($\beta > 0.76$). In the long run, workers support remote work for city sizes above roughly $M = 2.8$ and on-site job presence lower than roughly $\beta = 0.95$ (gray).

8 Discussion

Hybrid work models will probably persist in the post-pandemic era. Employees will be expected to return to their workplaces, but they will be most probably be allowed to work remotely some days per week/month. This working scheme is likely to provide more advantages compared to full on-site and full remote work schemes. In this paper, we study how WFH can change the internal structure of cities and we estimate the benefits and losses associated with the adoption of a hybrid work model.

Our results suggest that the changes in the demand for office and home office space can either shrink or expand the city size. The business area shrinks and the business land rents decrease. The residential land rents decrease in more central locations, while they may increase close to the boundaries of the city. Remote work benefits the residents of large cities. Finally, we study what the choice of WFH is in the short run, when rents and wages are fixed. We show that workers and firms have different incentives with respect to the implementation and the frequency of WFH.

WFH is not a panacea. Our analysis shows that the optimal level of WFH is lower than the one preferred by workers. The gap between these two levels requires some policy intervention that will assure that WFH will not exceed the optimal level. Examples of policies that can ensure that are subsidizing office work, taxing WFH or defining a social norm that will promote the welfare maximizing WFH level. The implementation of these or other policies needs discussion and further investigation.

Our model can be extended to analyse a number of interesting and related issues. First, an open question in many countries is who should pay the home office expenses when people WFH. In some countries, people are able to claim tax relief on the additional costs of remote work, such as electricity, heat or broadband. There might also be some options or tax-incentives for employers to cover employee expenses. The second interesting question is whether WFH is good or bad for the environment. The savings from the lower use of energy at the office and the less frequent commuting should be compared to the higher energy use at home and the longer commuting distances. Our model can answer this question, but the true answer requires some quantitative analysis. Third, our model assumes exogenous use of space. Endogenizing the density will allow us study the more realistic case of increasing housing size as we move towards the suburbs of the city. This shall be particularly important when studying the environmental impact of remote work. We leave this ideas for future research.

Appendix

Necessary conditions, rents and wages Conditions (8) and (9) give two linear equations that solve as

$$w(b_1) = A(b_1) - \frac{\beta^2}{1+\gamma} t\,(b_2 - b_1) \tag{17}$$

$$U^* = A(b_1) - \frac{\beta\,(1+\beta+\gamma)}{1+\gamma} t\,(b_2 - b_1) \tag{18}$$

where $b_2 - b_1 = (1+\gamma)\,M/2$ and

$$A\,(b_1) = A\left(\frac{\beta M}{2}\right) = (\beta+\phi)\,M\left(\alpha - \tau\frac{\beta M}{2}\right) \tag{19a}$$

Those conditions are used to compute the residential and firm rents.

The residential rent is given by $R(x) = \Psi(x, U^*) = [w(b_1) + \beta t b_1 - \beta t x - U^*]\,/\,(1+\gamma) = t\beta\,(b_2 - x)\,/\,(1+\gamma)$, which yields (13). The rent without WFH ($\beta = 1$ and $\gamma = 0$) is given by $R^0(x) = t\,(M - x)$. Then, $R(x) \geq R^0(x)$, if and only if $x \geq x_a$ where

$$x_a \equiv \frac{M}{2} + (1-\beta)\,\frac{1+\beta+\gamma}{1-\beta+\gamma}\frac{M}{2} \in (b_1, b_2)$$

The house rent is equal to $(1+\gamma)R(x)$. WFH raises house rents if and only if $(1+\gamma)\,R(x) > R^0(x)$ where the RHS is the house rent in the absence of remote work. Some lines of computations show that $(1+\gamma)\,R(x) \geq R^0(x)$ if $x \geq x_b$ where

$$x_b \equiv \frac{2 - \beta\,(1+\beta+\gamma)}{(1-\beta)}\frac{M}{2}$$

and where $x_a \leq x_b$ if and only if $\gamma \geq (1-\beta)$.

The business bid rent is given by $R(y) = \Phi(y) = [A(y) + \beta t y - w(b_1) - \beta t b_1]\,/\beta = [A(y) - A(b_1)]\,/\beta + ty - tb_1 + \beta t\,(b_2 - b_1)\,/\,(1+\gamma)$, which yields (14). The equilibrium wage obtains by combining (17) and (19a).

Existence We have to show that $\Phi(0) > \Psi(0)$. Using (11), (17) and (18), this is equivalent to $A(0) - A(b_1) > \beta t b_1\,(1+\beta+\gamma)\,/\,(1+\gamma)$ where the LHS reflects production and its economies of business density and the RHS reflects commuting costs. Applying the values of district borders yields

$$M > M_m \equiv \frac{2}{\tau}\frac{t\beta}{\beta+\phi}\frac{1+\beta+\gamma}{1+\gamma}$$

References

[1] Althoff L., Eckert, F., Ganapati, S., Walsh, C., 2021. The geography of remote work, NBER Working Papers 29181, National Bureau of Economic Research, Inc.

[2] Antràs, P., Garicano, L., Rossi-Hansberg, E., 2006. Offshoring in a Knowledge Economy. Quarterly Journal of Economics, 121(1): 31–77.

[3] Antràs, P., Garicano, L., Rossi-Hansberg, E., 2008. Organizing Offshoring: Middle Managers and Communication Costs. The Organization of Firms in a Global Economy, edited by E. Helpman, T. Verdier, D. Marin, p. 311-39. Cambridge, MA: Harvard University Press.

[4] Arzaghi, M., Henderson, J.V., 2008. Networking off Madison Avenue. *Review of Economic Studies*, 75 (4), 1011–1038.

[5] Augeraud-Veron, E., Maruhenda, F., Picard, P. M., 2021. Local Social Interaction and Urban Equilibria. Mathematical Social Sciences, 112(C): 72-83.

[6] Barrero, J., Bloom, N., Davis, S., 2020. Covid-19 is also a reallocation shock, Edited by Jeffrey Miron, Cato Institute, 2020, http://www.jstor.org/stable/resrep26227.

[7] Barrero, J., Bloom, N., Davis, S., 2021a. Why working from home will stick. Working paper.

[8] Barrero, J., Bloom, N., Davis, S., 2021b. Let me work from home or I will find another job. Working paper.

[9] Bartik, A., Cullen, Z., Glaeser, E., Luca, M., Stanton, C., 2020. What jobs are being done at home during the Covid-19 crisis? Evidence from firm-level surveys, NBER Working Paper 27422.

[10] Behrens, K., Kichko, S., Thisse, J.F., 2021. Working from Home: Too Much of a Good Thing?, CESifo Working Paper Series 8831, CESifo.

[11] Bloom, N., Liang, J., Roberts, J., Ying, J., 2015. Does Working from Home Work? Evidence from a Chinese Experiment. Quarterly Journal of Economics, 130(1): 165–218.

[12] Bloom, N., Sadun, R., van Reenen, J., 2016. Management as a technology? NBER Wroking Paper Series.

[13] Bloom, N., Sadun, R., van Reenen, J., 2012. The organization of firms across countries. *Quarterly Journal of Economics*, 1663-1705.

[14] Brueckner, J., Kahn, M.E., Lin, G.C., 2021. A New Spatial Hedonic Equilibrium in the Emerging Work-from-Home Economy?, NBER Working Papers 28526, National Bureau of Economic Research, Inc.

[15] Brynjolfsson, E., Horton, J., Ozimek, A., Rock, D., Sharma, G. Yi Tu Ye, H., 2020. COVID-19 and Remote Work: An Early Look at US Data. Working paper.

[16] Ciccone, A. Hall, R.E., 1996. Productivity and the Density of Economic Activity. *American Economic Review* 86, 54-70.

[17] Combes, P. P., Gobillon, L. (2015). The empirics of agglomeration economies. In Handbook of regional and urban economics 5, 247-348.

[18] Davis, M.A., Ghent, A.C., Gregory, J.,M., 2021. The Work-at-Home Technology Boon and Its Consequences, Working paper.

[19] De Fraja G., Matheson, J., Rockey, J., 2020. Zoomshock: The geography and local labour market consequences of working from home, Discussion Papers 20-31, Department of Economics, University of Birmingham.

[20] Delventhal, M., Kwon, E., Parkhomenko, A., 2021. JUE Insight: How do cities change when we work from home? Journal of Urban Economics, 103331.

[21] Delventhal, M., Parkhomenko, A., 2021. Spatial implications of telecommuting. Working paper.

[22] Dingel J.I., Neiman, B., 2020. How many jobs can be done at home? White Paper, Becker Friedman Institute for Economics at UChicago

[23] EU-OSHA, 2021. Regulating telework in a post-COVID-19 Europe. European Agency for Safety and Health at Work. ISBN: 978-92-9479-541-0.

[24] Fujita, M., Ogawa H., 1982. Multiple Equilibria and Structural Transition of Non-Monocentric Urban Configurations. *Regional Science and Urban Economics*, 12: 161-196.

[25] Fujita, M., Thisse, J.-F., 2002. Economics of Agglomeration: Cities, Industrial Location and Regional Growth. Cambridge University Press.

[26] Global Workplace Analytics, 2021. Work-At-Home After Covid-19 – Our Forecast. https://globalworkplaceanalytics.com/work-at-home-after-covid-19-our-forecast

[27] Gibbs, M., Mengel, F., Siemroth, C., 2021. Work from Home and Productivity: Evidence from Personnel and Analytics Data on IT Professionals. Working paper.

[28] Greenstone, M., Hornbeck, R., Moretti, E., 2010. Identifying agglomeration spillovers: Evidence from winners and losers of large plant openings. *Journal of Political Economy*, 118: 536-598.

[29] Gupta, A., Mittal, V., Peeters, J., Van Nieuwerburgh, S., 2021. Flattening the Curve: Pandemic-Induced Revaluation of Urban Real Estate. NBER Working Papers 28675, National Bureau of Economic Research, Inc.

[30] Kyriakopoulou, E., Picard, P.M., 2021. On the design of sustainable cities: Local traffic pollution and urban structure. Journal of Environmental Economics and Management, 107: 102443.

[31] Lennox, J., 2020. More working from home will change the shape and size of cities, Centre of Policy Studies/IMPACT Centre Working Papers g-306, Victoria University, Centre of Policy Studies/IMPACT Centre.

[32] Liu, S., Su, Y., 2021. The impact of the COVID-19 pandemic on the demand for density: Evidence from the US housing market. Economics Letters, 207: 110010.

[33] Lucas, R., Rossi-Hansberg, E., 2002. On the internal structure of cities. *Econometrica*, 70:1445-1476.

[34] Moretti, E., 2004. Human capital externalities in cities. In Handbook of Urban and Regional Economics, vol. 4, edited by J. Vernon Henderson and Jacques-François Thisse. Amsterdam: North-Holland.

[35] OECD, 2020. Productivity gains from teleworking in the post COVID-19 era: How can public policies make it happen? OECD Policy Responses to Coronavirus (COVID-19).

[36] Ramani, A., Bloom, N., 2021. Time to make the donuts: Real estate in the COVID-19 era. Policy Brief: Institute for Economic Policy Research (SIEPR), Standford.

[37] Regnier, C., Legras, S., 2018. Urban Structure and Environmental Externalities. *Environmental and Resource Economics*, 70: 31

[38] Rosenthal, S. S., Strange, W.C., 2008. The Attenuation of Human Capital Spillovers. *Journal of Urban Economics* 64 (2): 373–89.

[39] Rosenthal, S. S., Strange, W.C., 2020. How close is close? The spatial reach of agglomeration economies. *Journal of Economic Perspectives*, 34 (3), 27-49.