Productivity Externalities of Working from Home: Welfare and Policy Implications *

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November 21, 2026

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Abstract

I study the socially optimal mix of onsite work and remote work. I develop a model in which workers choose how much to work onsite versus from home, without internalizing the productivity spillovers that occur within and between onsite and remote workers. I measure these spillovers using post-pandemic U.S. survey data at the city-sector-work mode level. Remote work generates positive but weaker productivity spillovers than onsite work. The effect of hybrid workers' onsite time on productivity varies across cities and sectors. Matching the model to these data, I find that a social planner could, on average, improve social welfare by encouraging more onsite workers but encouraging hybrid workers to spend more time working from home. Remote productivity spillovers lower the cost of achieving the socially optimal work arrangement.

Keywords: productivity externality, remote collaboration technology, working from home, social welfare, optimal policy

JEL Classication: C54, D62, H23, R13

* I am extremely grateful to Farid Farrokhi, Chong Xiang, David Hummels, and Victoria Prowse for their invaluable support and guidance on this project. I am also sincerely thankful to Yichen Su, Lindsay Relihan, Sunham Kim, Xiaofang Dong, John R Umbeck, J Ryan Umbeck for their insightful feedback. I am greatly appreciative of the helpful comments and suggestions from MEA, Remote Work Conference, UEA and SMUE.

1 Introduction

There is a substantial increase in working from home (WFH) due to the COVID-19 pandemic. In 2025, an average worker in the U.S. spent around 27% of workdays WFH, which is around a 4-fold increase compared to the pre-pandemic level (around 7%) (Barrero et al. (2021)). The surge of working from home and reduction in in-person interaction raise a concern that the society may benefit less from productivity spillovers stemming from physical proximity. Is the shift to WFH socially optimal? One key to answering this question lies in whether more remote workers generate positive externalities that might compensate for reduced externalities from less onsite interaction.

Empirical studies suggest that more remote workers may create productivity spillovers through sharing, matching, and learning. Sharing arises as a larger user base spurs innovation in remote technologies used by remote workers (Bloom et al. (2021)). Matching improves when remote work connects firms with distant workers (Akan et al. (2025)) and expands job access for disabled workers and caregivers (Bloom et al. (2026); Harrington and Kahn (2025); Song (2025)). Learning occurs as workers learn from others through remote collaboration (Forman and van Zeebroeck (2019); Chen et al. (2022); Brucks and Levav (2022); Ishikura (2026)). Productivity spillovers may also arise between remote and onsite workers through virtual interactions and more efficient task allocation across work modes.

While the literature has separately studied productivity spillovers from physical proximity[1] and the benefits of remote work and remote collaboration , these papers have not addressed the relative strength of onsite and remote productivity spillovers and how these spillovers affect the social optimum. This paper quantifies onsite and remote productivity spillovers, the gap between the socially optimal and the market equilibrium level of onsite work, and the optimal policies to achieve the social optimum.

I begin by documenting two empirical facts about onsite and remote work: first,

[1] For surveys of the agglomeration economies studies and estimates of agglomeration elasticities, see Rosenthal and Strange (2004); Melo et al. (2009); Combes and Gobillon (2015); Ahlfeldt and Pietrostefani (2019); Donovan et al. (2024).

the extent of remote work varies by city and sector, and second, remote (onsite) workers' residual wages are positively correlated with remote (onsite) employment size across cities and sectors.

Motivated by the empirical pattern, I employ a Roy-Fréchet model in which workers in each city choose a sector and one of three work arrangements (onsite, hybrid, or fully WFH). Hybrid workers choose their shares of onsite and WFH time by comparing productivity and disutility across the two work modes. Remote labor consists of fully WFH workers' work time and hybrid workers' WFH time; onsite labor consists of fully onsite workers' work time and hybrid workers' onsite time. Productivity spillovers can occur within and between onsite labor and remote labor. In other words, both onsite and remote labor can contribute to both onsite and remote productivity. Four productivity elasticity parameters measure within-mode and cross-mode productivity spillovers.

In addition, I consider an intensive margin of productivity externalities that measures how much remote (onsite) productivity increases when hybrid workers spend more time working from home (onsite). The remote time elasticity captures the gain from more remote labor net of the loss of cross-mode spillover from less onsite labor. The same applies to the onsite time elasticity. These elasticities vary by city and sector with labor composition and the hybrid workers' onsite time share. The model predicts that a larger gap between onsite and remote time elasticities leads to a larger gap between the social optimum and the market equilibrium for hybrid workers' onsite share. I'm not aware of any literature that directly investigates this intensive margin of productivity spillover.

I match the model to U.S. 2022-2025 Current Population Survey (CPS), Quarterly Census of Employment and Wages (QCEW), and American Community Survey (ACS) data for estimation and quantification. The data provide employment, wages, hybrid workers' onsite-time shares by city-sector-work arrangement, and commuting time. I use these observable variables to recover the model shifters and estimate the productivity spillover effects. Productivity spillover effects are estimated using a 2SLS regression implied by the model. It regresses the residual wages of fully onsite or fully WFH workers on onsite and remote labor across cities and sectors. I use Bartik instrumental variables

to identify the productivty spillover elasticities. The Bartik instruments are constructed by interacting the occupation share within city-sector cells in 2000 with the national level of onsite labor or remote labor in the occupation. The identification assumption is that the occupation share in 2000 is uncorrelated with the error term that affects the changes in fully onsite or fully remote workers' wages during 2022-2025, conditional on city-sector fixed effects.

For within-mode spillovers, the estimated onsite spillover elasticity is around 40 % larger than the estimated remote spillover elasticity. For cross-mode spillovers, the estimated onsite-to-remote spillover is larger than the estimated remote-to-onsite spillover. Based on these four estimates and the labor composition across city-sector cells, I calculate the onsite and remote time elasticities that measure the impact of hybrid workers' time allocation on productivity. Remote time elasticity is larger than onsite time elasticity in most city-sector cells.

I then solve for the socially optimal level of labor allocation, measure the gap between the social optimum and the market outcome and calculate the subsidies required to achieve the social optimum. The subsidies incentivize hybrid workers to adjust their shares of time spent working onsite to achieve the socially optimal levels of onsite time and employment composition through productivity spillover and labor mobility effects.

The main findings are that, on average, a social planner would favor more onsite workers, less hybrid and remote workers but more WFH time for hybrid workers. The existence of remote productivity spillovers brings the market equilibrium closer to the socially optimal level of onsite work than in a case with no remote spillovers. On average, a social planner could improve welfare by 1% by decreasing hybrid workers' share of onsite time by 3% and increasing the number of fully onsite workers by 1%. This could be accomplished by levying an income tax and offering a subsidy to onsite work equal to 3% of hybrid workers' gross income. Without remote productivity spillovers, a 2% welfare improvement would require larger changes: hybrid workers' share of onsite time would need to increase by 41%, and the number of fully onsite workers would need to increase by 4%. Achieving this outcome would require a higher subsidy—36% of hybrid

workers' gross income when funded by an income tax.

There exist variations across cities and sectors. In 31 % of city-sector cells, a social planner would favor hybrid workers spending more time working onsite because the onsite time elasticity is larger than remote time elasticity or onsite distuility is smaller than WFH disutility in these cells. The socially optimal employment allocation features a shift from initially high-income to low-income sectors and results in a reduction of the income premium for onsite, hybrid, and fully WFH workers.

This paper relates to four strands of literature. The first strand of literature empirically studies how remote work affects productivity spillovers. Some researchers document the negative effect of WFH on onsite productivity spillovers: Frakes and Wasserman (2021) and Emanuel et al. (2022) show that increased WFH reduces knowledge sharing at the individual level using citation patterns and online feedback data, respectively. Liu and Su (2022) show that more WFH reduces the urban agglomeration effect and urban wage premium. Other researchers document the benefits of remote collaboration at the firm (Forman and Van Zeebroeck (2012) and Forman and van Zeebroeck (2019)), institution (Chen et al. (2022)), and team levels (Brucks and Levav (2022); Ishikura (2026)).

The second strand of literature uses structural models to study the effect of remote work. Researchers make different assumptions about productivity spillover effects. Some studies assume that remote work does not contribute to productivity spillovers (Safirova (2002); Rhee (2008); Behrens et al. (2021); Delventhal et al. (2022); Monte et al. (2023)), while others consider the possibility that remote work generates productivity spillovers (Lennox (2020), Davis et al. (2024a), Delventhal and Parkhomenko (2026)). Davis et al. (2024b) consider onsite-to-remote productivity spillover. The model in this paper features endogenous time allocation and imperfect substitution between working onsite and WFH as in Delventhal and Parkhomenko (2026) and Davis et al. (2024a). This paper complements the existing literature by modeling and measuring productivity spillovers within and across onsite and remote work. Additionally, I use post-pandemic data to study the socially optimal level of onsite work, whereas previous studies match pre-pandemic data with their models to predict the effects of the WFH shock and use post-pandemic data

to verify those model predictions.

Third, this paper relates to the literature studying WFH policies. Safirova (2002) examines the subsidies and taxes required to achieve the socially optimal land allocation in a city with remote workers. Bertram et al. (2024) use a principal-agent model to study the optimal level of remote work and the related incentive scheme in a firm. Ding and Ma (2023) and Flynn et al. (2024) document firms' return-to-office policies. This paper considers socially optimal policies and quantifies city-sector-specific subsidies that incentivize hybrid workers to adjust their onsite work time.

Finally, this paper is related to the literature that studies the socially optimal allocation in the presence of productivity spillovers (Fajgelbaum and Gaubert (2020); Rossi-Hansberg et al. (2019)). In these studies, market equilibrium deviates from social optimum in terms of employment. This paper shows that the market equilibrium may also deviate from the social optimum in terms of work time allocation between working onsite and WFH.

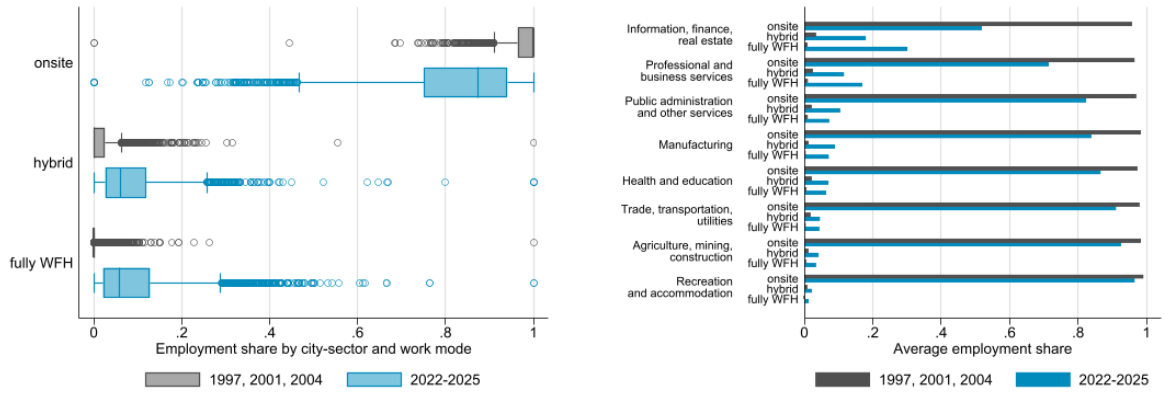
The structure of the paper is as follows. Section 2 discusses empirical facts about onsite and remote work. Section 3 presents a basic theoretical model with homogeneous workers. Section 4 presents the full model with variations in cities, sectors, and work modes. Section 5 describes the data and estimation of productivity spillovers. Section 6 analyzes the quantification results for the gap between the market outcome and the social optimum and the socially optimal subsidies. Section 7 concludes.

2 Empirical Patterns of Working From Home

This section documents the increase in WFH, the variations of remote work across cities and sectors, the evidence suggesting remote externalities, and the residential and workplace patterns of onsite and remote workers.

The COVID-19 pandemic has caused a significant shift to WFH in the US. according to Barrero et al. (2023), the average share of full paid days WFH gradually increased from around 3% in 2003 to 7.2 % in 2019. After the pandemic, the average days WFH have persisted at around 25%-30 % from 2022 to 2026 (see Figure 15, 16 in the appendix),

which is around a 4-fold increase compared to the pre-pandemic level.



(a) Distribution of Work Mode Composition Across City-Sector Cells

(b) City Averages of Employment Share by Work Mode and Sector

Figure 1: Increased Hybrid and Fully Working from Home Workers

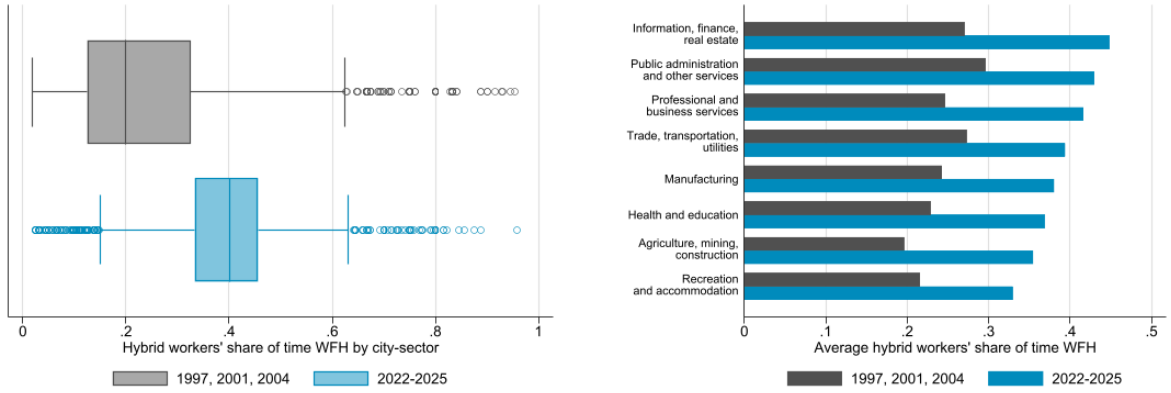
Note: The figure first calculates the share of onsite, hybrid, and fully WFH workers within city-sector cells. Figure 1(a) shows the distribution across city-sector cells. Figure 1(b) shows the average across cities within each sector. Post-shock monthly shares are first averaged within each city-sector cell. The data source is the Current Population Survey (CPS) Work Schedules Supplement in May 1997, 2001, and 2004 and the basic monthly CPS from October 2022 to December 2025. The samples exclude self-employed, armed-forces, and unpaid workers. 1997,2001,2004 data only count paid work at home.

The increase in WFH also appears at the city-sector level employment share (Figure 1) and work time (Figure 2). Figure 1(a) compares the distribution of the share of onsite, hybrid, and fully WFH workers at the city-sector level before and after the WFH shock. It shows that the shares of hybrid and fully WFH workers increase in the first three quantiles of the distribution.

Figure 1(b) compares the city averages of onsite, hybrid, and fully WFH shares in 8 industry groups before and after the WFH shock. Across all sectors, the average shares of hybrid and fully WFH shares increase, and the onsite shares decrease. The magnitude of these changes varies across sectors. In the information, finance, and real estate group, hybrid and fully WFH shares rise to approximately 5 and 30 times their pre-pandemic levels, respectively. The change in the recreation and hospitality group is a relatively smaller increase.

Figure 2(a) shows that the median of hybrid workers' WFH time across city-sector cells rises from 20.0% to 40.5%. Figure 2(b) shows that across all sectors, the city average of the share of time spent WFH for hybrid workers increases. The variation across sectors

is not as large as the variation in terms of the number of hybrid workers as in Figure1(b). Hybrid workers' WFH time in the information and financial activities increases by 67 %, and that in recreation and accomodation also increases by 53 %.



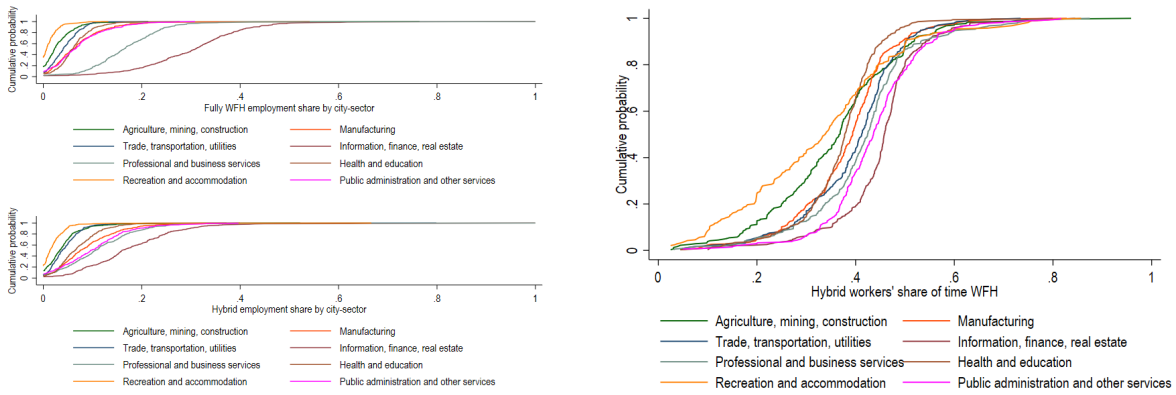
(a) Distribution of the Average Share of Time WFH by Hybrid Workers Across City-Sector Cells

(b) City Averages of Hybrid Workers' Share of Time WFH by Sector

Figure 2: Hybrid Workers Spend More Time Working from Home

Note: The figure first calculates the share of onsite, hybrid, and fully WFH workers within city-sector cells. Figure 1(a) shows the distribution across city-sector cells. Figure 1(b) shows the average across cities within each sector. Post-shock monthly shares are first averaged within each city-sector cell. The data source is the Current Population Survey (CPS) Work Schedules Supplement in May 1997, 2001, and 2004 and the basic monthly CPS from October 2022 to December 2025. The samples exclude self-employed, armed-forces, and unpaid workers. 1997,2001,2004 data only count paid work at home. The share of time spent WFH is weekly WFH hours divided by total weekly work hours.

Focusing on the measures after the WFH shock, the level of remote work varies across cities and sectors. Figures 1(b) and 2(b) demonstrate the sectoral variations. Based on the average across cities, the information, finance, and real estate sector has around 18% hybrid workers and 30 % fully WFH workers, while the recreation and accommodation group has less than 3%. Hybrid workers in theinformation, finance, and real estate sector spend nearly 45% of their work time WFH, whereas those in the recreation and accommodation sector spend around 33% of their work time WFH. Figure 3 shows the cumulative distribution of remote employment or work time shares by sector across cities. Different curves show the variations in remote work levels across sectors. Each curve in Figure 3(a) shows that within a sector, fully WFH and hybrid employment shares vary across cities. Figure 3(b) shows that within each sector, hybrid workers' WFH time varies across cities.



(a) Cumulative Distribution of Employment Share

(b) Cumulative Distribution of Hybrid Workers' Share of Time WFH

Figure 3: Variations of Remote Employment and WFH Time Across Cities and Sectors

Note: The data source is the CPS basic monthly survey from 2022 October to 2025 December. The samples are labor forces excluding self-employed, armed forces, and unpaid family workers.

With the rise of WFH, the methods of knowledge sharing have shifted from relying primarily on in-person meetings to an increasing use of virtual interactions thanks to the wide adoption of video conferencing. Telecommunication technology facilitates knowledge sharing among remote workers and between onsite and remote workers. Figure (4) shows that a higher number of onsite and fully WFH workers is associated with higher average residual wages for these worker groups across city-sector cells. The positive correlation suggests that productivity externalities might also exist among remote workers.

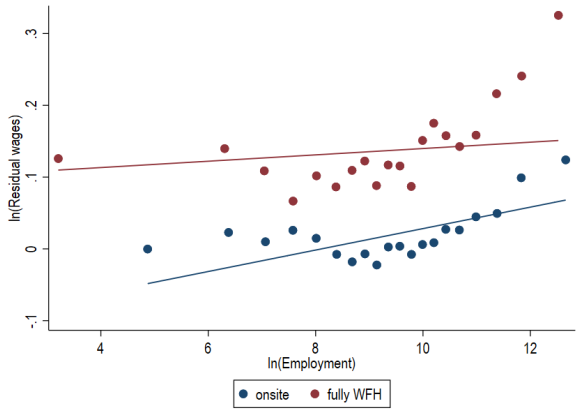


Figure 4: Onsite and Remote Productivity Externalities at the City-Sector Level

Note: The data source is the CPS basic monthly survey from 2022 October to 2025 December. The samples are labor forces excluding self-employed, armed forces, and unpaid family workers. The figures are binned scatterplots of residual wages against employment with the city fixed effect. Appendix F describes the method for obtaining residual wages.

Figure 4 implies the presence of onsite and remote productivity spillover within cities.

The onsite agglomeration effect within a city has been well documented. One may wonder to what extent the remote productivity externality within cities aligns with real-world practice, given that WFH provides feasibility in terms of work location. Table 1 reveals that nearly 85% of onsite workers and 96% of home-based workers live and work in the same core-based statistical area (CBSA). Additionally, Table 4 in the appendix shows that over 85% of onsite and home-based workers do not move across CBSAs in the short term. These empirical facts suggest local workforce stability, which may stem from two factors: first, the prevalence of onsite and hybrid work arrangements that encourage workers to live within commuting distance, and second, the influence of agglomeration effects on fully WFH workers. For example, remote workers live in the workplace cities to maintain professional connections within their local sector. This local workforce stability for remote workers contributes to the observed remote productivity externality at the CBSA-sector level.

Motivated by these empirical facts, I build a model incorporating onsite and remote productivity externalities. I begin with a basic model that focuses on implications of the productivity spillover pattern within one city with homogenous workers. In the full model, I introduce the variations by city, sector, and work mode.

Table 1: Most Onsite and Home-based Workers Live and Work in the Same CBSA

	2022-2024 average	
	on-site worker	home-based worker
Work and live in the same CBSA (%)	85.38	95.51
Work and live in different CBSA (%)	14.62	4.49
Observation	7,869,305	

Note: The data source is the American Community Survey (ACS). Samples are wage workers excluding unpaid family workers and military workers. Residence PUMAs and workplace PWPUMAs are matched to CBSAs using the allocation procedure described in Section 5.

3 The Basic Model

3.1 The Market Outcome

3.1.1 Preference and Production

Consider a city with $\bar{L}$ homogenous workers. Each worker chooses the share of time spent working onsite and consumes tradable goods and housing. The utility function of a worker is:

$$U = \frac{c^{\alpha} h^{1-\alpha}}{\bar{\phi} d(\theta)}, \tag{1}$$

where c and h are the quantities of tradable goods and housing, respectively. The constant is $\bar{\phi} = \alpha^{\alpha}(1-\alpha)^{1-\alpha}$. $\theta \in [0,1]$ is the share of time spent working onsite. Total work time is normalized to 1. Therefore, $1-\theta$ represents the share of time spent WFH.

The disutility $d(\theta)$ is a weighted average of disutility for onsite work (ζ^o)[2] and amenity costs of WFH (ζ)[3]:

$$d(\theta) = \theta\zeta^o + (1-\theta)\zeta. \tag{2}$$

The derivative of disutility with respect to the share of time spent working onsite is:

$$d'(\theta) = \zeta^o - \zeta. \tag{3}$$

When onsite disutility equals WFH amenity costs, total disutility is a constant. When onsite disutility is greater than WFH amenity cost $(\zeta^o > \zeta)$, total disutility increases with the share of time spent working onsite; conversely, when onsite disutility is less than WFH amenity cost, total disutility decreases with the share of time spent working onsite.

The budget constraint of the worker is $Pc+qh = I(\theta)$, where P is the price of tradable goods, q denotes the housing price, and $I(\theta)$ refers to income. Income combines wages $(W(\theta))$ and returns from returns to land (R). Assuming the ratio of land returns to wages is $r = R/W(\theta)$, then workers' income can be expressed as $I(\theta) = (1+r)W(\theta)$. A

[2] In the full model, I use commuting costs to measure onsite disutility.

[3] This function form follows Delventhal and Parkhomenko (2026). It leads to a concise and intuitive solution of θ in market equilibrium (7).

worker's total wage is the unit wage multiplied by hybrid productivity: $W(\theta) = wA^h(\theta)$. Hybrid productivity combines the remote and onsite components:

$$A^h(\theta) = \left[\left(A^f(1-\theta) \right)^{\frac{\rho-1}{\rho}} + \left(A^o\theta \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}, \tag{4}$$

where remote productivity A^f and onsite productivity A^o are given constants from workers' perspective. ρ denotes the elasticity of substitution between WFH and working onsite. The model focuses on the imperfect substitution between WFH and working onsite ($\rho > 1$). Davis et al. (2024a) estimats ρ is around 3.5.

Given the share of time spent working onsite, the indirect utility function is:

$$u = \frac{(1+r)W(\theta)}{d(\theta)P^{\alpha}q^{1-\alpha}}. \tag{5}$$

Workers face trade-offs between onsite and WFH distulity and onsite and remote productivity when deciding the share of time spent working onsite. Spending more time working onsite means (1) experiencing more disutility from onsite work but less amenity cost from WFH, and (2) relying more on onsite productivity and less on remote productivity to produce outputs and earn wages. Maximizing the indirect utility with respect to θ yields the first-order condition that characterizes the share of time spent working onsite chosen by workers:

$$\frac{\theta}{1-\theta} = \left(\frac{A^o}{A^f} \right)^{\rho-1} \left(\frac{\zeta}{\zeta^o} \right)^{\rho}. \tag{6}$$

Equation (6) indicates that the relative onsite share increases with relative onsite productivity and relative onsite amenity (inverse of onsite disutility). Rearranging this equation gives the solution for the share of time spent working onsite:

$$\theta = \frac{1}{1 + (\frac{\zeta^o}{\zeta})^{\rho}(\frac{A^f}{A^o})^{\rho-1}}. \tag{7}$$

The production function of tradable goods is $Y = A^h(\theta)\bar{L}$. By profit maximization, the wage is $W(\theta) = PA^h(\theta)$. The price of tradable goods P is normalized to 1.

The construction firm uses land and tradable goods to produce housing. Assume the

production function for the housing sector is

$$H = K^{\gamma}\bar{H}^{1-\gamma}, \tag{8}$$

where K is the tradable goods used for producing housing. $\bar{H}$ is land used. γ is the share of tradable goods used in producing housing. The housing supply elasticity is $\frac{\gamma}{1-\gamma}$, thus $\gamma = 0$ suggests a perfectly inelastic housing supply; $\gamma = 1$ corresponds to a perfectly elastic housing supply.

The profit maximization problem of the housing production firm is $\max_{K,\bar{H}} \pi = qK^{\gamma}\bar{H}^{1-\gamma} - pK - r\bar{H}$, where r denotes the unit returns to land. Solving the problem gives the total land returns: $R\bar{L} = r\bar{H} = (1-\gamma)qH$. Combining housing market clearing ($h\bar{L} = H$) and demand for housing ($h = (1-\alpha)\frac{I}{q}$) gives the housing quantity $H = \frac{(1-\alpha)I\bar{L}}{q}$. The returns to land become $R\bar{L} = (1-\alpha)(1-\gamma)I\bar{L} = (1-\alpha)(1-\gamma)(W(\theta)+R)\bar{L}$. Re-arranging this equation gives the ratio of rent to wages as $\bar{r} = \frac{1}{\alpha+\gamma(1-\alpha)} - 1$. Therefore, income can be expressed as $I = \frac{1}{\alpha+\gamma(1-\alpha)}W(\theta)$.

By the profit maximization problem of the housing production firm, the demand for tradable goods used to produce housing is $K = \gamma\frac{qH}{P}$. Substituting the housing demand $H = \frac{1-\alpha}{q}I(\theta)\bar{L}$ into this equation, K can be expressed as a function of income: $K = \gamma(1-\alpha)\frac{I(\theta)\bar{L}}{P}$. Combining this equation with housing market clearing, demand for housing, and the housing production function yields the housing price as $q = \left(\frac{(1-\alpha)I(\theta)\bar{L}}{\bar{H}}\right)^{1-\gamma}\left(\frac{P}{\gamma}\right)^{\gamma}$.

3.1.2 Productivity Externalities

Define onsite labor ($L^O(\theta)$) and remote labor ($L^R(\theta)$) as the total onsite and remote time:

$$L^O(\theta) = \theta\bar{L}, \;\; L^R(\theta) = (1-\theta)\bar{L}. \tag{9}$$

Onsite productivity increases with onsite labor and can also be contributed by remote labor:[4]

$$A^o(\theta) = \bar{a}^o \left[L^O(\theta)\right]^{\lambda} \left[L^R(\theta)\right]^{\tau_{ro}\mathbf{1}_{\{L^R\neq 0\}}}. \tag{10}$$

Remote productivity also increases with onsite labor and remote labor:

$$A^f(\theta) = \bar{a}^f \left[L^R(\theta)\right]^{\lambda^R} \left[L^O(\theta)\right]^{\tau_{or}\mathbf{1}_{\{L^O\neq 0\}}}. \tag{11}$$

Here $\bar{a}^o$ and $\bar{a}^f$ are exogenous onsite and remote productivity. The parameter λ is the elasticity of onsite productivity with respect to onsite labor, and τ_{ro} is its elasticity with respect to remote labor. The parameter λ^R is the elasticity of remote productivity with respect to remote labor, and τ_{or} is its elasticity with respect to onsite labor. λ and λ^R govern within-mode spillover effects, whereas τ_{ro} and τ_{or} govern cross-mode spillover effects.

There is no cross-mode spillover when $\tau_{ro} = \tau_{or} = 0$. A positive τ_{ro} captures a spillover from remote labor to onsite productivity, while a positive τ_{or} captures a spillover from onsite labor to remote productivity.

The indicator function $\mathbf{1}_{\{.\}}$ takes a value of 0 if remote labor or onsite labor is 0, and a value of 1 otherwise. At $\theta = 1$ there is no remote labor and $A^o(1) = \bar{a}^o(\bar{L})^{\lambda}$; at $\theta = 0$ there is no onsite labor and $A^f(0) = \bar{a}^f(\bar{L})^{\lambda^R}$.

3.1.3 The Share of Time Spent Working Onsite in Market Equilibrium

This section discusses how the share of time spent working onsite (θ) is determined in the market equilibrium, focusing on the interior case ($\theta \in (0, 1)$). Equation (7) shows that workers choose the share of time working onsite based on relative onsite productivity and relative onsite disutility. Workers do not internalize the spillover effect and take the onsite and remote productivity as given. Equation (7) characterizes the supply side of

[4] One may consider another form of externalities where remote labor and onsite labor are perfectly substitutable but subject to a discount for cross-mode spillover: $A^o(\theta) = \bar{a}^o \left[L^O(\theta) + \tau'_{ro} L^R(\theta)\right]^{\lambda'}$, $A^f(\theta) = \bar{a}^f \left[L^R(\theta) + \tau'_{or} L^O(\theta)\right]^{\lambda^{R'}}$, where $\tau'_{ro}, \tau'_{or} \in [0, 1]$ discount the cross-mode contribution. There is not enough data variation to identify cross-mode spillovers in this setup. Therefore, I use a cobb-doglaus form, which yields a tractable log-linear estimating equation.

the onsite time:

$$\theta = f\left(\frac{A^o}{A^f}\right) = \frac{1}{1 + (\frac{\zeta}{\zeta^o})^{-\rho}(\frac{A^o}{A^f})^{1-\rho}}.$$

Equations (11) and (10) imply that the relative onsite productivity is a function of the share of time spent working onsite:

$$\frac{A^o(\theta)}{A^f(\theta)} = \frac{\bar{a}^o}{\bar{a}^f}\frac{(\theta\bar{L})^{\lambda-\tau_{or}}}{((1-\theta)\bar{L})^{\lambda^R-\tau_{ro}}},\ \theta \in (0,1).$$

The relative onsite productivity characterizes the relative demand curve for onsite time. Since $\frac{\partial \ln(A^o(\theta)/A^f(\theta))}{\partial\theta} = \frac{\lambda-\tau_{or}}{\theta} + \frac{\lambda^R-\tau_{ro}}{1-\theta}$, relative onsite productivity is increasing in $\theta \in (0,1)$ when $\lambda \geq \tau_{or}$ and $\lambda^R \geq \tau_{ro}$. The curve of relative onsite productivity with respect to onsite time is horizontal when within and cross-mode spillover effects are the same ($\lambda = \tau_{or}$ and $\lambda^R = \tau_{ro}$). The share of time spent working onsite and relative onsite productivity are simultaneously determined. The intersection of the relative demand and supply curves for onsite time pins down the market outcome of onsite time θ as shown in Figure 5.

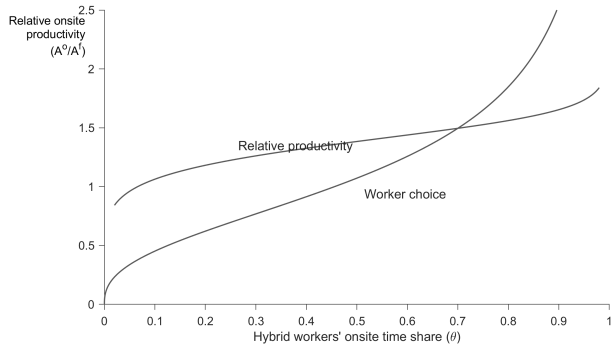


Figure 5: Onsite Time and Relative Onsite Productivity in Market Equilibrium

3.2 The Socially Optimal Share of Time Spent Working Onsite

3.2.1 The Intensive Margins of Productivity Externalities

In contrast to market equilibrium, a social planner will internalize the productivity externalities when choosing the share of time spent working onsite. Appendix B shows the process of solving the social planner's problem. The first-order condition characterizing

the interior solultion for the socially optimal share of time spent working onsite is

$$\frac{\theta}{1-\theta} = \left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{\rho-1} \left[\frac{\zeta + \underbrace{d(\theta)}_{\substack{\text{composite of} \\ \text{disutility}}} \left(\underbrace{\tilde{\gamma}}_{\substack{\text{housing} \\ \text{congestion}}} \left(\overbrace{\delta}^{\text{onsite productivity externality}} + 1\right) - 1\right)}{\zeta^o + \underbrace{d(\theta)}_{\substack{\text{composite of} \\ \text{disutility}}} \left(\underbrace{\tilde{\gamma}}_{\substack{\text{housing} \\ \text{congestion}}} \left(\underbrace{\delta^R}_{\substack{\text{remote} \\ \text{productivity} \\ \text{externality}}} + 1\right) - 1\right)}\right]^{\rho}, \tag{12}$$

where $A^o(\theta) = \bar{a}^o \left[L^O(\theta)\right]^{\lambda} \left[L^R(\theta)\right]^{\tau_{ro}\mathbf{1}_{\{L^R \neq 0\}}}$, $A^f(\theta) = \bar{a}^f \left[L^R(\theta)\right]^{\lambda^R} \left[L^O(\theta)\right]^{\tau_{or}\mathbf{1}_{\{L^O \neq 0\}}}$, $L^O(\theta) = \theta\bar{L}$, $L^R(\theta) = (1-\theta)\bar{L}$, $\tilde{\gamma} = \alpha + \gamma(1-\alpha)$ and $d(\theta) = \theta\zeta^o + (1-\theta)\zeta$.

δ and δ^R denote the intensive margins of onsite and remote productivity externalities, respectively:

$$\delta = \frac{\partial A^o(\theta)/A^o(\theta)}{\partial\theta/\theta} = \lambda - \tau_{ro}\frac{\theta}{1-\theta}, \theta \in (0,1), \tag{13}$$

and

$$\delta^R = \frac{\partial A^f(\theta)/A^f(\theta)}{\partial(1-\theta)/(1-\theta)} = \lambda^R - \tau_{or}\frac{1-\theta}{\theta}, \theta \in (0,1). \tag{14}$$

The onsite time elasticity δ measures how much onsite productivity changes with onsite time. It is the onsite spillover effect λ minus the loss of the remote-to-onsite spillover when onsite time rises. Similarly, the remote time elasticity δ^R measures how much remote productivity changes with WFH time. It is the remote spillover effect λ^R minus the loss of the onsite-to-remote spillover when remote time rises. When cross-mode spillove does not exist ($\tau_{ro} = \tau_{or} = 0$), intensive margin elasticities are the same as the within-mode spillover elasticities ($\delta = \lambda$ and $\delta^R = \lambda^R$).

3.2.2 Sources of Externalities

The first-order condition for the socially optimal onsite time (equation (12)) is different from the market equilibrium ($(\frac{\theta}{1-\theta} = \left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{\rho-1} \left(\frac{\zeta}{\zeta^o}\right)^{\rho})$) because the social planner internalizes externalities while workers do not. Equation (12) accounts for onsite and remote productivity externalities (δ, δ^R) and housing congestion ($\tilde{\gamma}$). In addition, these externalities interact with the composite of onsite and WFH disutility ($d(\theta)$). This section explains how these externalities create a social-market gap and under what conditions the gap disappears.

In terms of productivity, workers take onsite and remote productivity as constants. They do not internalize how their allocation in onsite or WFH time affects the aggregate productivity. However, a change in work-mode allocation affects productivity through spillover effects. The change in each productivity combines a positive within-mode spillover effect and a negative reallocation effect through the cross-mode spillover. For example, increasing onsite labor has a positive effect on onsite productivity through within-mode spillover and a negative effect on onsite productivity through cross-mode spillover due to reduced remote labor. The social planner internalizes these spillovers (governed by δ and δ^R), while workers do not. The productivity wedges disappear when $\delta = \delta^R = 0$. This condition need not require all four spllover elasticities to be zero.

Regarding housing, workers take housing prices as given when allocating work time onsite or remote. However, the share of time spent working onsite affects housing prices when the housing supply is not perfectly elastic ($\gamma \neq 1$). The share of time spent working onsite affects the efficiency units of labor. And an increasing efficiency unit of labor leads to a rise in income and thus higher housing demand and housing prices. The housing congestion is absent if the housing supply is perfectly elastic (when $\gamma = 1$, $\tilde{\gamma} = 1$.) or the consumption share of housing is extremely low (when $1 - \alpha \to 0$, $\tilde{\gamma} \to 1$.).

An additional composite of disutility appears in (equation (12)) due to the social-market disparity created by productivity externalities and housing congestion. In the presence of these two externalities, the social planner may choose a share of time spent working onsite that is different from the market equilibrium, which can result in a different composite of disutility in the social optimum compared to the market equilibrium. This changes the social-market gap caused by the externalities. This interaction effect will be illustrated in Figure 6, and 7. When the productivity externalities and housing congestion are absent ($\delta = \delta^R = 0$ and $\tilde{\gamma} = 1$), the market equilibrium coincides with the socially optimal allocation.

3.2.3 The Social Planner's Trade-offs

This section discusses the social planner's trade-offs. I start with the simplified case where there are only productivity externalities and then the case where all externalities

are present. Finally, I derive the condition that the share of time spent working onsite in the social optimum is larger than, smaller than, or equal to that in the market equilibrium in the presence of externalities.

By removing housing congestion (set $\tilde{\gamma} = 1$) and the interaction effect from work-mode disutility (set $\zeta^o = \zeta$), equation (12) becomes:

$$\frac{\theta}{1-\theta} = \left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{\rho-1} \left(\frac{1+\delta}{1+\delta^R}\right)^{\rho}. \tag{15}$$

The impact of onsite and remote externalities on the socially optimal onsite time resembles a rope-pulling contest, under imperfect subsitution between working onsite and WFH ($\rho \in (0,1)$) and fixed total working time. When the onsite time elasticity is stronger than the remote time elasticity ($\delta > \delta^R$), more onsite time results in a gain in onsite productivity that outweighs the loss in remote productivity, so the social planner prefers more onsite time than in the market equilibrium. When the onsite time elasticity equals the remote time elasticity ($\delta = \delta^R$), the socially optimal onsite time coincides with market equilibrium, which leads to the coincidence of other optimal allocations and the market outcome.

If all externalities are present as in equation (12), the social planner balances the positive and negative effects of the externalities to choose an optimal share of onsite time. For example, the social planner may choose a share of time spent working onsite that leads to higher productivity compared to market equilibrium at the costs of increased housing prices and increased composite of disutility. On the other hand, the social planner may choose a share of time spent working onsite that leads to lower productivity compared to market equilibrium with the gains from decreased housing prices and decreased composite of disutility. The gains in reduced disutility outweigh the decreased productivity cost, leading to higher social welfare.

To compare the share of time spent working onsite in market equilibrium and socially optimal level in the presence of all externalities, I transform the first-order condition of

optimal share of time spent working onsite as (Appendix B shows the derivation process):

$$\frac{\theta}{1-\theta} = \left(\frac{B(\theta)}{A(\theta)}\right)^{\rho-1} \left(\frac{\tilde{\gamma}(\delta+1)-\delta_d}{\tilde{\gamma}(\delta^R+1)-\delta_d^R}\right)^{\rho}, \tag{16}$$

where δ_d and δ_d^R are the elasticities of the disutility composite with respect to the share of time spent working onsite and share of time spent WFH, respectively:

$$\delta_d = \frac{\partial d(\theta)/d(\theta)}{\partial\theta/\theta} = \frac{(\zeta^o-\zeta)\theta}{d(\theta)}, \tag{17}$$

$$\delta_d^R = \frac{\partial d(\theta)/d(\theta)}{\partial(1-\theta)/(1-\theta)} = \frac{(\zeta-\zeta^o)(1-\theta)}{d(\theta)}. \tag{18}$$

In equation (16), $\tilde{\gamma}(\delta+1)-\delta_d$ incorporates the effect of changes in the share of time spent working onsite on housing price, onsite productivity, and the composite of disutility. $\tilde{\gamma}(\delta^R+1)-\delta_d^R$ incorporates the effect of changes in the share of time spent WFH on housing price, remote productivity, and the composite of disutility.

Comparing equation (16) with the first-order condition in the market equilibrium (equation (6)) gives the following conditions if $\theta^{soc}, \theta^{mkt} \in (0,1)$, $\frac{\theta}{1-\theta}\left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{1-\rho}$ is increasing in θ, and $\frac{\widetilde{\gamma}\left(\delta(\theta)+1\right)-\delta_d(\theta)}{\widetilde{\gamma}\left(\delta^R(\theta)+1\right)-\delta_d^R(\theta)} > 0$ [5].

$$\theta^{soc} = \theta^{mkt} \Leftrightarrow \frac{\widetilde{\gamma}(\delta+1)-\delta_d}{\widetilde{\gamma}(\delta^R+1)-\delta_d^R} = \frac{\zeta}{\zeta^o}, \tag{19}$$

$$\theta^{soc} > \theta^{mkt} \Leftrightarrow \frac{\widetilde{\gamma}(\delta+1)-\delta_d}{\widetilde{\gamma}(\delta^R+1)-\delta_d^R} > \frac{\zeta}{\zeta^o}, \tag{20}$$

$$\theta^{soc} < \theta^{mkt} \Leftrightarrow \frac{\widetilde{\gamma}(\delta+1)-\delta_d}{\widetilde{\gamma}(\delta^R+1)-\delta_d^R} < \frac{\zeta}{\zeta^o}, \tag{21}$$

where θ^{soc} refers to the socially optimal share of time spent working onsite. θ^{mkt} refers to the share of time spent working onsite in the market equilibrium. Equation (19) gives the condition for the market outcome to coincide with the social optimum in the presence of externalities. Equation (20) implies that the social planner chooses a higher onsite share than market equilibrium when the adjusted relative onsite spillover effect is larger than

[5] $\frac{\theta}{1-\theta}\left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{1-\rho}$ being increasing in θ implies $1+(1-\rho)\left[(\lambda-\tau_{or})(1-\theta)+(\lambda^R-\tau_{ro})\theta\right] > 0$for all$\theta \in (0,1)$.

the relative onsite amenity (relative WFH disutility).

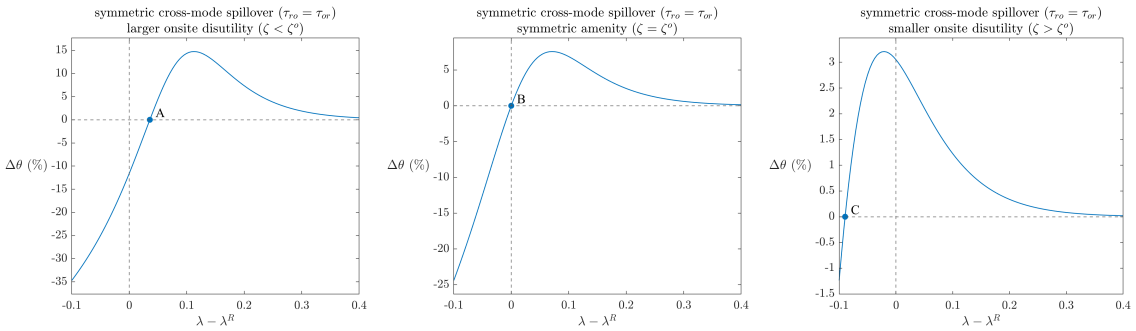
3.2.4 The Role of the Extensive Margin of Productivity Externalities

The previous section discusses how the intensive margin of productivity externality affects socially optimal onsite time. The intensive margin is governed by onsite and remote time elasticities (δ, δ^R) that measure how productivity changes with onsite or remote time allocation. This section discusses how the extensive margin of productivity externalities affects the sign and magnitude of the gap between the social optimum and market equilibrium. The extensive margin includes within-mode spillover (λ, λ^R) and cross-mode spillover (τ^{or}, τ^{ro}) that measure how productivity changes with onsite or remote labor pool.

Figure (6) shows how the gap between onsite and remote spillovers $(\lambda - \lambda^R)$ affects the social-market gap of the share of time spent working onsite. This effect interacts with the relative onsite amenity as shown in 3 cases of the figure. For simplicity, the figure assumes no cross-mode spillovers. The effect of cross-mode spillover will be discussed in Figure 7.

Figure (6) shows that the socially optimal onsite time coincides with the market equilibrium in an interior case and a corner case. The corner case corresponds to the onsite spillover being much larger than the remote spillover, where onsite time in the social optimum and the market equilibrium converge to fully onsite. The following discusses the interior cases denoted by points A,B,C.

In figure (6(b)), onsite disutility and WFH disutility are the same, so the composite of disutility is a constant and the interaction effect of composite of disutility mentioned in section 3.2.2 is absent. In this case, when extensive margins of onsite and remote productivity externalities have the same strength $(\lambda = \lambda^R)$, the market equilibrium coincides with the social optimum (point B). When oniste spillover is stronger, the social planner perfers more onsite work (Figure (6(b)) shows when $\lambda > \lambda^R$, $\Delta\theta > 0$).



(a) (b) (c)

Figure 6: The Gap Between Onsite-Remote Productivity Externalities Affects the Direction of the Optimum-Market Gap

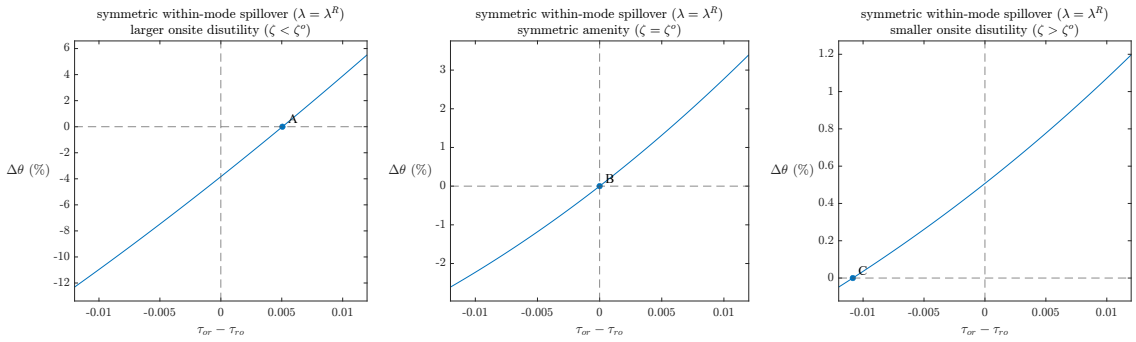
Note: $\Delta\theta = (\theta^{soc}/\theta^{mkt} - 1) \times 100\%$. Parameter values are $\lambda^R = 0.1$ (with $\lambda - \lambda^R$ on the horizontal axis), $\tau_{ro} = \tau_{or} = 0$, $\bar{a}^o = \bar{a}^f = 1$, $\rho = 3.5$, $\gamma = 0.09$, and $\alpha = 0.76$. The corresponding levels of θ^{mkt} and θ^{soc} are shown in Appendix Figure 17.

In figure (6(c)), onsite disutility is smaller than WFH disutility. Therefore, an increase in onsite time leads to a decrease in the composite of onsite and WFH disutility. Suppose the social planner increases the share of time spent working onsite; workers benefit from a reduction in the composite of onsite and WFH disutility, so the onsite spillover can be smaller than the remote spillover to keep the benefits from onsite and remote work balanced. The figure shows a smaller onsite spillover when the market equilibrium coincides with the social optimum (point C). When the cost of increasing the share of time spent working onsite is relatively low, the social planner will choose more onsite work even if the onsite productivity externality is relatively weaker ($\Delta\theta > 0$ for $\lambda - \lambda^R$ between point C and 0).

Figure (6(a)) shows that when onsite disutility is higher than WFH disutility, onsite spillover is larger than remote spillover when the market equilibrium coincides with the social optimum (point A). When the cost of more onsite work is relatively high, the benefit from onsite productivity spillover needs to be strong enough for the social planner to choose a share of time spent working onsite larger than the market equilibrium ($\lambda > \lambda^R$ is not enough for $\Delta\theta > 0$, $\lambda - \lambda^R$ needs to be larger than point A).

Similar logic applies to how the gap between the two cross-mode spillovers ($\tau_{or} - \tau_{ro}$) affects the social-market gap of onsite time. Figure 7 repeats the same three relative-amenity cases. To focus on cross-mode spillover, I set the two within-mode spillovers

to be equal ($\lambda = \lambda^R$). When spillover effects and disutilities are symmetric between onsite and remote work, the market equilibrium level of onsite time coincides with the socially optimal level (7(b) point B). When onsite disutility is lower than WFH disutility, the onsite-to-remote spillover can be smaller than the remote-to-onsite spillover for the market equilibrium to coincide with the social optimum (7(b) point C). When onsite disutility is larger than WFH disutility, the onsite-to-remote spillover needs to be larger than the remote-to-onsite spillover for the market equilibrium to coincide with the social optimum (7(a) point A).



(a) (b) (c)

Figure 7: The Gap Between Onsite-to-Remote and Remote-to-Onsite Spillovers Affects the Direction of the Optimum-Market Gap
Note: $\Delta\theta = (\theta^{soc}/\theta^{mkt} - 1) \times 100\%$. Parameter values are $\lambda = \lambda^R = 0.1$, $\tau_{ro} = 0.012$, $\bar{a}^o = \bar{a}^f = 1$, $\rho = 3.5$, $\gamma = 0.09$, and $\alpha = 0.76$.

Larger spillover gaps ($\lambda - \lambda^R$ and $\tau_{or} - \tau_{ro}$) lead to a larger social–market gap in onsite time, which further affects the social–market gaps in other outcomes and the optimal policy. Figure 8(a) shows that as the gap for onsite and remote spillover effect becomes larger, the gaps in onsite time, productivity, income, and utility between market equilibrium and the social optimum become larger. As a result, the required subsidy to achieve the social optimum increases (Figure 8(b)).

Two types of policy are considered in 8(b). The first is implementing an income tax to subsidize onsite work or remote work. The disposable income under this policy is

$$\mathscr{W}(\theta) = I(\theta)h(\theta), \quad h(\theta) = (1 - \mathscr{T})(1 + s\theta), \tag{22}$$

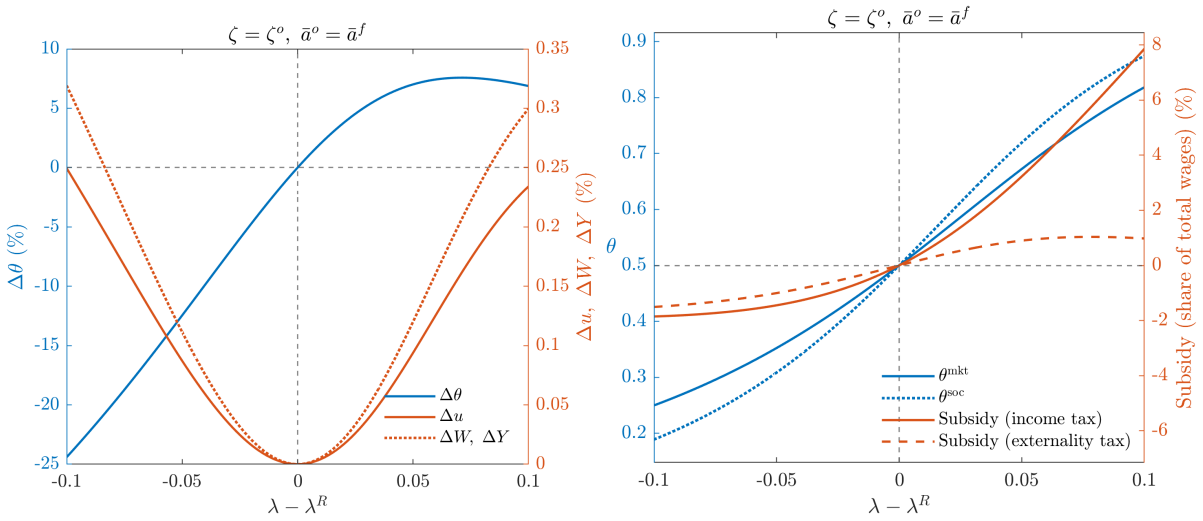
where $\mathscr{T}$ is the income tax rate. s is the onsite subsidy (tax) rate. $s > 0$ corresponds to

subsidizing onsite work or taxing remote work; $s < 0$ corresponds to taxing onsite work or subsidizing remote work.

The second is levying an externality tax to fund the subsidy. For example, collect a remote tax (income tax adjusted by the share of time spent WFH) and use the tax to subsidize onsite work. If the social planner taxes (subsidizes) remote work and subsidizes (taxes) the onsite work, the disposable income becomes

$$\mathscr{W}(\theta) = I(\theta)g(\theta), \quad g(\theta) = (1 - \text{ŧ}(1-\theta))\,(1 + t\theta)\,, \tag{23}$$

where ŧ is the tax (subsidy) rate based on the share of time spent WFH; t is the subsidy (tax) rate based on the share of time spent working onsite. (See Appendix (C) for derivation details.)

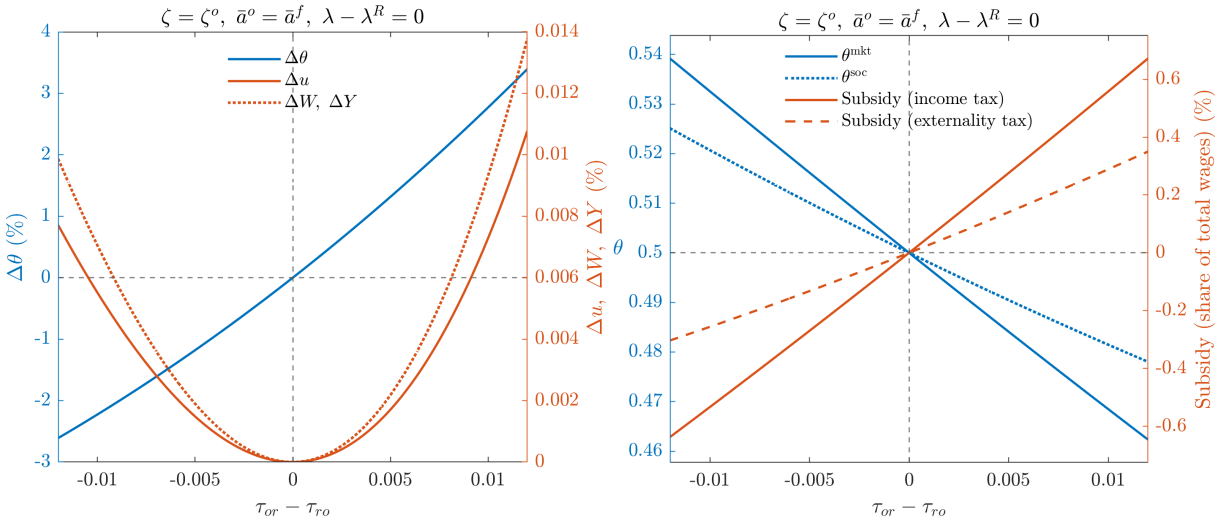


(a) (b)

Figure 8: The Gap Between Onsite-Remote Spillover Affects the Magnitude of the Social-Market Gap and Optimal Policy

Note: $\Delta\theta = (\theta^{soc}/\theta^{mkt} - 1) \times 100\%$; Δu, ΔW, and ΔY are defined analogously for utility, the wage, and output. The figure assumes WFH amenity costs equal onsite disutility and no cross-mode spillover. Parameter values are $\zeta = \zeta^o$, $\bar{a}^o = \bar{a}^f = 1$, $\tau_{ro} = \tau_{or} = 0$, $\lambda^R = 0.1$, $\gamma = 0.09$, $\alpha = 0.76$, and $\rho = 3.5$.

Similarly, a larger gap between onsite-to-remote and remote-to-onsite spillovers ($\tau_{or} - \tau_{ro}$) leads to larger gaps in onsite time, utility, wage, and productivity between market equilibirium and social optimum (9(a)) and optimal subsidy (9(b)).



(a) (b)

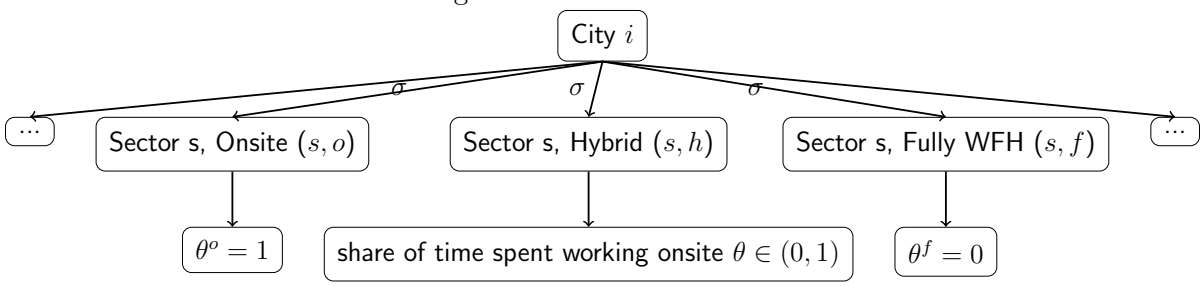
Figure 9: Directional Cross-mode Spillovers and the Optimum-Market Gap

Note: Parameter values are $\tau_{ro} = 0.012$, $\zeta = \zeta^o$, $\bar{a}^o = \bar{a}^f = 1$, $\lambda = \lambda^R = 0.1$, $\gamma = 0.09$, $\alpha = 0.76$, and $\rho = 3.5$.

4 The Full Model

4.1 The Market Equilibrium

Figure 10: Workers' Choices



Note: A worker living and working in city i chooses a sector s and one of three work arrangements. If the worker chooses working onsite or fully WFH, her share of time spent working onsite is determined as 1 or 0. If the worker chooses hybrid, she then chooses a share of time spent working onsite $\theta \in (0, 1)$. σ measures the dispersion of preferences for sectors-work mode pairs.

The economy has $i = 1, .., N$ cities. Each city has a fixed size of employment $(\bar{L}_i)$. Workers live where they work. There is no migration across cities, but there is mobility across sectors $s \in \{1, 2, ..., S\}$ and work modes. Each worker chooses a pair of sector-work mode (s, m), where the work modes are $(m \in \{o, h, f\})$ fully onsite (o), hybrid(h), and fully WFH (f). If workers choose hybrid work, they then decide the share of time spent

working onsite, $\theta_{is} \in (0,1)$, and the share of time spent WFH, $1-\theta_{is}$.[6]

Each city produces a tradable good that uses labor inputs from all sectors in the city. Tradable goods produced by cities are freely traded, and they are perfect substitutes. Workers consume tradable goods and housing. Housing is produced using parts of tradable goods and land as inputs. The returns to land are allocated to local workers. At the city-sector level, productivity spillover takes place both within and between onsite and remote labor.

4.1.1 Preference

The utility for a worker ω who lives and works in city i and works in sector s, and chooses a work mode m is:

$$u^m_{is\omega} = \frac{(c^m_{is})^{\alpha}(\not{h}^m_{is})^{1-\alpha}\epsilon^m_{is}}{\bar{\phi} d^m_{is}(\theta^m_{is})} z_{(s,m)\omega}, \tag{24}$$

where c^m_{is} and $\not{h}^m_{is}$ are consumption for tradable goods and housing, respectively. $\bar{\phi} = \alpha^{\alpha}(1-\alpha)^{1-\alpha}$ is a constant. The disutility $d^m_{is}(\theta^m_{is})$ varies by city, sector, and work mode. For onsite workers, disutility is the commuting cost; for hybrid workers, disutility combines the commuting cost and WFH amenity cost; for workers fully WFH, their disutility is the WFH amenity cost:

$$d^m_{is}(\theta^m_{is}) = \begin{cases} e^{kt_i} & \text{if } m = o, \\ e^{kt_i}\theta_{is} + \zeta_{is}(1-\theta_{is}) & \text{if } m = h, \\ \zeta_{is} & \text{if } m = f. \end{cases} \tag{25}$$

ζ_{is} denotes the WFH amenity cost. e^{kt_i} refers to the commuting cost, where t_i is the city-specific commuting time and k denotes the elasticity of commuting cost to commuting time.

ϵ^m_{is} is an exogenous shifter that governs workers' preference for sector-work mode choices. $z_{(s,m)\omega}$ is the worker's idiosyncratic preference for a sector-work mode pair. Assume $z_{(s,m)\omega}$ is independent for all individuals and follows the Fréchet distribution

[6] Onsite workers' share of time spent working onsite is $\theta^o_{is} = 1$. Fully WFH workers' share of time spent working onsite is $\theta^f_{is} = 0$. For hybrid workers, $\theta^h_{is} \in (0,1)$. For simplicity, I ignore the subscript h and use θ_{is} to refer to the share of time hybrid workers spend working onsite.

with cumulative distribution function $F_{z_{(s,m)\omega}}(z) = e^{-z^{-\sigma}}$. σ governs the dispersion of preference for sector-work mode pairs.

By utility maximization, the indirect utility is:

$$u^m_{is\omega} = \frac{I^m_{is}(\theta^m_{is})\epsilon^m_{is}}{d^m_{is}(\theta^m_{is})P^\alpha q_i^{1-\alpha}} z_{(s,m)\omega}, \tag{26}$$

where the worker's income $I^m_{is}(\theta^m_{is})$ consists of wages and returns to land. W^m_{is} denotes wages and R^m_{is} denotes returns to land. Assume the returns to land are distributed locally and are proportional to a worker's total wages: $R^m_{is} = \bar{r}W^m_{is}$. This assumption ensures that workers' choices and labor supply are not affected by the allocation of returns to land. The ratio of returns to land to total wages, $\bar{r}$, is a constant related to the share of tradable goods in consumption (α) and housing supply elasticity. To summarize, the income is $I^m_{is} = (1+\bar{r})W^m_{is}$. P is the price of tradable goods, which is equalized across cities due to free trade. The price of tradable goods is normalized to 1. q_i is the housing price in city i. Wages for workers are multiplications of city-sector-specific unit wages (w_{is}) and work mode-specific efficiency labor units:

$$W^m_{is}(\theta^m_{is}) = \begin{cases} w_{is}A^o_{is} & \text{if } m = o, \\ w_{is}\bar{a}^h_{is}A^h_{is}(\theta_{is}) & \text{if } m = h, \\ w_{is}A^f_{is} & \text{if } m = f. \end{cases} \tag{27}$$

A hybrid worker's efficiency labor unit $A^h_{is}(\theta_{is})$ combines the onsite and remote productivity:

$$A^h_{is}(\theta_{is}) = [(A^f_{is}(1-\theta_{is}))^{\frac{\rho-1}{\rho}} + (A^o_{is}\theta_{is})^{\frac{\rho-1}{\rho}}]^{\frac{\rho}{\rho-1}}, \tag{28}$$

where $\rho > 1$ is the elasticity of substitution between working onsite and WFH. A^f_{is} refers to remote productivity and A^o_{is} denotes onsite productivity. Workers consider onsite and remote productivity to be constant. $\bar{a}^h_{is}$ refers to the exogenous hybrid productivity that cannot be explained by w_{is} and $A^h_{is}(\theta_{is})$.

Hybrid workers choose the share of time onsite (θ_{is}) by utility maximization. The

share of time spent working onsite depends on relative productivity and relative amenity of onsite work:

$$\frac{\theta_{is}}{1-\theta_{is}} = \left(\frac{A_{is}^o}{A_{is}^f}\right)^{\rho-1} \left(\frac{\zeta_{is}}{e^{kt_i}}\right)^{\rho}. \tag{29}$$

Rearranging this equation gives the solution for the share of time hybrid workers spend working onsite in the market equilibrium:

$$\theta_{is} = \frac{1}{1+\left(\frac{A_{is}^f}{A_{is}^o}\right)^{\rho-1}\left(\frac{e^{kt_i}}{\zeta_{is}}\right)^{\rho}}. \tag{30}$$

4.1.2 Labor Supply

Since the idiosyncratic preference for sector-work mode follows a Fréchet distribution, the labor supply for workers in city i, sector s with work mode m is:

$$L_{is}^m = \left(\frac{\phi_{is}^m}{\Phi_i}\right)^{\sigma} \bar{L}_i, m \in \{o,h,f\}, \tag{31}$$

where $\phi_{is}^m = \frac{I_{is}^m \epsilon_{is}^m}{d_{is}^m(\theta_{is}^m)}$, $\Phi_i = [\sum_s \sum_m (\phi_{is}^m)^\sigma]^{\frac{1}{\sigma}}$. The employment in city i and sector s can be derived as

$$L_{is} = \sum_m L_{is}^m = \frac{1}{\Phi_i^\sigma} \sum_m \left(\frac{I_{is}^m \epsilon_{is}^m}{d_{is}^m(\theta_{is}^m)}\right)^{\sigma} \bar{L}_i, \tag{32}$$

Define $\widetilde{\epsilon}_{is}^m = \frac{\epsilon_{is}^m}{\sum_m \epsilon_{is}^m}$; then city-sector employment can be expressed as

$$L_{is} = \frac{\epsilon_{is}}{\Phi_i^\sigma} \sum_m \left(\frac{I_{is}^m \widetilde{\epsilon}_{is}^m}{d_{is}^m(\theta_{is}^m)}\right)^{\sigma} \bar{L}_i, \tag{33}$$

where $\epsilon_{is} = (\sum_m \epsilon_{is}^m)^\sigma$ is the city-sector specific labor supply shifter. This shifter will be used as an instrumental variable for city-sector employment in the structural estimation in section 5. Combining equations (31) and (32), labor supply for workers in city i, sector s with work mode m can be expressed as a function of city-sector employment:

$$L_{is}^m = \left(\frac{\phi_{is}^m}{\Phi_{is}}\right)^{\sigma} L_{is}, m \in \{o,h,f\}, \tag{34}$$

where $\Phi_{is} = [\sum_m (\phi_{is}^m)^\sigma]^{\frac{1}{\sigma}}$.

4.1.3 Production

The production function of the tradable good in city i combines outputs from all sectors:

$$Y_i = \left[\sum_s \left(\bar{y}_{is} (y_{is})^{\frac{\eta-1}{\eta}} \right) \right]^{\frac{\eta}{\eta-1}}, \tag{35}$$

where $\bar{y}_{is}$ is the city-sector specific productivity shifter. Assume constant returns to scale, thereby $\sum_s \bar{y}_{is} = 1$. η is the elasticity of substitution between sectors. The output in city i sector s (y_{is}) is a linear combination of outputs from workers in different work modes:

$$y_{is} = y_{is}^o + y_{is}^h + y_{is}^f = A_{is}^o L_{is}^o + \bar{a}_{is}^h A_{is}^h(\theta_{is}) L_{is}^h + A_{is}^f L_{is}^f. \tag{36}$$

By profit maximization, the city-sector-specific unit wage is:

$$w_{is} = P \bar{y}_{is} \left(\frac{Y_i}{y_{is}} \right)^{\frac{1}{\eta}}. \tag{37}$$

Onsite, hybrid, and fully WFH workers receive the following total wages, respectively:

$$W_{is}^o = w_{is} A_{is}^o, \quad W_{is}^h = w_{is} \bar{a}_{is}^h A_{is}^h(\theta_{is}), \quad W_{is}^f = w_{is} A_{is}^f. \tag{38}$$

The production function of housing in city i is:

$$H_i = K_i^\gamma \bar{H}_i^{1-\gamma}, \tag{39}$$

where K_i is the tradable goods used as an input to produce housing. $\bar{H}_i$ refers to land. γ governs the elasticity of the housing supply. By profit maximization, the demand for tradable goods used to produce housing is

$$K_i = \gamma \frac{q_i}{P} H_i, \tag{40}$$

where q_i is the housing price. The demand for land $\bar{H}_i = \frac{1-\gamma}{\gamma} \frac{P}{r_i} K_i$ implies the total returns

to land in city i are

$$R_i = r_i \bar{H}_i = \frac{1-\gamma}{\gamma} P K_i, \tag{41}$$

where r_i is the per unit returns to land.

4.1.4 Externalities

Workers do not account for the impact of their choices of work mode on aggregate productivity. Firms do not internalize the productivity externalities among workers when choosing the number of employees to maximize their profits. In other words, workers and firms treat onsite productivity A^o_{is} and remote productivity A^f_{is} as constant when making choices.

However, from a societal perspective, the onsite and remote productivity are functions of aggregated labor. The total onsite labor L^O_{is} in city i, sector s combines labor from onsite workers and hybrid workers' onsite time:

$$L^O_{is}(\theta_{is}) = L^o_{is} + \theta_{is} L^h_{is}. \tag{42}$$

Remote labor L^R_{is} combines labor from fully WFH workers and hybrid workers' WFH time:

$$L^R_{is}(\theta_{is}) = L^f_{is} + (1-\theta_{is}) L^h_{is}. \tag{43}$$

Onsite productivity is defined as:

$$A^o_{is} = \bar{a}^o_{is} \left[L^O_{is}(\theta_{is})\right]^{\lambda} \left[L^R_{is}(\theta_{is})\right]^{\tau_{ro} \mathbf{1}_{\{L^R_{is} \neq 0\}}}. \tag{44}$$

Fully remote productivity is:

$$A^f_{is} = \bar{a}^f_{is} \left[L^R_{is}(\theta_{is})\right]^{\lambda^R} \left[L^O_{is}(\theta_{is})\right]^{\tau_{or} \mathbf{1}_{\{L^O_{is} \neq 0\}}}. \tag{45}$$

where $\bar{a}^o_{is}$ and $\bar{a}^f_{is}$ are exogenous onsite and remote productivity, respectively. The parameter λ measures the elasticity of onsite productivity with respect to onsite labor, while τ_{ro} measures its elasticity with respect to remote labor. The parameter λ^R measures

the elasticity of remote productivity with respect to remote labor, while τ_{or} measures its elasticity with respect to onsite labor.

The indicator function $\mathbf{1}_{\{\cdot\}}$ turns off a cross-mode term whenever the sending labor pool is empty. If a city-sector cell has no remote labor ($L^R_{is}(\theta_{is}) = 0$), onsite productivity is $\bar{a}^o_{is}[L^O_{is}(\theta_{is})]^{\lambda}$; if it has no onsite labor ($L^O_{is}(\theta_{is}) = 0$), remote productivity is $\bar{a}^f_{is}[L^R_{is}(\theta_{is})]^{\lambda^R}$.

4.1.5 Market Clearing

The labor market clearing condition for workers is:

$$L^m_{is} = \left(\frac{\phi^m_{is}}{\Phi_i}\right)^{\sigma} \bar{L}_i, m \in \{o, h, f\} \tag{46}$$

where $\phi^m_{is} = \frac{I^m_{is}\epsilon^m_{is}}{d^m_{is}(\theta^m_{is})}$, $\Phi_i = [\sum_s \sum_m (\phi^m_{is})^{\sigma}]^{\frac{1}{\sigma}}$. $I^m_{is} = (1+\bar{r})W^m_{is}$. $W^o_{is} = w_{is}A^o_{is}, W^h_{is} = w_{is}\bar{a}^h_{is}A^h_{is}(\theta_{is}), W^f_{is} = w_{is}A^f_{is}$. The unit wage $w_{is} = P\bar{y}_{is}\left(\frac{Y_i}{y_{is}}\right)^{\frac{1}{\eta}}$.

The housing market clearing condition is:

$$\sum_s \sum_{m\in\{o,h,f\}} \hbar^m_{is} L^m_{is} = H_i \tag{47}$$

$$\frac{1-\alpha}{q_i} I_i = H_i, \tag{48}$$

where the total income in city i combines the total wage and returns to land $I_i = W_i + R_i$. The total wages are $W_i = \sum_s \sum_m (W^m_{is} L^m_{is})$. Combining equations (48) and (40), the demand for tradable goods used to produce housing can be expressed as a function of total income:

$$K_i = \gamma(1-\alpha)\frac{I_i}{P}. \tag{49}$$

Substituting this equation and the housing production function (39) into equation (48), the housing price can be solved as:

$$q_i = \left(\frac{P}{\gamma}\right)^{\gamma} \left(\frac{(1-\alpha)I_i}{\bar{H}_i}\right)^{1-\gamma}. \tag{50}$$

Substituting equation (49) into equation (41), the total returns to land in city i can be expressed as $R_i = (1-\gamma)(1-\alpha)I_i = (1-\gamma)(1-\alpha)(W_i + R_i)$. Rearranging the equation

yields a relation between returns to land and total wages: $R_i = \frac{(1-\gamma)(1-\alpha)}{1-(1-\gamma)(1-\alpha)} W_i$. By assumption, returns to land allocated to all workers have the same proportion r relative to their wages, $R_i = rW_i$. Therefore, the proportion of land returns to wages is:

$$\bar{r} = \frac{(1-\gamma)(1-\alpha)}{1-(1-\gamma)(1-\alpha)} = \frac{1}{\alpha+\gamma(1-\alpha)} - 1. \tag{51}$$

A worker's income is $I_{is}^m = (1+\bar{r})W_{is}^m = \frac{1}{\alpha+\gamma(1-\alpha)} W_{is}^m$. Total income in city i is $I_i = \frac{W_i}{\alpha+\gamma(1-\alpha)}$. Substituting $I_i = \frac{W_i}{\alpha+\gamma(1-\alpha)}$ and the zero profit condition ($W_i = PY_i$) into $K_i = \gamma(1-\alpha)\frac{I_i}{P}$, the tradable goods used to produce housing can be expressed as a function of total outputs $K_i = \frac{\gamma(1-\alpha)}{\gamma(1-\alpha)+\alpha} Y_i$.

The goods market clearing condition is:

$$P \sum_s \sum_{m \in \{o,h,f\}} c_{is}^m L_{is}^m + PK_i = PY_i \tag{52}$$

$$\alpha \frac{I_i}{P} + K_i = Y_i \tag{53}$$

Substituting $K_i = \gamma(1-\alpha)\frac{I_i}{P}$ and $I_i = \frac{W_i}{\alpha+\gamma(1-\alpha)}$ into equation (53) gives $W_i = PY_i$. This condition is satisfied according to the zero profit condition.

4.1.6 The Market Equilibrium

Given parameters $\{k, \rho, \sigma, \eta, \gamma, \lambda^R, \lambda, \tau_{ro}, \tau_{or}\}$, exogenous variables $\{t_i, \bar{L}_i, \bar{H}_i\}$, and exogenous shifters $\{\zeta_{is}, \epsilon_{is}^o, \epsilon_{is}^h, \epsilon_{is}^f, \bar{a}_{is}^h, \bar{y}_{is}, \bar{a}_{is}^f, \bar{a}_{is}^o\}$, a competitive allocation consists of the share of time spent working onsite chosen by hybrid workers (θ_{is}), employment ($L_{is}^o, L_{is}^h, L_{is}^f$), total wages ($W_{is}^o, W_{is}^h, W_{is}^f$), tradable goods used to produce housing (K_i), local returns to land (R_i), housing price (q_i), onsite productivity (A_{is}^o) and remote productivity (A_{is}^f) such that equations (28), (30), (31), (38), (40), (41), (44), (45), (47), and (50) are satisfied.

4.2 Welfare

The expected utility for a worker in city i is:

$$U_i = \Phi_i \frac{\Gamma(1-\frac{1}{\sigma})}{P^\alpha q_i^{1-\alpha}}, \tag{54}$$

where $\Phi_i = [\sum_s \sum_m (\phi_{is}^m)^\sigma]^{\frac{1}{\sigma}}$, $\phi_{is}^m = \frac{I_{is}^m \epsilon_{is}^m}{d_{is}^m(\theta_{is}^m)}$. $I_{is}^m = \frac{W_{is}^m}{\alpha+\gamma(1-\alpha)}$. $W_{is}^o = w_{is}A_{is}^o$, $W_{is}^h = w_{is}\bar{a}_{is}^h A_{is}^h(\theta_{is})$, $W_{is}^f = w_{is}A_{is}^f$.

The social welfare for the economy is defined as:

$$U = \sum_i U_i \bar{L}_i. \tag{55}$$

4.3 The Socially Optimal Labor Allocations

The social planner internalizes externalities and solves for allocations in the share of time spent working onsite for hybrid workers, employment, consumption, housing, and tradable goods used to produce housing to maximize the total welfare within each city (See Appendix D for derivation details). The first-order conditions determining the socially optimal allocation differ from those of the market equilibrium in terms of both the intensive and extensive margins of labor.

4.3.1 The Optimal Share of Time Spent Working Onsite For Hybrid Workers

The equation that characterizes the socially optimal share of time spent working onsite for hybrid workers is:

$$\frac{\theta_{is}^*}{1-\theta_{is}^*} = \left(\frac{A_{is}^o(\theta_{is}^*)}{A_{is}^f(\theta_{is}^*)}\right)^{\rho-1} \left[\frac{\zeta_{is} + \underbrace{d_{is}(\theta_{is}^*)}_{\substack{\text{hybid worker's}\\ \text{composite of}\\ \text{disutility}}} \left(\underbrace{F_{is}}_{\substack{\text{housing congestion,}\\ \text{onsite/remote/sector}\\ \text{productivity spillover}}} \left(\overbrace{\delta_{is}}^{\text{onsite time elasticity}} + 1\right) - 1\right)}{e^{kt_i} + \underbrace{d_{is}(\theta_{is}^*)}_{\substack{\text{hybid worker's}\\ \text{composite of}\\ \text{disutility}}} \left(\underbrace{F_{is}}_{\substack{\text{housing congestion,}\\ \text{onsite/remote/sector}\\ \text{productivity spillover}}} \left(\underbrace{\delta_{is}^R}_{\substack{\text{intensive margin of}\\ \text{remote productivity}\\ \text{externality}}} + 1\right) - 1\right)}\right]^{\rho}, \tag{56}$$

where $L_{is}^O(\theta_{is}) = L_{is}^o + \theta_{is}L_{is}^h$ and $L_{is}^R(\theta_{is}) = L_{is}^f + (1-\theta_{is})L_{is}^h$. The elasticity of onsite productvity with respect to hybrid workers' onsite time is

$$\delta_{is} = \frac{\partial \ln A_{is}^o(\theta_{is})}{\partial \ln \theta_{is}} = \lambda \frac{\partial \ln L_{is}^O(\theta_{is})}{\partial \ln \theta_{is}} + \tau_{ro} \frac{\partial \ln L_{is}^R(\theta_{is})}{\partial \ln \theta_{is}} = \lambda \frac{\theta_{is}L_{is}^h}{L_{is}^O} - \tau_{ro} \frac{\theta_{is}L_{is}^h}{L_{is}^R}. \tag{57}$$

The elasticity of remote productvity with respect to hybrid workers' WFH time is

$$\delta_{is}^{R} = \frac{\partial \ln A_{is}^{f}(\theta_{is})}{\partial \ln(1-\theta_{is})} = \lambda^{R}\frac{\partial \ln L_{is}^{R}(\theta_{is})}{\partial \ln(1-\theta_{is})} + \tau_{or}\frac{\partial \ln L_{is}^{O}(\theta_{is})}{\partial \ln(1-\theta_{is})} = \lambda^{R}\frac{(1-\theta_{is})L_{is}^{h}}{L_{is}^{R}} - \tau_{or}\frac{(1-\theta_{is})L_{is}^{h}}{L_{is}^{O}}. \tag{58}$$

The onsite and remote time elasticities vary across cities and sectors because of the variations of labor composition and hybrid workers' onsite shares. Each elasticity consists of a within work-mode spillover gain minus a cross-mode spillover cost. For example, more onsite time increases onsite labor, so onsite productivity benefits from stronger within-mode spillovers. However, more onsite time is also associated with less WFH time, reducing remote labor and weakening the cross-mode spillovers that benefit onsite productivity.

$$F_{is} = \frac{\widetilde{P}_i \frac{\partial Y_i}{\partial \theta_{is}}}{\widetilde{I}_{is}^{h} L_{is}^{h} \frac{\partial A_{is}^{h}(\theta_{is})/\partial \theta_{is}}{A_{is}^{h}(\theta_{is})}}, \quad \widetilde{P}_i = \frac{(\alpha + \gamma(1-\alpha))\sum_s \sum_m \widetilde{I}_{is}^{m} L_{is}^{m}}{Y_i} \tag{59}$$

F_{is} refers to the cross-sector productivity spillover effect driven by the change of the share of time hybrid workers spend working onsite in sector s. $\widetilde{P}_i$ is the shadow price of tradable goods in city i. The numerator $\widetilde{P}_i \frac{\partial Y_i}{\partial \theta_{is}}$ measures the change in the value of the tradable goods in city i when hybrid workers change their share of time spent working onsite. This term reflects the marginal total product value of hybrid workers' onsite work. It also captures the sectoral spillover effect. For example, a change in hybrid workers' onsite time in sector s that increases the total productivity of sector s might result in a relative decline in the productivity of other sectors when total employment is fixed.

The denominator $\widetilde{I}_{is}^{h} L_{is}^{h} \frac{\partial A_{is}^{h}(\theta_{is})/\partial \theta_{is}}{A_{is}^{h}(\theta_{is})}$ measures the change in total income of the hybrid workers when they adjust their share of time spent working onsite. $\widetilde{I}_{is}^{m}$ denotes the total expenditure in the social planner's problem. It represents the value of hybrid workers' marginal product from onsite work. Thus, the ratio of the two terms reflects how much the net value of tradable goods changes in response to hybrid workers' onsite time change in a specific sector. In the case where there is only one city and one sector and all workers are hybrid, F_{is} simplifies to $\alpha+\gamma(1-\alpha)$, which only includes the housing congestion effect, as in the basic model.

Similar to the basic model (3.2.3), when determining the socially optimal share of time spent working onsite, the social planner balances the effect on the hybrid worker's composite of disutility, housing congestion, as well as intensive margins of onsite and remote productivity externalities. In addition, the social planner also considers the productivity spillover across work modes and sectors.

Due to the cross-sector productivity spillover effect, the social planner may choose a share of time spent working onsite in a sector even if it results in lower productivity for hybrid workers in this sector, as long as the benefits to other work modes or sectors outweigh the loss. This mechanism operates through the labor reallocation channel. For example, suppose a change in the share of time spent working onsite reduces the productivity of hybrid workers in sector s, causing hybrid workers' wages in sector s to decrease. As a consequence, workers reallocate to other sector-work mode cells, thereby increasing productivity in those sectors and work modes. If the productivity increases in other sector-work mode cells exceed the hybrid workers' productivity decrease in sector s, then the social planner will implement this change in the share of time spent working onsite.

Equation (56) can be expressed as

$$\frac{\theta_{is}}{1-\theta_{is}} = \left(\frac{A_{is}^{o}(\theta_{is})}{A_{is}^{f}(\theta_{is})}\right)^{\rho-1} \left(\frac{F_{is}(\delta_{is}+1)-\delta_{d,is}}{F_{is}(\delta_{is}^{R}+1)-\delta_{d,is}^{R}}\right)^{\rho}, \tag{60}$$

where $\delta_{d,is}$ and $\delta_{d,is}^{R}$ are the elasticities of the hybrid worker's composite of disutility with respect to their share of time spent working onsite and share of time spent WFH in city i sector s, respectively:

$$\delta_{d,is} = \frac{\partial d_{is}(\theta_{is})/d_{is}(\theta_{is})}{\partial\theta_{is}/\theta_{is}} = \frac{(e^{kt_i}-\zeta_{is})\theta_{is}}{d_{is}(\theta_{is})}, \tag{61}$$

$$\delta_{d,is}^{R} = \frac{\partial d_{is}(\theta_{is})/d_{is}(\theta_{is})}{\partial(1-\theta_{is})/(1-\theta_{is})} = \frac{(\zeta_{is}-e^{kt_i})(1-\theta_{is})}{d_{is}(\theta_{is})}. \tag{62}$$

$\frac{F_{is}(\delta_{is}+1)-\delta_{d,is}}{F_{is}(\delta_{is}^{R}+1)-\delta_{d,is}^{R}}$ represents the relative onsite time elasticity adjusted by the other sources of externalities.

Comparing equation (60) with the first-order condition in market equilibrium (equation (29)) gives the following conditions:

$$\theta_{is}^{soc} > \theta_{is}^{mkt} \Leftrightarrow \left(\frac{A_{is}^{o}(\theta_{is}^{soc}, L_{is,soc}^{m})}{A_{is}^{f}(\theta_{is}^{soc}, L_{is,soc}^{m})}\right)^{\rho-1}\left(\frac{F_{is}(\delta_{is}+1)-\delta_{d,is}}{F_{is}(\delta_{is}^{R}+1)-\delta_{d,is}^{R}}\right)^{\rho} > \left(\frac{A_{is}^{o}(\theta_{is}^{mkt}, L_{is,mkt}^{m})}{A_{is}^{f}(\theta_{is}^{mkt}, L_{is,mkt}^{m})}\right)^{\rho-1}\left(\frac{\zeta_{is}}{e^{kt_i}}\right)^{\rho}, \tag{63}$$

$$\theta_{is}^{soc} < \theta_{is}^{mkt} \Leftrightarrow \left(\frac{A_{is}^{o}(\theta_{is}^{soc}, L_{is,soc}^{m})}{A_{is}^{f}(\theta_{is}^{soc}, L_{is,soc}^{m})}\right)^{\rho-1}\left(\frac{F_{is}(\delta_{is}+1)-\delta_{d,is}}{F_{is}(\delta_{is}^{R}+1)-\delta_{d,is}^{R}}\right)^{\rho} < \left(\frac{A_{is}^{o}(\theta_{is}^{mkt}, L_{is,mkt}^{m})}{A_{is}^{f}(\theta_{is}^{mkt}, L_{is,mkt}^{m})}\right)^{\rho-1}\left(\frac{\zeta_{is}}{e^{kt_i}}\right)^{\rho}. \tag{64}$$

where θ_{is}^{soc} and θ_{is}^{mkt} denote the share of time hybrid workers spend working onsite for hybrid workers in the social optimum and market equilibrium, respectively. $L_{is,soc}^{m}$ and $L_{is,mkt}^{m}$ denote employment in the social optimum and market equilibrium, respectively. Conditions (63) and (64) suggest that whether the optimal onsite share is larger than in market equilibrium depends on two aspects: (1) whether the adjusted relative onsite time elasticity is larger than relative onsite amenity ($\frac{F_{is}(\delta_{is}+1)-\delta_{d,is}}{F_{is}(\delta_{is}^{R}+1)-\delta_{d,is}^{R}}$ v.s. $\frac{\zeta_{is}}{e^{kt_i}}$). (2) whether relative onsite productivity in the social optimum is larger than market equilibrium ($\frac{A_{is}^{o}(\theta_{is}^{soc},L_{is,soc}^{m})}{A_{is}^{f}(\theta_{is}^{soc},L_{is,soc}^{m})}$ v.s. $\frac{A_{is}^{o}(\theta_{is}^{mkt},L_{is,mkt}^{m})}{A_{is}^{f}(\theta_{is}^{mkt},L_{is,mkt}^{m})}$). The difference in employment between the social optimum and market equilibrium is discussed in section 4.3.2.

Condition (63) has two implications: (1) optimal hybrid workers' share of time spent working onsite will be larger than market equilibrium if the adjusted relative onsite time elasticity is strong enough (the first effect dominates). (2) When the adjusted relative onsite time elasticity is not strong enough ($\frac{F_{is}(\delta_{is}+1)-\delta_{d,is}}{F_{is}(\delta_{is}^{R}+1)-\delta_{d,is}^{R}} < \frac{\zeta_{is}}{e^{kt_i}}$), optimal hybrid workers' share of time spent working onsite can also be larger than market equilibrium when optimal employment allocation results in relative onsite productivity in the social optimum being much higher than that in market equilibrium ($\frac{A_{is}^{o}(\theta_{is}^{soc},L_{is,soc}^{m})}{A_{is}^{f}(\theta_{is}^{soc},L_{is,soc}^{m})} > \frac{A_{is}^{o}(\theta_{is}^{mkt},L_{is,mkt}^{m})}{A_{is}^{f}(\theta_{is}^{mkt},L_{is,mkt}^{m})}$). Condition (64) has similar implications based on the strength of adjusted relative onsite time elasticity and relative onsite productivity.

4.3.2 The Optimal Employment Composition

The socially optimal employment by city-sector-work mode is

$$L_{is}^{m*} = \left(\frac{\widetilde{\phi}_{is}^{m}}{\widetilde{\widetilde{\Phi}}_i} \right)^{\sigma} \bar{L}_i, \tag{65}$$

where $\widetilde{\phi}_{is}^{m} = \frac{\widetilde{I}_{is}^{m} \epsilon_{is}^{m}}{d_{is}^{m}(\theta_{is}^{m})}$, $\widetilde{\widetilde{\Phi}}_i = \left(\sum_s \sum_m \left(\widetilde{\phi}_{is}^{m} \right)^{\sigma} \right)^{\frac{1}{\sigma}}$. Equation (65) has the same form as the labor supply function in market equilibrium (31). However, the socially optimal expenditure (corresponding to income in the market equilibrium) is different. The socially optimal expenditure for a worker in city i, sector s, work mode m is

$$\widetilde{I}_{is}^{m} = \frac{\sigma}{\sigma + 1} \left(\widetilde{P}_i \frac{\partial Y_i}{\partial L_{is}^{m}} - e_i \right), \tag{66}$$

where $\widetilde{P}_i$ is the shadow price of the tradable goods produced by city i. $\frac{\partial Y_i}{\partial L_{is}^{m}}$ is the marginal product of workers in city i, sector s, and work mode m. e_i is the opportunity cost of reallocating workers to other sector-work modes within a city. The marginal product of a worker in the social planner's problem is:

$$\frac{\partial Y_i}{\partial L_{is}^{m}} = \frac{\partial Y_i}{\partial y_{is}} \Bigg(y_{is}^{m} + \underbrace{\sum_{m' \in \{o,h,f\}} L_{is}^{m'} \frac{\partial y_{is}^{m'}}{\partial L_{is}^{m}}}_{\text{productivity spillover}} \Bigg), \tag{67}$$

where $y_{is}^{o} = A_{is}^{o}(L_{is}^{m}, \theta_{is})$, $y_{is}^{h} = \bar{a}_{is}^{h} A_{is}^{h}(L_{is}^{m}, \theta_{is})$, and $y_{is}^{f} = A_{is}^{f}(L_{is}^{m}, \theta_{is})$. Equation (67) shows that an increase of employment in city i sector s work mode m affects the total product of city i through 3 channels: (1) the direct effect for sector s work mode m (y_{is}^{m}): more workers in the sector-work mode cell result in increased production for this sector and work mode. (2) the productivity spillover within sector s ($\sum_{m'} L_{is}^{m'} \frac{\partial y_{is}^{m'}}{\partial L_{is}^{m}}$): for example, more onsite workers increase onsite productivity and remote productivity through within-mode and cross-mode spillovers. If these effects outweigh the negative effect of reduced spillovers from remote workers, hybrid workers' productivity will increase. (3) the marginal effect of sector s on city-wide productivity ($\frac{\partial Y_i}{\partial y_{is}}$): more workers in sector

s make the city's total productivity depend more on that sector. With a fixed city size, it also means fewer workers and lower productivity in other sectors. The social planner chooses a labor composition where the benefit of increasing workers in sector s exceeds the productivity loss in other sectors.

The opportunity cost of reallocating workers to other sector-work modes within a city is

$$e_i = \widetilde{P}_i \sum_s \sum_m \left(\frac{L_{is}^m}{\bar{L}_i} \frac{\partial Y_i}{\partial L_{is}^m} \right) - \frac{\sigma + 1}{\sigma} U_i, \tag{68}$$

where the first term is the weighted average of the value of the marginal product of labor across all sectors and work modes in a city. The weight is the share of employment in a sector-work mode as a percentage of total employment in a city. The second term is proportional to the city welfare index $U_i = \frac{1}{\widetilde{P}_i^{\alpha} \widetilde{q}_i^{1-\alpha}} \left[\sum_s \sum_m \left(\frac{\widetilde{I}_{is}^m(e_i) \epsilon_{is}^m}{d_{is}^m(\theta_{is}^m)} \right)^{\sigma} \right]^{\frac{1}{\sigma}}$.

Optimal expenditure (66) differs from market equilibrium income ($I_{is}^m = (1+\bar{r}) P \frac{\partial Y_i}{\partial y_{is}} y_{is}^m$) by incorporating the productivity spillover effect and the opportunity cost of reallocation. These two channels also explain why employment composition differs between the social optimum and the market equilibrium. In other words, the social planner allocates more workers to a sector-work mode compared to market equilibrium if it generates more productivity spillover and is associated with a low opportunity cost.

5 Data and Estimation

5.1 Data

I use U.S. data to estimate spillover effects, quantify the gap between the social optimum and the market outcome, and measure optimal subsidies.

Dataset, Time, and Samples. Wages and employment shares of onsite, hybrid, and fully WFH workers, as well as the share of time spent WFH for hybrid workers at the city and sector level are from the IPUMS Current Population Survey (CPS) basic monthly survey from 2022 October to 2025 December. Total employment by city, sector, and month is from the Quarterly Census of Employment and Wages (QCEW) data from 2022 October to 2025 December. Bartik instruments use 2000 American Community Survey

(ACS) data to calculate occupational shares in each city-sector cell before the sample period. Average commuting time data is from 2022-2024 ACS data. The samples consist of labor forces excluding self-employed, armed forces, and unpaid family workers. The samples for calculating average commuting time are further constrained to those who live and work in the same city.

Sectors and Cities. Each sector in the empirical analysis consists of 1 or 2 super-sectors classified by the Bureau of Labor Statistics (BLS) based on the North American Industry Classification System (NAICS) 2-digit level. The 8 sectors in the analysis are (1) Agriculture, mining, construction, (2) Manufacturing, (3) Trade, transportation, utilities, (4) Information, finance, real estate, (5) Professional and business services, (6) Health and education, (7) Recreation and accommodation, (8) Public administration and other services.

I match the cities in the model to the 2020 version of Core-Based Statistics Areas (CBSAs). For CPS data, I match the resident metropolitan area or county to CBSA using the crosswalk in the Missouri Census Data Center (MCDC)[7] or the Census Bureau's delineation files [8]. QCEW county data are matched to CBSA using similar crosswalks. ACS data are matched to CBSA using the crosswalk from public use micro areas (PUMAs) to CBSAs in MCDC or crosswalk from county or metropolitan area to CBSAs. For ACS, work public use micro areas (PWPUMAs) are first matched to PUMAs using the crosswalk from IPUMS [9], and then matched to CBSAs. Changes in county delineations are accounted for by converting counties to their 2020 definitions using the time-consistent county crosswalk from Ferrara et al. (2024). If a sample's county, metropolitan area, or PUMA belongs to multiple CBSAs, I duplicate this sample and each duplicate is assigned an allocation factor that denotes the share of the original geography unit in the matched CBSA. The allocation factor is multiplied by the sample weight when aggregating to the city-sector level.

[7] The website address for the MCDC crosswalk files is https://mcdc.missouri.edu/applications/geocorr.html.

[8] https://www.census.gov/geographies/reference-files/time-series/demo/metro-micro/delineation-files.html

[9] One PWPUMA may contain several PUMAs. The place of work PUMAs to PUMAs crosswalk is at https://usa.ipums.org/usa/volii/00pwpuma.shtml and https://usa.ipums.org/usa/volii/10pwpuma.shtml.

Hybrid Workers' Share of Time Spent Working Onsite. The share of time spent working onsite is calculated by one minus the share of time WFH. The CPS basic monthly survey variable TELWRKHR reports hours WFH for pay in the last week. I only include workers who have one job (identified by the variable MULTJOB) to calculate the average share of time spent WFH. The share of time spent WFH is calculated by hours WFH per week divided by hours worked per week. If the workers report not being WFH (reported in the variable TELWRKPAY) or their WFH hours are zero, they are classified as onsite workers. If workers' weekly WFH hours equal their working hours, they are classified as fully WFH workers.

Residual Wages. I use average residual wages to estimate spillover effects and match wages in the model and recover the shifters. I first regress the invidual wages on demographic variables and other control variables and then take the average of residual wages. The data used to estimate spillover effects are at the city-sector-work-mode-month level, whereas the data used to recover the shifters are cross-sectional and measured at the city-sector-work-mode level. Data process details are in Appendix F.

Employment. The CPS basic monthly survey has variables to indicate workers' work mode (TELWRKHR, TELWRKPAY). QCEW has a more accurate account of employment at the city-sector level than CPS[10]. I calculate the city-sector-work model level employment in the following steps. Firstly, I use the CPS basic monthly survey to calculate onsite, hybrid, and fully WFH employment shares by city-sector cells. Then, the employment for each city-sector-work mode is calculated by multiplying the employment in each city-sector cell from QCEW by the respective employment share of the work mode from CPS[11].

[10] CPS is a household survey whereas QCEW is based on administrative unemployment-insurance records covering most payroll jobs.

[11] CPS only reports residential places, where as QCEW employment is workplace-based. This calculation assumes that work-mode shares calculated based on resient or workplace are similar. This assumption is supported by the evidence that most people work and live in the same CBSA shown in Table 1.

5.2 Identification

The fully WFH wage in the model is $W_{is}^f = w_{is}\bar{a}_{is}^f \left(L_{is}^R\right)^{\lambda^R} \left(L_{is}^O\right)^{\tau_{or}}$. The log form and time-varying version of the fully WFH wage implies the following reduce-form equation:

$$ln(W_{ist}^f) = \beta_{is} + \beta_t + \lambda^R ln\left(L_{ist}^R\right) + \tau_{or} ln\left(L_{ist}^O\right) + \epsilon_{ist}^f, \tag{69}$$

where dependent variable is the residual wages for fully WFH workers (appendix F). $L_{is}^R = L_{is}^f + (1-\theta_{is})L_{is}^h, L_{is}^O = L_{is}^o + \theta_{is}L_{is}^h$ are aggregated onsite and remote labor. β_{is} is a city-sector fixed effect that corresponds to the unit wage ω_{is} in the model. I consider year and month fixed effects β_t to remove the common trend and seasonality. ϵ_{is}^f is the residual correspoding to fully remote productivity by city-sector. Based on the fully onsite wage, one can obtain a similar equation:

$$ln(W_{ist}^o) = \beta_{is} + \beta_t + \lambda ln\left(L_{ist}^O\right) + \tau_{ro} ln\left(L_{ist}^R\right) + \epsilon_{ist}^f. \tag{70}$$

I use these 2 equations implied by the model to estimate onsite spillover λ, remote spillover λ^R, onsite-to-remote spillover τ_{or}, and remote-to-onsite spillover τ_{ro}.

Ordinary least squares (OLS) estimates of equation (69) have three identification issues: (1) reverse causality: higher remote wages in some city-sector cells attract more workers, rather than more remote workers lead to higher fully WFH productivity and wages. (2) endogeneity: the residuals may correlate with the employment. For example, larger cities tend to have higher wages and more onsite and remote workers, which leads to an upward bias of spillover estimates. (3) selection bias: workers who choose to work remotely may have systematically different productivity levels than those who choose to work onsite. Harrington and Emanuel (2021) find that call center workers with less productivity are more likely to choose remotely than onsite. This negative selection implies a downward bias of the estimate of remote productivity externality. On the other hand, if workers with higher producivity are more likely to choose WFH, it will lead to a positive bias. There will be similar issues for OLS estimates of equation (70).

Therfore, I use Bartik instrumental variables (IV) (Goldsmith-Pinkham et al. (2020)) to identify spillover parameters. Monte et al. (2023) use a similar Bartik instrument variable to estimate productivity spillover among commuters. The Bartik instruments for remote labor are constructed as follows:

$$Z^R_{ist} = \sum_{occ} S_{occ,is,t_0} L^R_{occ,-i,t}, \tag{71}$$

where *occ* denotes occupation. t_0 represents the pre-sample period 2000. t denotes a specific month in the sample period 2022-2025. S_{occ,is,t_0} denotes the share of occuaption *occ* in city-sector cell is in the pre-sample period t_0[12]. $L^R_{occ,-i,t}$ is national remote labor in occupation *occ* excluding employment in city i. This leave-own-city-out construction removes the mechanical contribution of a city's employment to its own national shift. Remote labor consists of fully WFH workers and hybrid workers' WFH time ($L^R_{occ,-i,t} = L^f_{occ,-i,t} + (1-\theta_{occ,-i,t})L^h_{is}$). The Bartik IV for onsite labor is constructed in a similar way ($Z^O_{ist} = \sum_{occ} S_{occ,is,t_0} L^O_{occ,-i,t}$). Basically, one firstly intreacts occupational share in the pre-sample period with national remote labor at occupation level, and then aggregates the interaction term of all occupations within each city-sector cell. The two instruments use the same predetermined occupation shares (S_{occ,is,t_0}) but different work mode specific national employment shifts ($L^R_{occ,-i,t}$, $L^R_{occ,-i,t}$).

The instruments generate variations in local onsite and remote labor because each city-sector cell has different occupation compositions. A national increase in remote employment for an occupation has a larger effect on the city-sector cell that had a larger initial employment share in that occupation. The exclusion assumption is that the initial occupation share in 2000 is exogenous to the unobserved changes in local onsite or remote productivity during 2022-2025 conditional on the fixed effects.

Table 2 shows the estimation results. Columns 1 and 2 only estimate the within-mode

[12] Occupations are the time-consistent census major occupation groups constructed by Pollard (2019) (excluding the Armed Forces): management, business, and financial; professional and related; service; sales and related; office and administrative support; farming, fishing, and forestry; construction and extraction; installation, maintenance, and repair; production; and transportation and material moving. The occupation shares in 2000 are calculated from the ACS using employed workers who are not self-employed.

spillover. It shows that onsite spillover (λ) is larger than remote spillover (λ^R). Without considering cross-mode contribution, there might be omission bias. Columns 3 and 4 estimate both within-mode and cross-mode spillovers. The estimate results show stronger onsite spillover both within and across modes and weaker but non-zero remote spillover. The within-mode onsite spillover is around 0.3, which is larger than the estimate of remote spillover around 0.2. The onsite-to-remote spillover is around 0.4, which is larger than the estimate of remote-to-onsite spillover around 0.04. Remote spillover estimates imply that a 10% increase in remote labor will increase remote productivity by 2% and onsite productivity by 0.4%. Onsite spillover estimates imply that a 10% increase in onsite labor will increase onsite productivity by 3% and remote productivity by 4%.

Table 2: Bartik IV Estimates of Onsite and Remote Productivity Externalities

	(1) ln(onsite wages)	(2) ln(fully WFH wages)	(3) ln(onsite wages)	(4) ln(fully WFH wages)
ln(onsite labor)	0.3156**		0.2924***	0.4414***
	(0.1559)		(0.1007)	(0.1601)
ln(remote labor)		0.1162**	0.0444**	0.2091***
		(0.0460)	(0.0191)	(0.0743)
Observations	68,126	22,379	45,956	21,959
SW conditional F: onsite labor			45.80	21.94
SW conditional F: remote labor			55.44	29.58
Kleibergen-Paap rk Wald F	31.01	63.25	23.01	12.20
city-sector FE	Yes	Yes	Yes	Yes
year FE	Yes	Yes	Yes	Yes
month FE	Yes	Yes	Yes	Yes

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: Depandant variables are residual wages controling demographic characteristics and other variables that might affect wages (Appendix F). Onsite labor combines fully onsite workers and hybrid workers' onsite time. Remote labor combines fully working from home workers and hybrid workers' WFH time. The Bartik instrumental variable is constructed by occupational composition within city-sector cells and national work-mode specific shifts in each occupation: $Z^M_{ist} = \sum_{occ} S_{occ,is,t_0} L^M_{occ,-i,t}, M \in \{O, R\}$, where S_{occ,is,t_0} is the occupation share in each city-sector cell in 2000. $L^M_{occ,-i,t}$ is national onsite or remote workers in each occupation in a specific month (excluding own city). Standard errors clustered by city are in parentheses.

These four spillover estimates describe how work-mode productivity responds to onsite and remote labor. Appendix H expresses the sectoral productivity elasticity as a weighted combination of these spillovers under fixed work-mode employment shares. For the numerical comparison, I increase each city's population by 1% and re-solve the market equilibrium, allowing work-mode employment shares to adjust (Figure 11). The model-implied sectoral productivity elasticities have a mean of 0.410. This magnitude is

comparable to the industry-group estimates in Rossi-Hansberg et al. (2021).[13] It is larger than the typical mean estimates in the urban agglomeration literature and remains within the range of published estimates.[14]

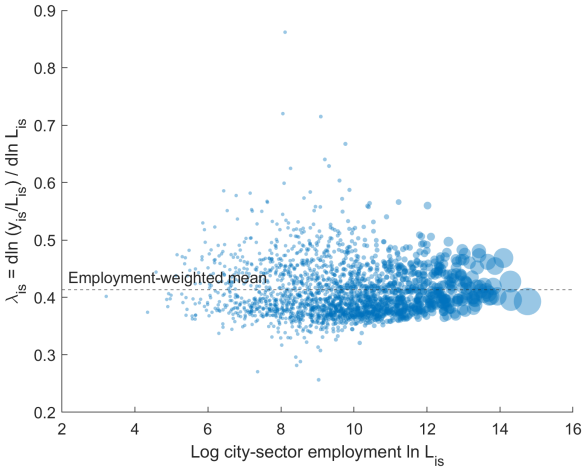


Figure 11: Model-Implied Sectoral Productivity Elasticities

Note: I solve the baseline market equilibrium using shifters recovered from the data and the estimated spillover parameters $\lambda, \lambda^R, \tau_{or}, \tau_{ro}$. I then increase each city's population by 1% and re-solve the market equilibrium, holding these shifters fixed. The sectoral productivity elasticity is calculated as the elasticity of average sectoral output with respect to sectoral employment: $\lambda_{is} = [\ln(\widehat{y}_{is}/\widehat{L}_{is}) - \ln(y_{is}/L_{is})]/[\ln \widehat{L}_{is} - \ln L_{is}]$. $\widehat{y}_{is}, \widehat{L}_{is}$ denote the output or employment after the population increase.

6 Quantification Results

This section presents the average gaps between the market equilibrium and the social optimum and subsidies. It then analyzes how the gap in employment allocation between the market equilibrium and the social optimum varies across city-sector cells.

To obtain the quantification results, I proceed as follows. (1) Given the estimated parameters, other parameter values from the literature and standard calibration targets (Table 6), and data on employment, wages, onsite time, and commuting time (Table 5), I recover the model's exogenous shifters (Table 7) using the model inversion algorithm in Appendix G.1. (2) I then solve for the market equilibrium and the socially optimal allocation using the algorithms in Appendices G.2 and G.3, respectively. (3) Finally, I calculate the gaps in employment allocation between the market equilibrium and the

[13] Table 1 of Rossi-Hansberg et al. (2021) reports that the elasticity of productivity of cognitive or non cognitive workers with respect to city employment is 0.20 in health and education, 0.39 in professional and other services, 0.51 in manufacturing, and 0.37 in accommodation, trade, and transportation.

[14] See Donovan et al. (2024); Ahlfeldt and Pietrostefani (2019); Melo et al. (2009); Rosenthal and Strange (2004) for surveys of urban agglomeration elasticity estimates.

social optimum, as well as the socially optimal subsidies (Appendix E).

6.1 The Average Gap between the Social Optimum and the Market Equilibrium

Table 3: Gaps and Subsidies

	Positive onsite and remote spillovers	No spillovers from remote labor $\lambda_R = \tau_{ro} = 0$	No cross-mode spillovers $\tau_{or} = \tau_{ro} = 0$
Welfare gain in social optimum, % chg	0.85	1.70	0.62
Hybrid workers' onsite time, % chg	-2.88	41.47	15.77
Onsite employment, % chg	1.35	3.89	2.69
Hybrid employment, % chg	-6.10	-8.05	-9.03
Fully WFH employment, % chg	-4.12	-21.84	-11.48
Onsite subsidy / hybrid gross income (income tax), %	2.47	35.57	6.13
Onsite subsidy / hybrid gross income (WFH tax), %	-0.41	5.86	1.63

Note: The welfare gain is the population-weighted average of each city's percentage welfare gain $\frac{\sum_i L_i\left(U_i^{soc}/U_i^{mkt}-1\right)}{\sum_i L_i} \times 100\%$, where U_i^{soc} and U_i^{mkt} denote social welfare in the social optimum and market equilibrium in city i, respectively. The hybrid worker's onsite time gap is weighted by market hybrid employment, and each work-mode employment gap is weighted by that mode's market employment. The last two rows report the total onsite subsidy funded by income tax or WFH tax as a percentage of total hybrid workers' gross income ($\frac{\sum_{is} \text{Subsidy Share}_{is} \times I_{is}^h L_{is}^h}{\sum_{is} I_{is}^h L_{is}^h}$.). The onsite subsidy shares in each city-sector cell are calculated according to Appendix E.

Table 3 shows the gap between the social optimum and the market outcome and the shares of onsite subsidies with two tax sources. Column 1 shows the results in the presence of remote productivity spillover. On average, the social planner would like hybrid workers to spend more time WFH, while increasing onsite employment. The average optimal share of time hybrid workers spend working onsite is around 2.88 % lower than the market equilibrium. Average optimal onsite employment is around 1.35 % higher than market equilibrium, while average hybrid or fully WFH employment is around 6 % and 4 % lower than market equilibrium. In the socially optimal labor allocation, Social welfare is around 0.85 % higher than the market equilibrium.

Why would the social planner prefer that hybrid workers spend more time WFH, even though the onsite spillover and the onsite-to-remote elasticity are larger than their remote counterparts? The answer lies in the marginal benefit of hybrid workers' WFH time. According to equation (56), the socially optimal level of onsite time depends on the relative strength of onsite time and remote time elasticities, which incoportate the within-mode spillover net of cross-mode spillover. To see whether the social planner prefers more or less onsite time comapred to the market equilibrium, one can evaluate the two elasticities at the market allocation. In most city-sector cells, hybrid workers

account for a small share of onsite labor but a relatively large share of remote labor, and their onsite time share is not close to 1. Thus, one additional hour of WFH leads to a large increase in remote labor and a smaller decrease in onsite labor in most cells.[15] For remote productivity, an additional hour of WFH is associated with a gain from the within-mode spillover that outweighs the loss from the cross-mode spillover. For onsite productivity, the opposite holds. As a result, the remote productivity increase from an additional hour of WFH is larger than the onsite productivity increase from an additional hour of onsite work. The social planner would prefer hybrid workers to spend more time WFH.

The policies target optimal hybrid workers' shares of time spent working onsite to achieve the social optimum. By adjusting hybrid workers' onsite time, the economy could achieve the socially optimal employment allocation through productivity spillover effects (See Appendix E for derivation details.). If the social planner implements an income tax to fund the subsidies for hybrid workers' onsite work, the average cost is around 2.47 % of hybrid workers' before-tax income. If the social planner levies an onsite tax to subsidize hybrid workers' WFH time, the aggregated transfer is equivalent to about 0.41% of hybrid workers' aggregate gross income. Using the externality tax to fund the subsidies costs less than using the income tax.

Column 2 in Table 3 shows the senarior where there are no spillovers from remote labor. In this case, I set onsite spillover and the remote-to-onsite spillover to be zero ($\lambda^R = \tau_{ro} = 0$), while keeping the onsite spillover and onsite-to-remote spillover as in the first column ($\lambda > 0, \tau_{or} > 0$). I then recovered the shifters and solve for market equilibrium and socially optimal allocation under this setup. Without remote spillover, the socially optimal welfare would be 1.7% higher than the market equilibirum. Achieving the optimal welfare requires a larger change compared to the senarior in the presence of remote spillover. On average, the socially optimal levels of hybrid workers' onsite time

[15] In market euilibirum (data), the elasticity of remote labor with respect to hybrid workers' WFH time, $\frac{(1-\theta)L^h}{L^R}$, is larger than the elasticity of onsite labor with respect to their onsite time, $\frac{\theta L^h}{L^O}$, in 94.3 % of city-sector cells (2,000 of 2,121). The averages are 0.304 and 0.077. Hybrid workers' onsite time share in the data ranges from 0.5 to 0.7 in most city-sector cells. As a result, the remote time elasticity ($\delta^R = \lambda^R \frac{(1-\theta)L^h}{L^R} - \tau_{or}\frac{(1-\theta)L^h}{L^O}$) is larger than the onsite time elasticity, ($\delta = \lambda \frac{\theta L^h}{L^O} - \tau_{ro}\frac{\theta L^h}{L^R}$) in most cells.

and onsite employment would be around 41% and 4% higher than the market equilibrium, respectively. The socially optimal level of hybrid employment and fully WFH employment would be 8% and 22% lower than the market equilibirum. To encourage these employment allocation adjustments, the subsidy required to achieve the social optimum becomes more costly. Subsidy funded by income tax equals 36% of hybrid workers' gross income; subsidy funded by externality tax equals around 6% of hybrid workers' gross income. These imply that the remote productivity spillovers bring the economy closer to the optimal level of employment allocation by compensating for some of the reduction in onsite productivity spillovers.

Column 3 in Table 3 shows the scenario with within-mode spillovers ($\lambda > 0, \lambda^R > 0$) but no cross-mode spillovers ($\tau_{or} = \tau_{ro} = 0$). Since onsite spillover is stronger than remote spillover, the social planner favors more onsite time for hybrid workers, higher onsite employment, and lower hybrid and fully WFH employment. The subsidy required to achieve the social optimum is larger than in cases where cross-mode spillovers exist.

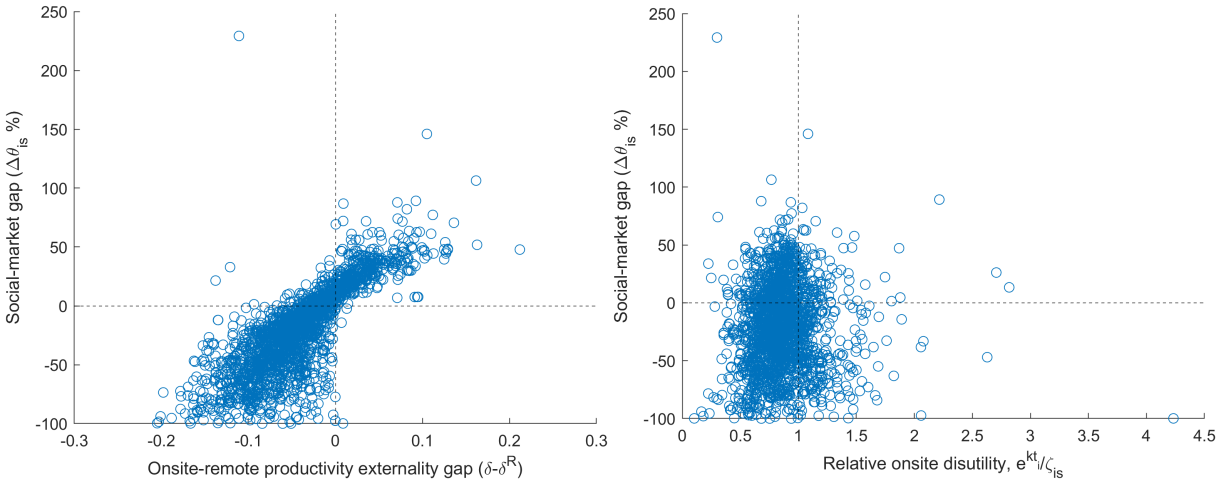
6.2 The Variations of the Gaps for Intensive and Extensive Margins of Labor

Column 1 in Table 3 shows that optimal allocation features hybrid workers spending more time WFH and more onsite employment on average. This section discusses the variations of the social optimum-market gap for hybrid workers' shares of time spent working onsite and labor composition for three work arrangements. I begin with the patterns of the socially optimal allocation and the gap, and then explain the mechanisms driving these patterns.

6.2.1 Hybrid Workers' Share of Time Working Onsite

As analyzed in section 4.3.1, whether the optimal share of time hybrid workers spend working onsite is larger than the market equilibrium depends on intensive margins of productivity externalities (δ and δ^R), relative onsite disutlity, and relative onsite productivity in the social optimum compared to market equilibrium. The following section shows that empirically, the productivity externalities are the main driving force.

Figure 12(a) shows how the gap between onsite and remote time elasticities affects the gap between socially optimal and market equilibrium shares of time spent working onsite. When the onsite time externality is stronger than the remote time externality ($\delta > \delta^R$), the socially optimal share of time spent working onsite tends to be larger than that in market equilibrium. Conversely, when the onsite time externality is weaker than the remote time externality ($\delta < \delta^R$), the socially optimal share of time spent working onsite is more likely to be smaller than that in market equilibrium. The gap between optimal and market equilibrium shares of time spent working onsite tends to be larger as the gap between onsite and remote time externalities becomes larger.



(a) (b)

Figure 12: Pattern and Determinants of the Gap in Hybrid Workers' Share of Time Working Onsite

Note: The gap between the social optimum and market equilibrium hybrid workers' shares of time spent working onsite is calculated as $\Delta\theta_{is} = (\frac{\theta^{soc}_{is}}{\theta^{mkt}_{is}} - 1) \times 100\%$.

Figure 12(b) shows that there is no clear correlation pattern between relative onsite disutility and the social-market gap of hybrid workers' onsite time. It implies that the relative onsite disutlity is not the main mechanism that determines the pattern of the gap.

The following pie charts further decompose the factors influencing whether the socially optimal share of time spent working onsite is larger than the market equilibrium. 31 % of city-sector cells have an optimal share of time spent working onsite larger than the market equilibrium, while 69 % have the opposite. Figure 13(a) shows the decomposition

for city-sector cells with higher socially optimal onsite time, while Figure 13(b) shows the corresponding decomposition for city-sector cells with lower socially optimal onsite time.

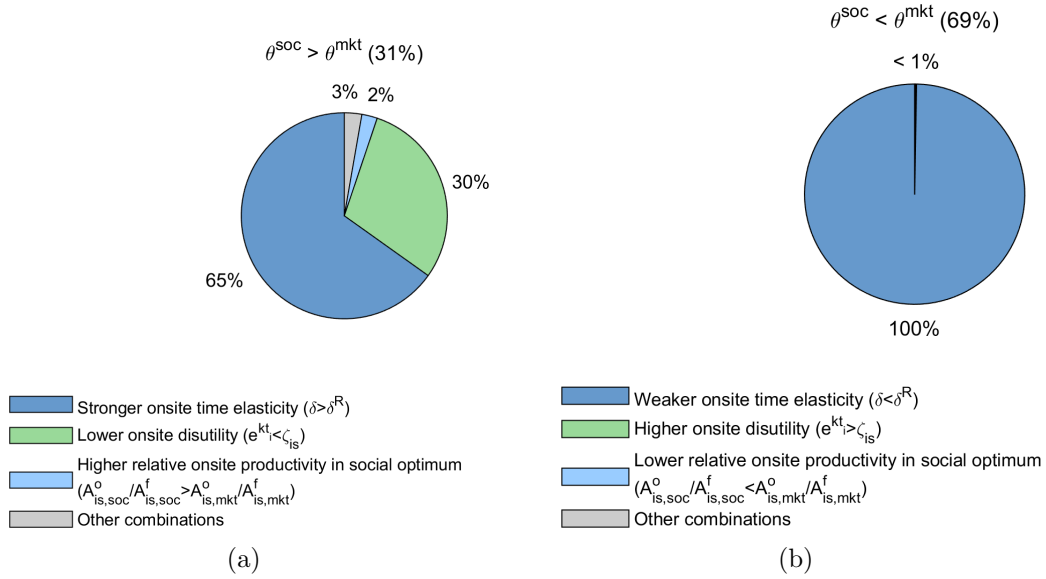


Figure 13: Decomposition of Factors Influencing the Sign of the Gap

Note: θ_{is}^{soc} denotes the socially optimal hybrid workers' shares of time spent working onsite. θ_{is}^{mkt} denotes the hybrid workers' shares of time spent working onsite in market equilibrium.

Figure 13(a) shows that among city-sector cells with a higher optimal share of time spent working onsite, 65 % of them have the intensive onsite productivity externality stronger than the intensive remote productivity externality. For 30 % of them, despite their onsite time externality being weaker than the remote time externality, a lower onsite disutility drives a higher socially optimal share of time spent working onsite.[16] 2 % of them have a weaker intensive onsite productivity externality and a higher onsite disutility. However, optimal employment results in a higher relative onsite productivity in the social optimum than in market equilibrium, which drives a higher optimal share of time spent working onsite. Figure 13(b) shows that for city-sector cells with a lower optimal share of time spent working onsite, a weake onsite time externality is the main cause.

[16] When onsite disutility is smaller than WFH amenity costs, an increase in the share of time spent working onsite decreases the disutility composite, leading the social planner to favor a higher share of time spent working onsite.

6.2.2 Employment by Work Mode

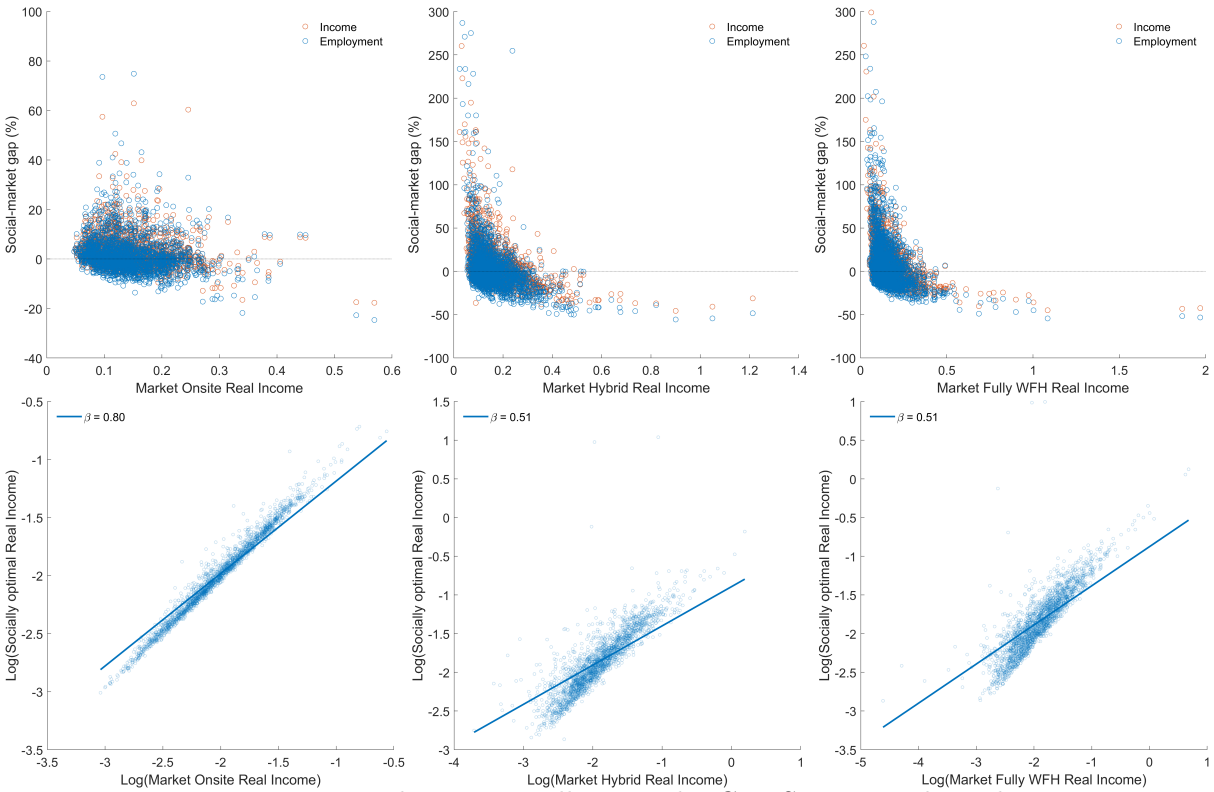


Figure 14: Employment Reallocation by City-Sector-Work mode

Note: Each point represents a city-sector cell. The gap between the social optimum and market equilibrium employment is calculated as $\Delta x_{is} = (\frac{x_{is}^{soc}}{x_{is}^{mkt}} - 1) \times 100\%$. β in the bottom row is the slope of the regression of the socially optimal income on the market equilibrium income with city fixed effect. $ln(I_{is}^{soc}) = \beta ln(I_{is}^{mkt}) + \gamma_i + \epsilon_{is}$. i denotes city and s denotes sector.

The top row of Figure 14 shows the reallocation pattern of employment from the social planner's perspective. Compared to the original market equilibrium, the social planner is more likely to reallocate workers from original relatively high-income sectors to relatively low-income sectors. This pattern is more pronounced for hybrid and fully WFH employment than for onsite employment. As a result, the productivity in original low income sectors increases due to the productivity externalities, leading to an increase in income for those sectors.

The bottom row of Figure 14 shows that sectors that originally have high income levels tend to retain relatively higher incomes after the reallocation, but the income gap between high-income and low-income sectors within a city gets smaller. A 10 % income gap in the market equilibrium shrinks to about 8 %, 5 %, and 5% in the social optimum

for onsite, hybrid, and fully WFH workers, respectively. [17]

7 Conclusion

This study incorporates productivity spillover effects both within and between onsite and remote labor in a quantitative spatial model. In the model, each worker selects a sector and work mode in each city. Hybrid workers choose the share of time spent working onsite and WFH. I estimate the within-mode and cross-mode productivity spillovers using Bartik instruments. The estimation results indicate that the within mode onsite spillover is stronger than the remote spillover and that the onsite-to-remote spillover is stronger than the remote-to-onsite spillover.

The socially optimal allocation differs from the market equilibrium in terms of the share of time hybrid workers spend working onsite and employment composition across cities and sectors. The socially optimal hybrid workers' onsite time depends on the onsite time elasticity relative to remote time elasticity. These two intensive margins of productivity externalities measure how onsite and remote productivity respond to changes in hybrid workers' share of time spent working onsite or WFH, and they are functions of within-mode, cross-mode productivity spillovers, and employment composition.

I apply the model to U.S. data at the CBSAs and sector levels. The quantification results show that a welfare gain in the socially optimal allocation is associated with a lower share of time hybrid workers spend working onsite, more onsite workers, less hybrid workers and less fully remote workers compared to the market equilibrium at the average level. However, there are variations at the city-sector level. City-sector cells with a stronger (weaker) onsite time elasticity relative to remote time elasticity tend to have a higher (lower) socially optimal share of time spent working onsite compared to the market equilibrium. A larger gap between socially optimal and market equilibrium shares of time spent working onsite is associated with a larger gap between the onsite and remote time

[17] This pattern is similar to Fajgelbaum and Gaubert (2020). Equation (66) in this paper is similar to Equation (88) in Appendix D of Fajgelbaum and Gaubert (2020). Fajgelbaum and Gaubert (2020) considers productivity spillover effect and mobility across cities. The socially optimal employment allocation in their paper features a reallocation from large to small cities and a decrease in urban skill premium.

elasticities.

I consider optimal policies targeting the share of time hybrid workers spend working onsite to simultaneously achieve socially optimal hybrid workers' onsite time and employment allocationr. The quantification results show that costs of achieving the social optimum are lower in the presence of remote productivity spillovers compared to the absence of remote spillovers. Remote productivity spillovers bring the economy closer to the social optimum by compensating for some of the reduction in onsite productivity spillovers.

This paper has several limitations that may be important to address in future studies. First, it focuses primarily on productivity externalities and their welfare implications, and it does not account for all the benefits, costs, and potential externalities associated with onsite and remote work. The benefits of onsite work not considered in the paper include the long-term effects of knowledge sharing, improved monitoring efficiency, etc. The unaccounted benefits of WFH include lower office real estate and utility expenses, higher job-match quality, saving commuting time, relatively lower housing costs, etc. The model assumes exogenous commuting costs and homogeneous housing prices within the same city. However, more WFH could lower the commuting costs and housing price in the city center, which affects the welfare. Another potential spillover effect of WFH that hasn't been incorporated is that workers might spend more time with their families, which could improve children's educational outcomes and future productivity.

Second, the model assumes the remote productivity externality occurs within each city. However, the remote productivity externality has the potential to extend beyond geographic boundaries.

Third, this paper considers socially optimal policies that target the hybrid workers' work arrangement. Other optimal policies, such as offering transfers across workers to adjust employment allocation, could also achieve the socially optimal allocation.

Additionally, the model in this paper assumes firms do not make policies about remote work. In the market equilibrium, the number of employments across work modes and hybrid workers' work arrangements are jointly determined by workers' choices and

societal productivity levels. However, firms are implementing return-to-office policies as documented by Ding and Ma (2023) and Flynn et al. (2024). These policies may only partially internalize the externalities if they focus only on onsite spillover effects while overlooking the remote spillover effects or ignoring spillovers to other firms. It may be worth exploring whether firms' return-to-office policies bring the economy closer to the social optimum.

Appendix

A Empirical Facts

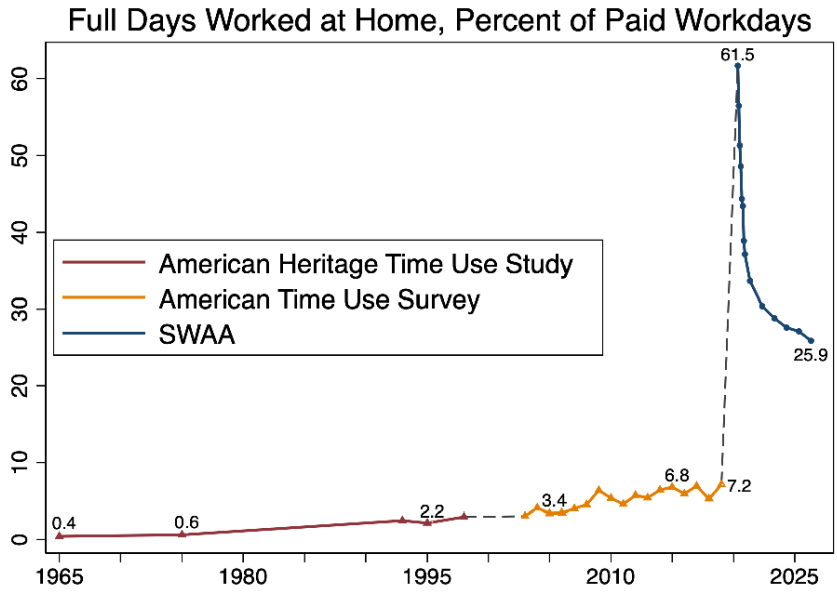


Figure 15: Historical and current WFH Trend
Figure source: Barrero et al. (2023).

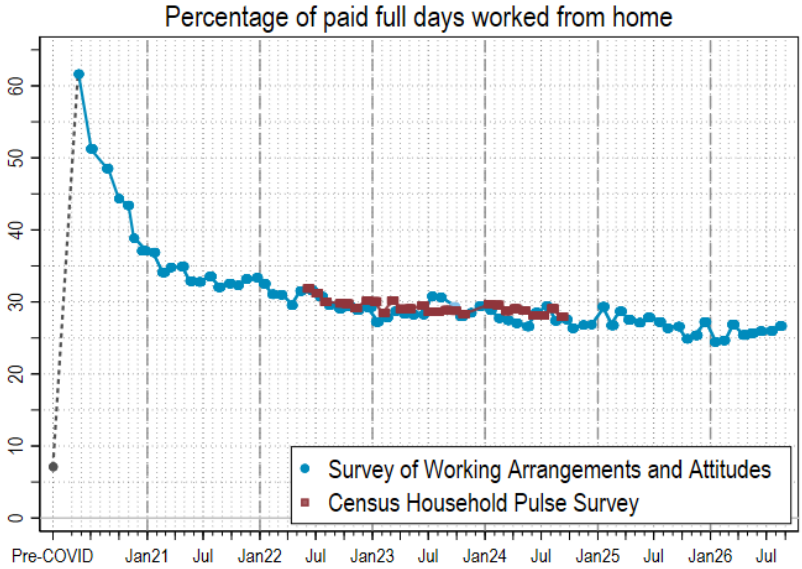


Figure 16: Working From Home Trend in the U.S.
Figure source: Barrero et al. (2023).

Table 4: Migration Shares of Home-Based and On-Site Workers Within 1 Year

Panel A: Shares in laborforce

	2022-2024 average	
	on-site worker	home-based worker
same house (%)	86.18	85.29
moved within CBSA (%)	8.05	8.23
moved between CBSAs (%)	5.10	5.99
abroad one year ago (%)	0.66	0.50
N (unweighted matched rows)	6,975,266	

Panel B: Shares in migrator

	on-site worker	home-based worker
moved within CBSA (%)	58.28	55.91
moved between CBSAs (%)	36.93	40.68
abroad one year ago (%)	4.79	3.41
N (unweighted matched rows)	1,198,540	

Note: The data source is the American Community Survey (ACS). Samples are wage workers excluding unpaid family workers and military workers. Residence PUMAs and workplace PWPUMAs are matched to CBSAs using the allocation procedure described in Section 5.

B Socially Optimal Share of Time Spent Working Onsite in the Basic Model

In the one city one sector model with homogenous workers, the social planner's problem is

$$\begin{aligned} &\max_{c,h,K,\theta} \frac{c^{\alpha}h^{1-\alpha}}{\bar{\phi}d(\theta)}\bar{L}, \\ &\text{s.t.} \begin{cases} c\bar{L} + K = Y = A^h(\theta)\bar{L} \text{ (goods market clearing)}, \\ h\bar{L} = K^{\gamma}\bar{H}^{1-\gamma} \text{ (housing market clearing)}. \end{cases} \end{aligned} \tag{B.1}$$

where $\bar{\phi} = \alpha^{\alpha}(1-\alpha)^{1-\alpha}$, $d(\theta) = \zeta^{o}\theta + \zeta(1-\theta)$. The production function is:

$$A^h(\theta) = \left[\left(A^f(\theta)(1-\theta)\right)^{\frac{\rho-1}{\rho}} + \left(A^o(\theta)\theta\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}, \tag{B.2}$$

$$A^o(\theta) = \bar{a}^o(\theta\bar{L})^{\lambda}\left((1-\theta)\bar{L}\right)^{\tau_{ro}\mathbf{1}_{\{\theta\neq 1\}}}, \tag{B.3}$$

$$A^f(\theta) = \bar{a}^f\left((1-\theta)\bar{L}\right)^{\lambda^R}(\theta\bar{L})^{\tau_{or}\mathbf{1}_{\{\theta\neq 0\}}}, \tag{B.4}$$

where $\mathbf{1}_{\{\cdot\}}$ is the indicator function.

The Lagrangian function is:

$$\mathscr{L} = \frac{c^{\alpha} h^{1-\alpha}}{\bar{\phi} d(\theta)} \bar{L} - \widetilde{P} \left(c\bar{L} + K - A^{h}(\theta)\bar{L} \right) - \widetilde{q} \left(h\bar{L} - K^{\gamma} \bar{H}^{1-\gamma} \right). \tag{B.5}$$

Let $u = \frac{c^{\alpha} h^{1-\alpha}}{\bar{\phi} d(\theta)}$ denote per-worker utility evaluated at an allocation. The first-order conditions are:

$$\partial c : \frac{\alpha u \bar{L}}{c} = \widetilde{P} \bar{L}; \tag{B.6}$$

$$\partial h : \frac{(1-\alpha) u \bar{L}}{h} = \widetilde{q} \bar{L}; \tag{B.7}$$

$$\partial K : \widetilde{P} = \widetilde{q} \gamma K^{\gamma - 1} \bar{H}^{1-\gamma}; \tag{B.8}$$

$$\partial \theta : u \bar{L} \frac{\partial d(\theta)/\partial \theta}{d(\theta)} = \widetilde{P} \frac{\partial A^{h}(\theta)}{\partial \theta} \bar{L}. \tag{B.9}$$

To solve for the socially optimal share of time spent working onsite, I first express h and K as functions of c, and then express c and h as functions of θ. Combining the first-order conditions with respect to consumption and housing gives

$$h = \frac{1-\alpha}{\alpha} \frac{\widetilde{P}}{\widetilde{q}} c. \tag{B.10}$$

Housing market clearing implies

$$K^{\gamma - 1} \bar{H}^{1-\gamma} = \frac{h\bar{L}}{K}. \tag{B.11}$$

Substituting this equality into the first-order condition for K, and then using equation (B.10), yields

$$\frac{\widetilde{P}}{\widetilde{q}} = \gamma \frac{h\bar{L}}{K}, \tag{B.12}$$

$$K = \frac{1-\alpha}{\alpha} \gamma c \bar{L}. \tag{B.13}$$

Substituting equation (B.13) into goods market clearing gives

$$c = \frac{\alpha}{\alpha + \gamma(1-\alpha)} A^h(\theta). \tag{B.14}$$

Equation (B.13) then gives tradable inputs used in housing production:

$$K = \frac{\gamma(1-\alpha)}{\alpha + \gamma(1-\alpha)} A^h(\theta)\bar{L}. \tag{B.15}$$

Substituting this solution into housing market clearing gives housing consumption as a function of θ:

$$h = \left[\frac{\gamma(1-\alpha)}{\alpha + \gamma(1-\alpha)}\right]^{\gamma} [A^h(\theta)]^{\gamma} \left(\frac{\bar{H}}{\bar{L}}\right)^{1-\gamma}. \tag{B.16}$$

Combining the first-order conditions (B.6) and (B.9), and then substituting equation (B.14), gives

$$\frac{\partial d(\theta)/\partial\theta}{d(\theta)} = \frac{\alpha}{c}\frac{\partial A^h(\theta)}{\partial\theta} = \tilde{\gamma}\frac{\partial A^h(\theta)/\partial\theta}{A^h(\theta)}, \quad \tilde{\gamma} = \alpha + \gamma(1-\alpha). \tag{B.17}$$

Finally, I simplify equation (B.17) to obtain an equation comparable to the one used to solve θ in market equilibrium. The social planner treats $A^o(\theta)$ and $A^f(\theta)$ as functions of the onsite share. The proportional change in hybrid productivity is

$$\begin{aligned}\frac{\partial A^h(\theta)/\partial\theta}{A^h(\theta)} = &\left[\left(A^f(\theta)(1-\theta)\right)^{\frac{\rho-1}{\rho}} + \left(A^o(\theta)\theta\right)^{\frac{\rho-1}{\rho}}\right]^{-1} \\ &\times \left[-\left(A^f(\theta)\right)^{\frac{\rho-1}{\rho}}(1-\theta)^{-\frac{1}{\rho}}(\delta^R+1) + \left(A^o(\theta)\right)^{\frac{\rho-1}{\rho}}\theta^{-\frac{1}{\rho}}(\delta+1)\right].\end{aligned} \tag{B.18}$$

where $\delta = \lambda - \tau_{ro}\theta/(1-\theta)$ and $\delta^R = \lambda^R - \tau_{or}(1-\theta)/\theta$. Substituting equation (B.18) into equation (B.17) gives

$$\left(A^f(\theta)\right)^{\frac{\rho-1}{\rho}}(1-\theta)^{\frac{-1}{\rho}}\left(\tilde{\gamma}d(\theta)(\delta^R+1) + \frac{\partial d(\theta)}{\partial\theta}(1-\theta)\right) = \left(A^o(\theta)\right)^{\frac{\rho-1}{\rho}}\theta^{-\frac{1}{\rho}}\left(\tilde{\gamma}d(\theta)(\delta+1) - \frac{\partial d(\theta)}{\partial\theta}\theta\right). \tag{B.19}$$

Rearranging this equation yields the interior solution for the socially optimal share of

time spent working onsite:

$$\frac{\theta}{1-\theta} = \left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{\rho-1}\left[\frac{\tilde{\gamma}d(\theta)(\delta+1) - \frac{\partial d(\theta)}{\partial\theta}\theta}{\tilde{\gamma}d(\theta)(\delta^R+1) + \frac{\partial d(\theta)}{\partial\theta}(1-\theta)}\right]^{\rho} \tag{B.20}$$

$$\frac{\theta}{1-\theta} = \left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{\rho-1}\left[\frac{\tilde{\gamma}d(\theta)(\delta+1) - d(\theta) + d(\theta) - \frac{\partial d(\theta)}{\partial\theta}\theta}{\tilde{\gamma}d(\theta)(\delta^R+1) - d(\theta) + d(\theta) + \frac{\partial d(\theta)}{\partial\theta}(1-\theta)}\right]^{\rho} \tag{B.21}$$

$$\frac{\theta}{1-\theta} = \left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{\rho-1}\left[\frac{\zeta + d(\theta)\left(\tilde{\gamma}\left(\delta+1\right)-1\right)}{\zeta^o + d(\theta)\left(\tilde{\gamma}\left(\delta^R+1\right)-1\right)}\right]^{\rho}, \tag{B.22}$$

where $\tilde{\gamma} = \alpha+\gamma(1-\alpha)$, $A^o(\theta) = \bar{a}^o(\theta\bar{L})^{\lambda}((1-\theta)\bar{L})^{\tau_{ro}\mathbf{1}_{\{\theta\neq 1\}}}$, $A^f(\theta) = \bar{a}^f((1-\theta)\bar{L})^{\lambda^R}(\theta\bar{L})^{\tau_{or}\mathbf{1}_{\{\theta\neq 0\}}}$, and $d(\theta) = \theta\zeta^o + (1-\theta)\zeta$. For $\theta \in (0,1)$, the time elasticities are $\delta = \lambda - \tau_{ro}\theta/(1-\theta)$ and $\delta^R = \lambda^R - \tau_{or}(1-\theta)/\theta$. Another way to simplify equation (B.20) is:

$$\frac{\theta}{1-\theta} = \left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{\rho-1}\left(\frac{\tilde{\gamma}(\delta+1) - \frac{\partial d(\theta)/d(\theta)}{\partial\theta/\theta}}{\tilde{\gamma}(\delta^R+1) + \frac{\partial d(\theta)/d(\theta)}{\partial\theta/(1-\theta)}}\right)^{\rho}, \tag{B.23}$$

$$= \left(\frac{A^o(\theta)}{A^f(\theta)}\right)^{\rho-1}\left(\frac{\tilde{\gamma}(\delta+1) - \delta_d}{\tilde{\gamma}(\delta^R+1) - \delta_d^R}\right)^{\rho}, \tag{B.24}$$

where $\delta_d = \frac{\partial d(\theta)/d(\theta)}{\partial\theta/\theta} = \frac{(\zeta^o-\zeta)\theta}{d(\theta)}$, $\delta_d^R = \frac{\partial d(\theta)/d(\theta)}{\partial(1-\theta)/(1-\theta)} = \frac{(\zeta-\zeta^o)(1-\theta)}{d(\theta)}$.

Equation (B.22) characterizes an interior solution. Substituting equations (B.14) and (B.16) into the objective simplifies total welfare to a function of θ:

$$u(\theta)\bar{L} = \bar{C}\frac{[A^h(\theta)]^{\tilde{\gamma}}}{d(\theta)}, \tag{B.25}$$

where $\bar{C} = \frac{\bar{L}}{\phi}\left[\frac{\alpha}{\alpha+\gamma(1-\alpha)}\right]^{\alpha}\left[\frac{\gamma(1-\alpha)}{\alpha+\gamma(1-\alpha)}\right]^{\gamma(1-\alpha)}\left(\frac{\bar{H}}{\bar{L}}\right)^{(1-\gamma)(1-\alpha)}$.

Because $d(0) = \zeta$, $d(1) = \zeta^o$, $A^h(0) = \bar{a}^f\bar{L}^{\lambda^R}$, and $A^h(1) = \bar{a}^o\bar{L}^{\lambda}$, welfare at the two corners is

$$u(0)\bar{L} = \bar{C}\frac{(\bar{a}^f\bar{L}^{\lambda^R})^{\tilde{\gamma}}}{\zeta}, \tag{B.26}$$

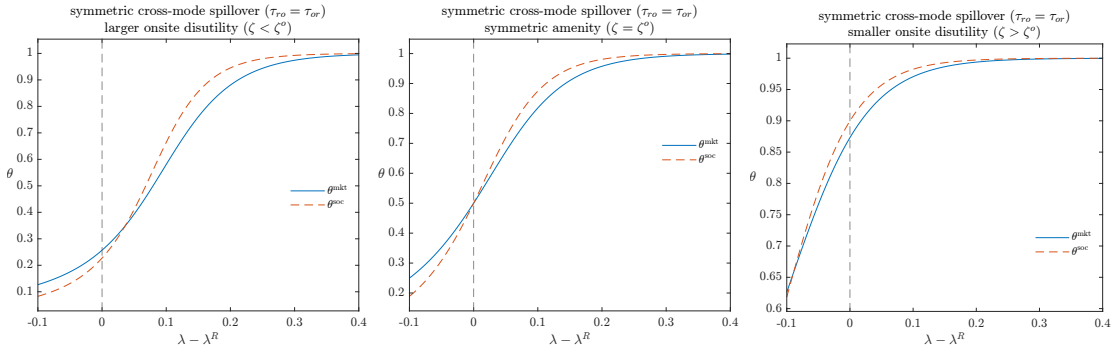
$$u(1)\bar{L} = \bar{C}\frac{(\bar{a}^o\bar{L}^{\lambda})^{\tilde{\gamma}}}{\zeta^o}. \tag{B.27}$$

All remote work is globally optimal if and only if

$$\frac{(\bar{a}^f \bar{L}^{\lambda^R})^{\tilde{\gamma}}}{\zeta} \geq \frac{[A^h(\theta)]^{\tilde{\gamma}}}{d(\theta)} \quad \text{for every } \theta \in (0,1]. \tag{B.28}$$

All onsite work is globally optimal if and only if

$$\frac{(\bar{a}^o \bar{L}^{\lambda})^{\tilde{\gamma}}}{\zeta^o} \geq \frac{[A^h(\theta)]^{\tilde{\gamma}}}{d(\theta)} \quad \text{for every } \theta \in [0,1). \tag{B.29}$$



(a) (b) (c)

Figure 17: Levels of θ^{mkt} and θ^{soc} Underlying Figure 6

Note: Same three relative-amenity cases and parameter values as Figure 6 ($\lambda^R = 0.1$ with $\lambda - \lambda^R$ on the horizontal axis, $\tau_{ro} = \tau_{or} = 0$, $\bar{a}^o = \bar{a}^f = 1$, $\rho = 3.6$, $\gamma = 0.09$, and $\alpha = 0.76$), but showing the levels of θ^{mkt} and θ^{soc} rather than their percentage gap $\Delta\theta$.

C Optimal Policies in the Basic Model

C.1 Using Income Tax to Subsidize Onsite Work or Remote Work

If the social planner uses income tax to subsidize onsite work or remote work, the disposable income under this policy becomes

$$\mathscr{W}(\theta) = I(\theta)h(\theta), \quad h(\theta) = (1 - \mathscr{T})(1 + s\theta), \tag{C.1}$$

where $\mathscr{T}$ is the income tax rate. s is the onsite subsidy (tax) rate. $s > 0$ corresponds to subsidizing onsite work or taxing remote work; $s < 0$ corresponds to taxing onsite work

or subsidizing remote work.

The social planner's budget constraint is

$$I(\theta)\mathscr{T}\bar{L} = I(\theta)(1-\mathscr{T})s\theta\bar{L}. \tag{C.2}$$

Simplifying this equation gives the relationship between income tax and subsidy: $\mathscr{T} = \frac{s\theta}{1+s\theta}$. Therefore, the share of onsite subsidy (tax) in gross income is:

$$SubsidySh_{inctax} = \frac{I(\theta)(1-\mathscr{T})s\theta}{I(\theta)} = \frac{s\theta}{1+s\theta}. \tag{C.3}$$

This share equals the income-tax share in gross income, $\frac{I(\theta)\mathscr{T}}{I(\theta)} = \mathscr{T}$.

Under the policy, the first-order condition with respect to θ in market equilibrium becomes

$$\frac{\partial d(\theta)/\partial\theta}{d(\theta)} = \frac{\partial A^h(\theta)/\partial\theta}{A^h(\theta)} + \frac{\partial h(\theta)/\partial\theta}{h(\theta)}, \tag{C.4}$$

where $\partial A^h(\theta)$ differs from the social planner's problem in that onsite and remote productivities (A^o, A^f) are taken as constant rather than as functions of θ.

Workers' choice after policy is

$$\frac{\theta}{1-\theta} = \left(\frac{A^o}{A^f}\right)^{\rho-1}\left(\frac{\zeta + H(\theta)d(\theta)\theta}{\zeta^o - H(\theta)d(\theta)(1-\theta)}\right)^{\rho}, \tag{C.5}$$

where $H(\theta) = \frac{dh(\theta)/d\theta}{h(\theta)} = \frac{s}{(1+s\theta)}$. Equating post-policy workers' choice (C.5) to the social optimum equation (12) gives the solution for $H(\theta)$ and the share of subsidy in gross income:

$$H(\theta) = \frac{\widetilde{Z}\zeta^o - \zeta}{d(\theta)\theta + \widetilde{Z}d(\theta)(1-\theta)}, \quad SubsidySh_{inctax} = H(\theta)\theta, \tag{C.6}$$

$$s = \frac{H(\theta)}{1 - H(\theta)\theta} \tag{C.7}$$

where $\widetilde{Z} = \frac{\zeta + d(\theta)(\widetilde{\gamma}(\delta+1)-1)}{\zeta^o + d(\theta)(\widetilde{\gamma}(\delta^R+1)-1)}$.

C.2 Taxing (Subsidizing) Remote Work and Subsidizing (Taxing) Onsite Work

An alternative policy is that tax and subsidy are both related to the sources of externalities. If the social planner taxes (subsidizes) remote work and subsidizes (taxes) the onsite work, the disposable income becomes

$$\mathscr{W}(\theta) = I(\theta)g(\theta), \quad g(\theta) = (1 - \text{ŧ}(1-\theta))\,(1 + t\theta)\,, \tag{C.8}$$

where ŧ is the tax (subsidy) rate based on the share of time spent WFH; t is the subsidy (tax) rate based on the share of time spent working onsite. The social planner's budget constraint is

$$I(\theta)\text{ŧ}(1-\theta)\bar{L} = I(\theta)(1 - \text{ŧ}(1-\theta))t\theta\bar{L}. \tag{C.9}$$

Simplifying this equation gives the relationship between the tax and the subsidy:

$$\text{ŧ}(1-\theta) = \frac{t\theta}{1+t\theta}. \tag{C.10}$$

Thus, the share of onsite subsidy (tax) in gross income can be derived as

$$SubsidySh_{exttax} = \frac{I(\theta)(1 - \text{ŧ}(1-\theta))t\theta}{I(\theta)} = \frac{t\theta}{1+t\theta}. \tag{C.11}$$

This share equals the share of remote tax (subsidy) in gross income $\frac{I(\theta)\text{ŧ}(1-\theta)}{I(\theta)} = \text{ŧ}(1-\theta)$.

Workers' choice after policy is

$$\frac{\theta}{1-\theta} = \left(\frac{A^o}{A^f}\right)^{\rho-1}\left(\frac{\zeta + G(\theta)d(\theta)\theta}{\zeta^o - G(\theta)d(\theta)(1-\theta)}\right)^{\rho}, \tag{C.12}$$

where $G(\theta) = \frac{\partial g(\theta)/\partial\theta}{g(\theta)} = \frac{t\left(t\theta^2+1\right)}{(1-\theta)(1+t\theta)}$. Letting post-policy workers' choice (C.12) equal the social optimum equation (12), I obtain

$$\theta^2 t^2 + (1 - \theta(1-\theta)G^*)\,t - G^*(1-\theta) = 0, \tag{C.13}$$

Therefore, the solution for the onsite subsidy (tax) rate is as follows:

$$t = \frac{1}{2\theta^2}\left[-1 + \theta(1-\theta)G^* + \sqrt{(1-\theta(1-\theta)G^*)^2 + 4\theta^2 G^*(1-\theta)}\right], \tag{C.14}$$

where $G^* = \frac{\widetilde{Z}\zeta^o - \zeta}{d(\theta)\theta + \widetilde{Z}d(\theta)(1-\theta)}$, $\widetilde{Z} = \frac{\zeta + d(\theta)(\widetilde{\gamma}(\delta+1)-1)}{\zeta^o + d(\theta)(\widetilde{\gamma}(\delta^R+1)-1)}$.

D Social Planner's Problem in the Full Model

In the full model, workers in the same city have the same expected utility. The social planner maximizes the population-weighted sum of city-level expected utilities subject to the resource constraints of each city:

$$\max \sum_i U_i \bar{L}_i$$

subject to

1. labor mobility constraint:

$$U_i \leq v_{is}^m \left(\frac{\bar{L}_i}{L_{is}^m}\right)^{\frac{1}{\sigma}} \forall i, s, m, \tag{D.1}$$

   where $v_{is}^m = \frac{\left(c_{is}^m\right)^{\alpha}\left(\hbar_{is}^m\right)^{1-\alpha}\varepsilon_{is}^m}{\bar{\phi} d_{is}^m\left(\theta_{is}^m\right)}$, $\bar{\phi} = \alpha^{\alpha}(1-\alpha)^{1-\alpha}$, $d_{is}^m(\theta_{is}^m) = e^{kt_i}\theta_{is}^m + \zeta_{is}(1-\theta_{is}^m)$, $\theta_{is}^o = 1, \theta_{is}^h = \theta_{is} \in (0,1)$, and $\theta_{is}^f = 0$;

2. goods market constraint [18]:

$$\sum_s \sum_m c_{is}^m L_{is}^m + K_i \leq Y_i \quad \forall i, \tag{D.2}$$

[18] Equation (D.2) implies that the planner reallocates resources across sectors and work modes within a city but does not transfer goods across cities. We have the same constraint under the assumption of no trade costs across cities and trade balance (goods a city sold equals what it buys).

where,

$$
\begin{aligned}
&Y_i = \left[\sum_s \bar{y}_{is} \left(y_{is}\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \qquad y_{is} = A^o_{is} L^o_{is} + \bar{a}^h_{is} A^h_{is}\left(\theta_{is}\right) L^h_{is} + A^f_{is} L^f_{is},\\
&A^h_{is}(\theta_{is}) = [\Big(A^f_{is}(\theta_{is})(1-\theta_{is})\Big)^{\frac{\rho-1}{\rho}} + \left(A^o_{is}(\theta_{is})\theta_{is}\right)^{\frac{\rho-1}{\rho}}]^{\frac{\rho}{\rho-1}},\\
&A^o_{is}(\theta_{is}) = \bar{a}^o_{is}\left[L^O_{is}(\theta_{is})\right]^{\lambda}\left[L^R_{is}(\theta_{is})\right]^{\tau_{ro}\mathbf{1}_{\{L^R_{is}\neq 0\}}},\\
&A^f_{is}(\theta_{is}) = \bar{a}^f_{is}\left[L^R_{is}(\theta_{is})\right]^{\lambda^R}\left[L^O_{is}(\theta_{is})\right]^{\tau_{or}\mathbf{1}_{\{L^O_{is}\neq 0\}}},\\
&L^O_{is}(\theta_{is}) = L^o_{is} + \theta_{is} L^h_{is}, \qquad\qquad L^R_{is}(\theta_{is}) = L^f_{is} + (1-\theta_{is}) L^h_{is};
\end{aligned}
$$

3. housing market clearing:

$$\sum_s \sum_m \hbar^m_{is} L^m_{is} \leq K^{\gamma}_i \bar{H}^{1-\gamma}_i \quad \forall i; \tag{D.3}$$

4. labor market clearing:

$$\sum_s \sum_m L^m_{is} = \bar{L}_i \quad \forall i. \tag{D.4}$$

The Lagrangian function for the social planner's problem is:

$$
\begin{aligned}
\mathscr{L} = &\sum_i U_i \bar{L}_i - \sum_i \sum_s \sum_m \widetilde{W}^m_{is}\left(U_i - v^m_{is}\left(\frac{\bar{L}_i}{L^m_{is}}\right)^{\frac{1}{\sigma}}\right) - \sum_i \widetilde{P}_i\left(\sum_s \sum_m c^m_{is} L^m_{is} + K_i - Y_i\right)\\
&- \sum_i \widetilde{q}_i\left(\sum_s \sum_m \hbar^m_{is} L^m_{is} - K^{\gamma}_i \bar{H}^{1-\gamma}_i\right) - \sum_i e_i\left(\sum_s \sum_m L^m_{is} - \bar{L}_i\right).
\end{aligned} \tag{D.5}
$$

The first-order conditions with respect to consumption, housing, share of time spent working onsite, goods used in housing production, employment, and the city welfare index

are:

$$\partial c_{is}^m : \widetilde{W}_{is}^m \frac{\partial v_{is}^m}{\partial c_{is}^m} \left(\frac{\bar{L}_i}{L_{is}^m} \right)^{\frac{1}{\sigma}} = \widetilde{P}_i L_{is}^m, \forall i, s, m; \tag{D.6}$$

$$\partial \hbar_{is}^m : \widetilde{W}_{is}^m \frac{\partial v_{is}^m}{\partial \hbar_{is}^m} \left(\frac{\bar{L}_i}{L_{is}^m} \right)^{\frac{1}{\sigma}} = \widetilde{q}_i L_{is}^m, \forall i, s, m; \tag{D.7}$$

$$\partial K_i : \widetilde{P}_i = \tilde{q}_i \gamma K_i^{\gamma-1} \bar{H}_i^{1-\gamma}, \forall i; \tag{D.8}$$

$$\partial \theta_{is} : \widetilde{W}_{is}^h \frac{\partial v_{is}^h}{\partial \theta_{is}} \left(\frac{\bar{L}_i}{L_{is}^h} \right)^{\frac{1}{\sigma}} = -\widetilde{P}_i \frac{\partial Y_i}{\partial \theta_{is}}, \forall i, s; \tag{D.9}$$

$$\partial L_{is}^m : -\widetilde{W}_{is}^m v_{is}^m \frac{1}{\sigma} \left(\frac{\bar{L}_i}{L_{is}^m} \right)^{\frac{1}{\sigma}} \frac{1}{L_{is}^m} - \widetilde{P}_i \left(c_{is}^m - \frac{\partial Y_i}{\partial L_{is}^m} \right) - \tilde{q}_i \hbar_{is}^m - e_i = 0, \forall i, s, m; \tag{D.10}$$

$$\partial U_i : \bar{L}_i - \sum_s \sum_m \widetilde{W}_{is}^m = 0, \forall i. \tag{D.11}$$

Consumption and Housing

Substituting the labor mobility constraint (D.1) into the first-order conditions with respect to consumption (D.6) and housing (D.7) yields

$$c_{is}^m = \frac{\alpha \widetilde{W}_{is}^m U_i}{\widetilde{P}_i L_{is}^m}, \quad \hbar_{is}^m = \frac{(1-\alpha) \widetilde{W}_{is}^m U_i}{\widetilde{q}_i L_{is}^m}. \tag{D.12}$$

Define $\widetilde{I}_{is}^m = \widetilde{P}_i c_{is}^m + \widetilde{q}_i \hbar_{is}^m$. Based on equation (D.12), $\widetilde{I}_{is}^m$ becomes

$$\widetilde{I}_{is}^m = \widetilde{P}_i c_{is}^m + \widetilde{q}_i \hbar_{is}^m = \frac{\widetilde{W}_{is}^m U_i}{L_{is}^m}. \tag{D.13}$$

Then, the solution for consumption and housing can be written as

$$c_{is}^m = \frac{\alpha \widetilde{I}_{is}^m}{\widetilde{P}_i}, \tag{D.14}$$

$$\hbar_{is}^m = \frac{(1-\alpha) \widetilde{I}_{is}^m}{\widetilde{q}_i}. \tag{D.15}$$

Therefore, utility can be expressed as

$$v_{is}^m = \frac{\widetilde{I}_{is}^m \epsilon_{is}^m}{\widetilde{P}_i^\alpha \widetilde{q}_i^{1-\alpha} d_{is}^m(\theta_{is}^m)}. \tag{D.16}$$

Final goods used to produce housing

Combining the first-order condition with respect to K_i (D.8) and housing market clearing (D.3) yields

$$\sum_s \sum_m \hbar_{is}^m L_{is}^m = \frac{K_i}{\gamma} \frac{\widetilde{P}_i}{\widetilde{q}_i}. \tag{D.17}$$

Substituting $\hbar_{is}^m = \frac{(1-\alpha)\widetilde{I}_{is}^m}{\widetilde{q}_i}$ to equation (D.17) yields

$$K_i = \frac{\gamma(1-\alpha)}{\widetilde{P}_i} \sum_s \sum_m \widetilde{I}_{is}^m L_{is}^m. \tag{D.18}$$

Based on equation (D.8), the multiplier of the housing market clearing constraint is:

$$\widetilde{q}_i = \frac{\widetilde{P}_i}{\gamma K_i^{\gamma-1} \bar{H}_i^{1-\gamma}}. \tag{D.19}$$

Substituting equation (D.18) into this equation gives the solution for $\widetilde{q}_i$:

$$\widetilde{q}_i = \left(\frac{\widetilde{P}_i}{\gamma}\right)^{\gamma} \left(\frac{(1-\alpha)\sum_s \sum_m \widetilde{I}_{is}^m L_{is}^m}{\bar{H}_i}\right)^{1-\gamma}. \tag{D.20}$$

Employment

Rearranging the labor mobility constraint (D.1) gives $L_{is}^m = \left(\frac{v_{is}^m}{U_i}\right)^{\sigma} \bar{L}_i$. Substituting this equation into the labor market clearing yields $U_i = (\sum_s \sum_m (v_{is}^m)^{\sigma})^{\frac{1}{\sigma}}$. The solution for employment is $L_{is}^m = \left(\frac{v_{is}^m}{U_i}\right)^{\sigma} \bar{L}_i$, where $v_{is}^m = \frac{\widetilde{I}_{is}^m \epsilon_{is}^m}{\widetilde{P}_i^{\alpha} \widetilde{q}_i^{1-\alpha} d_{is}^m(\theta_{is}^m)}$, $U_i = (\sum_s \sum_m (v_{is}^m)^{\sigma})^{\frac{1}{\sigma}}$. Simplifying this equation gives the solution for employment:

$$L_{is}^{m*} = \left(\frac{\widetilde{\phi}_{is}^m}{\widetilde{\widetilde{\Phi}}_i}\right)^{\sigma} \bar{L}_i, \tag{D.21}$$

where $\widetilde{\phi}_{is}^m = \frac{\widetilde{I}_{is}^m \epsilon_{is}^m}{d_{is}^m(\theta_{is}^m)}$, $\widetilde{\widetilde{\Phi}}_i = \left(\sum_s \sum_m \left(\widetilde{\phi}_{is}^m\right)^{\sigma}\right)^{\frac{1}{\sigma}}$.

Individual Expenditure

Substituting the labor mobility constraint (D.1) and equation (D.13) into the first-order condition with respect to employment (D.10) yields

$$\widetilde{I}_{is}^{m} = \frac{\sigma}{\sigma+1}\left(\widetilde{P}_i \frac{\partial Y_i}{\partial L_{is}^{m}} - e_i\right). \tag{D.22}$$

Equation (D.13) implies $\widetilde{W}_{is}^{m} = \frac{\widetilde{I}_{is}^{m} L_{is}^{m}}{U_i}$. Substituting this expression into the first-order condition with respect to U_i (D.11) gives

$$U_i = \frac{1}{\bar{L}_i} \sum_s \sum_m \widetilde{I}_{is}^{m} L_{is}^{m}. \tag{D.23}$$

Substituting equation (D.22) into equation (D.23) and rearranging gives the multiplier of labor market clearing:

$$e_i = \widetilde{P}_i \sum_s \sum_m \left(\frac{L_{is}^{m}}{\bar{L}_i} \frac{\partial Y_i}{\partial L_{is}^{m}}\right) - \frac{\sigma+1}{\sigma} U_i, \tag{D.24}$$

where $U_i = \frac{1}{\widetilde{P}_i^{\alpha} \widetilde{q}_i^{1-\alpha}} \left[\sum_s \sum_m \left(\frac{\widetilde{I}_{is}^{m}(e_i)\epsilon_{is}^{m}}{d_{is}^{m}(\theta_{is}^{m})}\right)^{\sigma}\right]^{\frac{1}{\sigma}}$.

Substituting equation (D.24) into equation (D.22) gives the solution for a worker's expenditure:

$$\widetilde{I}_{is}^{m} = \frac{\sigma \widetilde{P}_i}{\sigma+1}\left[\frac{\partial Y_i}{\partial L_{is}^{m}} - \sum_{s'} \sum_{m'} \frac{L_{is'}^{m'}}{\bar{L}_i} \frac{\partial Y_i}{\partial L_{is'}^{m'}}\right] + U_i \tag{D.25}$$

$$\text{where } \frac{\partial Y_i}{\partial L_{is}^{m}} = \bar{y}_{is}\left(\frac{Y_i}{y_{is}}\right)^{\frac{1}{\eta}} \frac{\partial y_{is}}{\partial L_{is}^{m}} \quad \forall m \in \{o, h, f\}; \tag{D.26}$$

$$\frac{\partial y_{is}}{\partial L_{is}^{m}} = \frac{\partial A_{is}^{o}}{\partial L_{is}^{m}} L_{is}^{o} + \bar{a}_{is}^{h} L_{is}^{h}\left(\frac{\partial A_{is}^{h}(\theta_{is})}{\partial A_{is}^{f}} \frac{\partial A_{is}^{f}}{\partial L_{is}^{m}} + \frac{\partial A_{is}^{h}(\theta_{is})}{\partial A_{is}^{o}} \frac{\partial A_{is}^{o}}{\partial L_{is}^{m}}\right) + \frac{\partial A_{is}^{f}}{\partial L_{is}^{m}} L_{is}^{f} + y_{is}^{m} \quad \forall m; \tag{D.27}$$

$$\frac{\partial A_{is}^{o}}{\partial L_{is}^{o}} = \frac{\lambda A_{is}^{o}}{L_{is}^{O}}, \quad \frac{\partial A_{is}^{o}}{\partial L_{is}^{f}} = \frac{\tau_{ro} A_{is}^{o}}{L_{is}^{R}}, \quad \frac{\partial A_{is}^{o}}{\partial L_{is}^{h}} = A_{is}^{o}\left[\frac{\lambda \theta_{is}}{L_{is}^{O}} + \frac{\tau_{ro}(1-\theta_{is})}{L_{is}^{R}}\right]; \tag{D.28}$$

$$\frac{\partial A_{is}^{f}}{\partial L_{is}^{o}} = \frac{\tau_{or} A_{is}^{f}}{L_{is}^{O}}, \quad \frac{\partial A_{is}^{f}}{\partial L_{is}^{f}} = \frac{\lambda^{R} A_{is}^{f}}{L_{is}^{R}}, \quad \frac{\partial A_{is}^{f}}{\partial L_{is}^{h}} = A_{is}^{f}\left[\frac{\tau_{or}\theta_{is}}{L_{is}^{O}} + \frac{\lambda^{R}(1-\theta_{is})}{L_{is}^{R}}\right]; \tag{D.29}$$

$$\frac{\partial A_{is}^h(\theta_{is})}{\partial A_{is}^o} = \left(\frac{A_{is}^h(\theta_{is})}{A_{is}^o}\right)^{\frac{1}{\rho}} (\theta_{is})^{\frac{\rho-1}{\rho}}, \quad \frac{\partial A_{is}^h(\theta_{is})}{\partial A_{is}^f} = \left(\frac{A_{is}^h(\theta_{is})}{A_{is}^f}\right)^{\frac{1}{\rho}} (1-\theta_{is})^{\frac{\rho-1}{\rho}}. \tag{D.30}$$

Shadow Price of Tradable Goods

Substituting equations (D.14) and (D.18) into the goods market constraint (D.2) gives the budget of city i:

$$\big(\alpha + \gamma(1-\alpha)\big) \sum_s \sum_m \widetilde{I}_{is}^m L_{is}^m = \widetilde{P}_i Y_i. \tag{D.31}$$

Rearranging it yields the multiplier of the goods market constraint of city i:

$$\widetilde{P}_i = \frac{(\alpha + \gamma(1-\alpha)) \sum_s \sum_m \widetilde{I}_{is}^m L_{is}^m}{Y_i}. \tag{D.32}$$

Hybrid workers' share of time spent working onsite

Subsituting $\partial v_{is}^h / \partial \theta_{is} = -v_{is}^h \frac{\partial d_{is}^h(\theta_{is})/\partial \theta_{is}}{d_{is}^h(\theta_{is})}$, the labor mobility constraint (D.1), and (D.13) into the first-order condition with respect to θ_{is} (D.9) gives

$$\widetilde{P}_i \frac{\partial Y_i}{\partial \theta_{is}} - \widetilde{I}_{is}^h L_{is}^h \frac{\partial d_{is}^h(\theta_{is})/\partial \theta_{is}}{d_{is}^h(\theta_{is})} = 0. \tag{D.33}$$

Equation (D.33) shows that the planner equates the marginal productivity benefit of onsite time with its marginal disutility cost. Multiplying and dividing the first term of equation (D.33) by $\frac{\partial A_{is}^h(\theta_{is})/\partial \theta_{is}}{A_{is}^h(\theta_{is})}$ and rearranging yields:

$$\frac{\partial d_{is}^h(\theta_{is})/\partial \theta_{is}}{d_{is}^h(\theta_{is})} = F_{is} \frac{\partial A_{is}^h(\theta_{is})/\partial \theta_{is}}{A_{is}^h(\theta_{is})}, \tag{D.34}$$

$$F_{is} = \frac{\widetilde{P}_i \frac{\partial Y_i}{\partial \theta_{is}}}{\widetilde{I}_{is}^h L_{is}^h \frac{\partial A_{is}^h(\theta_{is})/\partial \theta_{is}}{A_{is}^h(\theta_{is})}}, \tag{D.35}$$

where the numerator of F_{is} denotes the value of the marginal product of hybrid workers' onsite work. It measures the change of city i's total product in response to the change in the share of time hybrid workers spend working onsite in sector s. The denominator of F_{is} reflects the change in the total income of all hybrid workers in the sector s in response to the change in the share of time hybrid workers spend working onsite. Overall, F_{is}

compares the city-wide effect to the sector-work mode effect.

Similar to Appendix B, the solution of the share of time hybrid workers spend working onsite is characterized by the following equation:

$$\frac{\theta_{is}^*}{1-\theta_{is}^*} = \left(\frac{A_{is}^o(\theta_{is}^*)}{A_{is}^f(\theta_{is}^*)}\right)^{\rho-1} \left(\frac{\zeta_{is} + d_{is}^h(\theta_{is}^*)(F_{is}(\delta_{is}+1)-1)}{e^{kt_i} + d_{is}^h(\theta_{is}^*)(F_{is}(\delta_{is}^R+1)-1)}\right)^{\rho}, \tag{D.36}$$

$$\text{where } F_{is} = \frac{\widetilde{P}_i \frac{\partial Y_i}{\partial \theta_{is}}}{\widetilde{I}_{is}^h L_{is}^h \frac{\partial A_{is}^h(\theta_{is})/\partial \theta_{is}}{A_{is}^h(\theta_{is})}}, \tag{D.37}$$

$$\frac{\partial Y_i}{\partial \theta_{is}} = \bar{y}_{is}\left(\frac{Y_i}{y_{is}}\right)^{\frac{1}{\eta}} \left(\frac{\partial A_{is}^o}{\partial \theta_{is}} L_{is}^o + \bar{a}_{is}^h \frac{\partial A_{is}^h(\theta_{is})}{\partial \theta_{is}} L_{is}^h + \frac{\partial A_{is}^f}{\partial \theta_{is}} L_{is}^f\right), \tag{D.38}$$

$$\frac{\partial A_{is}^o}{\partial \theta_{is}} = A_{is}^o L_{is}^h \left(\frac{\lambda}{L_{is}^O} - \frac{\tau_{ro}}{L_{is}^R}\right), \frac{\partial A_{is}^f}{\partial \theta_{is}} = A_{is}^f L_{is}^h \left(\frac{\tau_{or}}{L_{is}^O} - \frac{\lambda^R}{L_{is}^R}\right), \tag{D.39}$$

$$\frac{\partial A_{is}^h}{\partial \theta_{is}} = (A_{is}^h(\theta_{is}))^{\frac{1}{\rho}} \left[-(A_{is}^f(\theta_{is}))^{1-\frac{1}{\rho}}(1-\theta_{is})^{-\frac{1}{\rho}}(\delta_{is}^R+1) + (A_{is}^o(\theta_{is}))^{1-\frac{1}{\rho}}\theta_{is}^{-\frac{1}{\rho}}(\delta_{is}+1)\right], \tag{D.40}$$

$$\widetilde{I}_{is}^h = \frac{\sigma \widetilde{P}_i}{\sigma+1}\left[\frac{\partial Y_i}{\partial L_{is}^h} - \sum_{s'}\sum_{m'} \frac{L_{is'}^{m'}}{\bar{L}_i} \frac{\partial Y_i}{\partial L_{is'}^{m'}}\right] + U_i, \tag{D.41}$$

$$\delta_{is} = \theta_{is} L_{is}^h \left(\frac{\lambda}{L_{is}^O} - \frac{\tau_{ro}}{L_{is}^R}\right), \delta_{is}^R = (1-\theta_{is}) L_{is}^h \left(\frac{\lambda^R}{L_{is}^R} - \frac{\tau_{or}}{L_{is}^O}\right), \tag{D.42}$$

$$L_{is}^O = L_{is}^o + \theta_{is} L_{is}^h, \quad L_{is}^R = L_{is}^f + (1-\theta_{is}) L_{is}^h. \tag{D.43}$$

Equation (D.36) can be expressed as the following as well:

$$\frac{\theta_{is}^*}{1-\theta_{is}^*} = \left(\frac{A_{is}^o(\theta_{is}^*)}{A_{is}^f(\theta_{is}^*)}\right)^{\rho-1} \left(\frac{F_{is}(\delta_{is}+1) - \delta_{d,is}}{F_{is}(\delta_{is}^R+1) - \delta_{d,is}^R}\right)^{\rho}. \tag{D.44}$$

where $\delta_{d,is} = \frac{\partial d_{is}(\theta_{is})/d_{is}(\theta_{is})}{\partial \theta_{is}/\theta_{is}} = \frac{(e^{kt_i} - \zeta_{is})\theta_{is}}{d(\theta_{is})}$, $\delta_{d,is}^R = \frac{\partial d_{is}(\theta_{is})/d_{is}(\theta_{is})}{\partial(1-\theta_{is})/(1-\theta_{is})} = \frac{(\zeta_{is} - e^{kt_i})(1-\theta_{is})}{d(\theta_{is})}$.

Equations (D.14), (D.15), (D.21), (D.18), and (D.36) correspond to equations characterizing solutions for consumption, housing, employment (46), tradable goods in housing production (49), and the share of time hybrid workers spend working onsite (29) in the market equilibrium. $\widetilde{I}_{is}^m$, $\widetilde{P}_i$, $\widetilde{q}_i$ correspond to income (I_{is}^m), goods price index (P), and housing prices (q_i) in market equilibrium. The city budget (D.31) is the counterpart of

the market condition $\widetilde{\gamma} I_i = PY_i$, so the planner's allocation, like the market equilibrium, involves no transfer of tradable goods across cities. Because no constraint links two cities, the problem separates by city, and the population weights $\bar{L}_i$ in the objective do not affect the solution. The socially optimal allocation consists of consumption, housing, tradable goods used to produce housing, employment, and the share of time hybrid workers spend working onsite characterized by equations (D.14), (D.15), (D.18), (D.20), (D.21), (D.23), (D.24), (D.25), (D.32), and (D.36).

E Optimal Policies in the Full Model

This section discusses policies for achieving a socially optimal share of time spent working onsite for hybrid workers similar to the basic model (section C). Because the goods market constraint (D.2) balances trade city by city, the social optimum involves no transfer across cities, and each policy below is budget balanced within a city-sector cell. If the social planner uses hybrid workers' income tax to subsidize (tax) hybrid workers' onsite work time, the share of onsite subsidy (tax) in gross income is:

$$SubsidySh_{is}^{inctax} = \frac{\widetilde{Z}_{is} e^{kt_i} - \zeta_{is}}{d_{is}(\theta_{is}^*)\theta_{is}^* + \widetilde{Z}_{is} d_{is}(\theta_{is}^*)(1-\theta_{is}^*)} \theta_{is}^*, \tag{E.1}$$

where $\widetilde{Z}_{is} = \frac{\zeta_{is} + d_{is}^h(\theta_{is}^*)(F_{is}(\delta_{is}+1)-1)}{e^{kt_i} + d_{is}^h(\theta_{is}^*)(F_{is}(\delta_{is}^R+1)-1)}$.

If the social planner taxes (subsidizes) hybrid workers' remote work time and subsidizes (taxes) the hybrid workers' onsite work time, the share of onsite subsidy (tax) in gross income is:

$$SubsidySh_{is}^{exttax} = \frac{t_{is}\theta_{is}^*}{1 + t_{is}\theta_{is}^*}, \tag{E.2}$$

$$\text{where } t_{is} = \frac{1}{2\theta_{is}^{*2}} \left[-1 + \theta_{is}^*(1-\theta_{is}^*)G_{is}^* + \sqrt{(1-\theta_{is}^*(1-\theta_{is}^*)G_{is}^*)^2 + 4\theta_{is}^{*2} G_{is}^*(1-\theta_{is}^*)} \right], \tag{E.3}$$

$$G_{is}^* = \frac{\widetilde{Z}_{is} e^{kt_i} - \zeta_{is}}{d_{is}(\theta_{is}^*)\theta_{is}^* + \widetilde{Z}_{is} d_{is}(\theta_{is}^*)(1-\theta_{is}^*)}. \tag{E.4}$$

In equations (E.1), (E.2), employment and share of time spent working onsite $L_{is}^{m*}, \theta_{is}^{m*}$ refer to the socially optimal labor allocation.

F Data

This section shows the details of deriving residual wages by city-sector-work mode, summary statistics of data, and recovered shifters.

Residual Wages

To obtain the residual wages, I firstly run the mincer regression to obtain individual residual wages for each period:

$$\ln(\mathrm{W}_{\omega}) = c + \boldsymbol{\beta}\boldsymbol{X}_{\boldsymbol{\omega}} + \epsilon_{\omega}, \tag{F.1}$$

where $ln(\mathrm{W}_{\omega})$ is the log of individual-level hourly wages (2020 dollars). $\boldsymbol{X}_{\boldsymbol{\omega}}$ are control variables including 3 groups: (1) demographic variables: age, age squared, education, education squared, experience, experience squared, race, gender, marriage status; (2) variables used to control the sorting effect of WFH: number of own children under age 5, Dingel and Neiman (2020)'s WFH feasibility index at detailed occupation level, interaction terms of this index and education, experience, age, and marriage status, respectively. Next, I calculate the average residual wages by averaging residual wages by city, sector, work mode, and months:

$$avgResigualWage_{ism} = \frac{1}{T}\sum_{t}\left(\frac{1}{L_{ism}}\sum_{\omega\in\{i,s,m\}}\hat{\epsilon}_{\omega(ismt)}\right), \tag{F.2}$$

where L_{ism} is the employment at a city-sector-work mode cell; T is the total number of months.

Summary Statistics of Data

Table 5: Summary Statistics of Variables Used for Recovering Shifters

	Observations	Mean	SD	Min	Median	Max
Onsite wages	2,121	1.11	0.18	0.61	1.09	3.90
Hybrid wages	2,121	1.29	0.51	0.16	1.22	8.08
Fully WFH wages	2,121	1.31	0.72	0.09	1.22	20.89
Onsite employment	2,121	42,339	106,507	20.76	11,646	2,249,354
Hybrid employment	2,121	5,747	17,882	0.00626	982.92	329,636
Fully WFH employment	2,121	5,417	15,357	0.000129	1,031	218,268
Hybrid workers' share of time working onsite	2,121	0.60	0.09	0.20	0.59	0.97
Commuting time	338	18.83	13.70	12.75	17.80	265.34

Note: The data for recovering shifters and conducting quantitative anlysis are cross-sectional and are obtained by taking the average of city-sector-work mode data from 2022 October to 2025 December. Quantification analysis in section 6 and figure 11 only include city-sector cells with positive employment and wages at all three work modes (onsite, hybrid, fully WFH)

Parameters and Shifters for Quantification Analyse

Table 6: Parameter Values for the Quantification Analysis

	Description	Value	Source
λ	Onsite spillover	0.292	Table 2, column (3)
λ^R	Remote spillover	0.209	Table 2, column (4)
τ_{ro}	remote-to-onsite spillover	0.044	Table 2, column (3)
τ_{or}	onsite-to-remote spillover	0.441	Table 2, column (4)
ρ	Elasticity of substitution between WFH and onsite work	3.546	Davis et al. (2024a)
σ	Labor supply elasticity	1.26	Burstein et al. (2019)
η	Labor demand elasticity	0.8	Lichter et al. (2015),Beaudry et al. (2018)
k	Elasticity of commuting costs	0.01	Ahlfeldt et al. (2015)
α	Share of tradable goods in consumption	0.76	Housing expenditure share of 0.24
γ	Share of tradable goods in housing production	0.091	Housing supply elasticity $\frac{\gamma}{1-\gamma} = 0.1$

Table 7: Recovered Shifters

	Observations	Mean	SD	Min	Median	Max
City-sector productivity ($\bar{y}_{is}$)	2,121	0.11	0.11	0.00104	0.07	1.04
Exogenous onsite productivity ($\bar{a}^o_{is}$)	2,121	0.06	0.04	0.00809	0.05	0.38
Exogenous hybrid productivity ($\bar{a}^h_{is}$)	2,121	0.86	0.37	0.09	0.81	5.87
Exogenous remote productivity ($\bar{a}^f_{is}$)	2,121	0.00740	0.01	0.000136	0.00364	0.21
Endogenous onsite productivity (A^o_{is})	2,121	1.00	0.08	0.33	1.01	2.35
Endogenous remote productivity (A^f_{is})	2,121	1.18	0.63	0.09	1.10	17.55
Onsite labor-supply shifter (ε^o_{is})	2,704	2.68	2.90	0	1.93	30.07
Hybrid labor-supply shifter (ε^h_{is})	2,704	0.45	0.63	0	0.30	12.74
Fully WFH labor-supply shifter (ε^f_{is})	2,704	0.49	0.65	0	0.35	16.65
WFH amenity cost (ζ_{is})	2,121	1.54	0.84	0.29	1.44	21.10

G Numerical Algorithms

G.1 Recovering endogenous productivities and shifters

This algorithm recovers endogenous productivities and other shifters without imposing the externality functions or knowing the externality parameters (λ, λ^R, τ_{ro}, and τ_{or}). Specifically, given parameters (σ, η, ρ, k) and variables in the data (employment $L^o_{is}, L^h_{is}, L^f_{is}$, wage $W^o_{is}, W^h_{is}, W^f_{is}$, share of time hybrid workers spend working onsite θ_{is}, commuting time t_i), I recover the endogenous productivities (A^f_{is}, A^o_{is}) and the structural shifters $(\bar{y}_{is}, \bar{a}^h_{is}, \epsilon^o_{is}, \epsilon^h_{is}, \epsilon^f_{is}, \zeta_{is})$ as follows:

1. Guess $A^f_{is}, A^o_{is}, \widetilde{\Phi}_i, \bar{a}^h_{is}$.

2. Calculate total output by city using wages and employment in all sectors and work modes:
$$Y_i = \frac{1}{P} \sum_s \sum_m W^m_{is} L^m_{is}, \tag{G.1}$$
where the price index is normalized to $P = 1$.

3. Calculate the city-sector-specific productivity shifter:
$$\bar{y}_{is} = \frac{W_{is}}{P} \left(\frac{y_{is}}{Y_i} \right)^{\frac{1}{\eta}} \frac{1}{y_{is}}, \tag{G.2}$$
where city-sector specific total wages $W_{is} = \sum_m W^m_{is} L^m_{is}$, $y_{is} = A^o_{is} L^o_{is} + \bar{a}^h_{is} A^h_{is}(\theta_{is}) L^h_{is} + A^f_{is} L^f_{is}$, $A^h_{is}(\theta_{is}) = [(A^f_{is}(1-\theta_{is}))^{\frac{\rho-1}{\rho}} + (A^o_{is}\theta_{is})^{\frac{\rho-1}{\rho}}]^{\frac{\rho}{\rho-1}}$.

4. Calculate the city-sector-specific unit wages implied in the data:
$$w_{is} = P\bar{y}_{is} \left(\frac{Y_i}{y_{is}} \right)^{\frac{1}{\eta}} = \frac{W_{is}}{y_{is}}. \tag{G.3}$$

5. Recover exogenous hybrid productivity using hybrid wages:
$$\bar{a}^h_{is,new} = \frac{W^h_{is}}{A^h_{is}(\theta_{is}) w_{is}}. \tag{G.4}$$

6. Recover the onsite productivity using onsite wage:

$$A^o_{is,new} = \frac{W^o_{is}}{w_{is}}. \tag{G.5}$$

If a city-sector cell does not have onsite workers but has hybrid workers, normalize $\bar{a}^h_{is,new} = 1$ and recover onsite productivity according to hybrid worker's wages ($A^h_{is}(\theta_{is}) = \frac{W^h_{is}}{w_{is}}$) and the definition of $A^h_{is}(\theta_{is})$:

$$A^o_{is,new} = \left[\left(\frac{W^h_{is}}{w_{is}}\right)^{\frac{\rho-1}{\rho}} - \left(A^f_{is}(1-\theta_{is})\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}} \frac{1}{\theta_{is}}. \tag{G.6}$$

Recovering A^o_{is} using this euqation requires $\frac{W^h_{is}}{w_{is}} > A^f_{is}(1-\theta_{is})$. If the previous two methods fail to recover onsite productivity and the city-sector cell has hybrid workers, recover A^o_{is} using the two way fixed effect regression:

$$log(\widetilde{A}^o_{is}) = \beta_i + \beta_s + e_{is}, \;\; A^o_{is,new} = exp(\hat{\beta}_i + \hat{\beta}_s) \tag{G.7}$$

where $\widetilde{A}^o_{is}$ is $A^o_{is,new}$ recovered from previous 2 methods.

7. Recover remote productivity using fully WFH wages:

$$A^f_{is,new} = \frac{W^f_{is}}{w_{is}}. \tag{G.8}$$

Similarly, if a city-sector cell does not have fully WFH workers but has hybrid workers, normalize $\bar{a}^h_{is,new} = 1$ and recover remote productivity using hybrid workers' wages and the definition of $A^h_{is}(\theta_{is})$

$$A^f_{is,new} = \left[\left(\frac{W^h_{is}}{w_{is}}\right)^{\frac{\rho-1}{\rho}} - \left(A^o_{is}\theta_{is}\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}} \frac{1}{1-\theta_{is}}. \tag{G.9}$$

Recovering A^f_{is} using this euqation requires $\frac{W^h_{is}}{w_{is}} > A^o_{is}\theta_{is}$. If A^f_{is} is not available from previous methods and a city-sector cell has hybrid and fully WFH workers,

recover A_{is}^f using the two way fixed effect regression:

$$log(\widetilde{A}_{is}^f) = \beta_i + \beta_s + e_{is}, \;\; A_{is,new}^f = exp(\hat{\beta}_i + \hat{\beta}_s) \tag{G.10}$$

where $\widetilde{A}_{is}^f$ is $A_{is,new}^f$ recovered from previous 2 methods.

8. The first-order condition of the indirect utility function with respect to θ_{is} is $\frac{1-\theta_{is}}{\theta_{is}} = \left(\frac{A_{is}^f}{A_{is}^o}\right)^{\rho-1}(\frac{e^{kt_i}}{\zeta_{is}})^{\rho}$. Given A_{is}^o and A_{is}^f, recover WFH amenity cost ζ_{is} based on this equation:

$$\zeta_{is} = \left[\frac{\left(\frac{A_{is}^f}{A_{is}^o}\right)^{\rho-1}(e^{kt_i})^{\rho}}{\frac{1-\theta_{is}}{\theta_{is}}}\right]^{\frac{1}{\rho}}. \tag{G.11}$$

In the following cases, the WFH amenity cost cannot be recovered using equation (G.11): (1) a city-sector does not have hybrid workers so θ_{is} in the city-sector is not available; (2) a city-sector does not have fully WFH workers and the wage ratio between hybrid and onsite workers does not satisfy $\frac{W_{is}^h}{W_{is}^o} > \theta_{is}$; therefore A_{is}^f is not available. In these cases, recover ζ_{is} using the two way fixed effect regression:

$$log(\widetilde{\zeta}_{is}) = \beta_i + \beta_s + e_{is}, \;\; \zeta_{is} = exp(\hat{\beta}_i + \hat{\beta}_s) \tag{G.12}$$

where $\widetilde{\zeta}_{is}$ is ζ_{is} recovered from equation (G.11).

9. Recover the normalized labor supply shifters:

$$\epsilon_{is}^m = \bar{c}_{is_1}^o \frac{d_{is}^m(\theta_{is}^m)}{W_{is}^m}\left(\frac{L_{is}^m}{\bar{L}_i}\right)^{\frac{1}{\sigma}}\widetilde{\Phi}_i, \tag{G.13}$$

where $d_{is}^m(\theta_{is}^m) = e^{kt_i}\theta_{is}^m + \zeta_{is}(1-\theta_{is}^m)$, $\theta_{is}^o = 1$, $\theta_{is}^h = \theta_{is} \in (0,1)$, and $\theta_{is}^f = 0$. $\bar{c}_{is_1}^o$ is a scaling term that normalizes the labor supply shifter of an onsite worker in the

reference sector (s_1) to 1 for any city i ($\epsilon^o_{is_1} = 1, \forall i$) [19]:

$$\bar{c}^o_{is_1} = \left[\frac{e^{kt_i}}{W^o_{is_1}} \left(\frac{L^o_{is_1}}{\bar{L}_i} \right)^{\frac{1}{\sigma}} \widetilde{\Phi}_i \right]^{-1}. \tag{G.14}$$

This normalization implies that the index Φ_i for the reference city i_1 is fixed: $\Phi_{i_1} = \bar{c}^o_{i_1 s_1}$ [20].

10. Update $\widetilde{\Phi}_i$:

$$\widetilde{\Phi}_{i,new} = \frac{\Phi_i}{\Phi_{i_1}}, \tag{G.15}$$

where $\Phi_i = \left[\sum_s \sum_m \left(\frac{W^m_{is} \epsilon^m_{is}}{d^m_{is}(\theta^m_{is})} \right)^\sigma \right]^{\frac{1}{\sigma}}$.

11. If the error $max \left\{ \left| \frac{A^f_{is,new}}{A^f_{is}} - 1 \right|, \left| \frac{A^o_{is,new}}{A^o_{is}} - 1 \right|, \left| \frac{\bar{a}^h_{is,new}}{\bar{a}^h_{is}} - 1 \right|, \left| \frac{\widetilde{\Phi}_{i,new}}{\widetilde{\Phi}_i} - 1 \right| \forall i, s \right\}$ is larger than a sufficiently small number,update the variables as follows and go back to step 2: $x = wx + wx_{new}, x \in \{A^f_{is}, A^o_{is}, \bar{a}^h_{is}, \widetilde{\Phi}_i\}$, w is the adaptive damping weight[21] Otherwise, stop iteration and obtain the solution for $A^f_{is}, A^o_{is}, \widetilde{\Phi}_i$ and the shifters $\bar{a}^h_{is}, \bar{y}_{is}, \zeta_{is}, \epsilon^o_{is}, \epsilon^h_{is}, \epsilon^f_{is}$.

Given the externality parameters $(\lambda, \lambda^R, \tau_{ro}, \tau_{or})$, I can further recover exogenous onsite and remote productivity:

$$\bar{a}^o_{is} = A^o_{is} \left[L^O_{is}(\theta_{is}) \right]^{-\lambda} \left[L^R_{is}(\theta_{is}) \right]^{-\tau_{ro} \mathbf{1}_{\{L^R_{is} \neq 0\}}}, \tag{G.16}$$

$$\bar{a}^f_{is} = A^f_{is} \left[L^R_{is}(\theta_{is}) \right]^{-\lambda^R} \left[L^O_{is}(\theta_{is}) \right]^{-\tau_{or} \mathbf{1}_{\{L^O_{is} \neq 0\}}}. \tag{G.17}$$

where $L^O_{is}(\theta_{is}) = L^o_{is} + \theta_{is} L^h_{is}, L^R_{is}(\theta_{is}) = L^f_{is} + (1 - \theta_{is}) L^h_{is}$.

[19] The labor supply equation implies that $(\epsilon^m_{is})^\sigma = \left(\frac{d^m_{is}(\theta^m_{is})}{W^m_{is}} \right)^\sigma \frac{L^m_{is}}{\bar{L}_i} \sum_s \sum_m \left[\left(\frac{W^m_{is}}{d^m_{is}(\theta^m_{is})} \right)^\sigma (\epsilon^m_{is})^\sigma \right]$. This is a linear system with respect to $(\epsilon^m_{is})^\sigma$. Consider that there is only 1 sector s_1; for each city, rewrite the equations in matrix form $A_i x_i = b_i$, where $x_i = [(\epsilon^o_{is_1})^\sigma, (\epsilon^h_{is_1})^\sigma, (\epsilon^f_{is_1})^\sigma]'$ is a vector consisting of 3 elements for the city i. The rank of matrix A_i is 2, so the solutions of x_i are infinite. Define onsite as the reference type. Given the value $(\epsilon^o_{is_1})^\sigma$, the solutions of the linear system can be written as a set of $\{(\epsilon^m_{is_1})^\sigma, \forall m \neq o\}$ relative to the value of onsite shifter. When there are multiple sectors, one can solve the relative values of the shifters in city i to $(\epsilon^o_{is_1})^\sigma$. Therefore, I fixed the shifter $\epsilon^o_{is_1}$ in each city. In all cities, the reference sector has positive onsite employment.

[20] Substituting equations (G.13) and (G.14) into the definition of Φ_{i_1} yields this result.

[21] Let e^r be the error in iteration r and w^r be the damping weight in iteration r. w^0=0.5. For $r > 1$, if $e^r < e^{r-1}$, $w^r = max\{0.2, w^{r-1} - 0.05\}$; If $e^r \geq e^{r-1}$, $w^r = min\{0.95, w^{r-1} + 0.15\}$.

G.2 The Algorithm for Solving Market Equilibrium

Given parameters $(\sigma, \eta, \rho, k, \lambda, \lambda^R, \tau_{ro}, \tau_{or})$, exogenous variables $(\bar{L}_i, t_i)$, and shifters ($\bar{y}_{is}$,$\bar{a}^o_{is}$,$\bar{a}^f_{is}$,$\bar{a}^h_{is}$, ζ_{is}, ϵ^o_{is},ϵ^h_{is},ϵ^f_{is}), I solve for wages $(W^o_{is}, W^h_{is}, W^f_{is})$, employment $(L^o_{is}, L^h_{is}, L^f_{is})$, and the share of time hybrid workers spend working onsite (θ_{is}) using the following algorithm:

1. Guess L^o_{is}, L^h_{is}, and L^f_{is} such that $\sum_s (L^o_{is} + L^h_{is} + L^f_{is}) = \bar{L}_i$. Guess the total wage for workers in different work modes $W^o_{is}, W^h_{is}, W^f_{is}$, the share of time hybrid workers spend working onsite θ_{is}, and the welfare index $\widetilde{\Phi}_i$.

2. Solve for the share of time spent working onsite for hybrid workers:

$$\theta_{is,new} = \frac{1}{1 + (\frac{e^{kt_i}}{\zeta_{is}})^{\rho} (\frac{A^f_{is}}{A^o_{is}})^{\rho-1}}, \tag{G.18}$$

   where $A^f_{is} = \bar{a}^f_{is}[L^R_{is}(\theta_{is})]^{\lambda^R}[L^O_{is}(\theta_{is})]^{\tau_{or}\mathbf{1}_{\{L^O_{is}\neq 0\}}}$, $A^o_{is} = \bar{a}^o_{is}[L^O_{is}(\theta_{is})]^{\lambda}[L^R_{is}(\theta_{is})]^{\tau_{ro}\mathbf{1}_{\{L^R_{is}\neq 0\}}}$, $L^O_{is}(\theta_{is}) = L^o_{is} + \theta_{is}L^h_{is}$, and $L^R_{is}(\theta_{is}) = L^f_{is} + (1-\theta_{is})L^h_{is}$.

3. Solve for the city-sector specific unit wages:

$$w_{is} = P\bar{y}_{is}\left(\frac{Y_i}{y_{is}}\right)^{\frac{1}{\eta}}, \tag{G.19}$$

   where $y_{is} = A^o_{is}L^o_{is} + \bar{a}^h_{is}A^h_{is}(\theta_{is})L^h_{is} + A^f_{is}L^f_{is}$. $A^h_{is}(\theta_{is}) = [(A^f_{is}(1-\theta_{is}))^{\frac{\rho-1}{\rho}} + (A^o_{is}\theta_{is})^{\frac{\rho-1}{\rho}}]^{\frac{\rho}{\rho-1}}$. $Y_i = \left[\sum_s \left(\bar{y}_{is}(y_{is})^{\frac{\eta-1}{\eta}}\right)\right]^{\frac{\eta}{\eta-1}}$. Update total wages for workers with different work modes:

$$W^o_{is,new} = w_{is}A^o_{is}, \quad W^h_{is,new} = w_{is}\bar{a}^h_{is}A^h_{is}(\theta_{is}), \quad W^f_{is,new} = w_{is}A^f_{is}. \tag{G.20}$$

4. Update employment:

$$L^m_{is,new} = \left(\frac{\phi^m_{is}}{\Phi_i}\right)^{\sigma}\bar{L}_i \tag{G.21}$$

   where $\phi^m_{is} = \frac{W^m_{is}\epsilon^m_{is}}{d^m_{is}(\theta^m_{is})}$. $d^m_{is}(\theta^m_{is}) = e^{kt_i}\theta^m_{is} + \zeta_{is}(1-\theta^m_{is})$. $\theta^o_{is} = 1, \theta^h_{is} = \theta_{is} \in (0,1)$, and $\theta^f_{is} = 0$. $\Phi_i = [\sum_s \sum_m (\phi^m_{is})^{\sigma}]^{\frac{1}{\sigma}}$.

5. Define reference city as i_1. Update $\widetilde{\Phi}_i$:

$$\widetilde{\Phi}_{i,new} = \frac{\Phi_i}{\Phi_{i_1}}, \tag{G.22}$$

where $\Phi_i = [\sum_s \sum_m (\phi_{is}^m)^\sigma]^{\frac{1}{\sigma}}$, $\phi_{is}^m = \frac{W_{is}^m \epsilon_{is}^m}{d_{is}^m(\theta_{is}^m)}, m \in \{o, h, f\}$.

6. Check the labor market clearing. Define the error $e_{is}^m = W_{is}^m - W_{is,supply}^m, m \in \{o, h, f\}$, where $W_{is,supply}^m$ is total wages calculated by rearranging the labor supply equation:

$$W_{is,supply}^m = \left(\frac{L_{is}^m}{\bar{L}_i}\right)^{\frac{1}{\sigma}} \frac{\Phi_i d_{is}^m(\theta_{is}^m)}{\epsilon_{is}^m} \tag{G.23}$$

7. If $max\left\{\left|\frac{\theta_{is,new}}{\theta_{is}} - 1\right|, \left|\frac{W_{is,new}^m}{W_{is}^m} - 1\right|, \left|\frac{L_{is,new}^m}{L_{is}^m} - 1\right|, \left|\frac{\widetilde{\Phi}_{i,new}}{\widetilde{\Phi}_i} - 1\right|, \left|e_{is}^m\right|, \forall i, s, m \in \{o, h, f\}\right\}$ is larger than a sufficiently small number,update the variables as follows and go back to step 2: $x = wx + wx_{new}, x \in \{\theta_{is}, W_{is}^m, L_{is}^m, \widetilde{\Phi}_i, e_{is}^m\}$, w is the adaptive damping weight. Otherwise, stop the iteration and obtain the solution for $\theta_{is}, W_{is}^m, L_{is}^m$.

G.3 The Algorithm for Solving Socially Optimal Allocation

The algorithm runs city by city. Given parameters $(\sigma, \eta, \rho, k, \alpha, \gamma, \lambda, \lambda^R, \tau_{ro}, \tau_{or})$, exogenous variables $(\bar{L}_i, t_i)$, and shifters ($\bar{y}_{is}$,$\bar{a}_{is}^o$,$\bar{a}_{is}^f$,$\bar{a}_{is}^h$, ζ_{is}, ϵ_{is}^o,ϵ_{is}^h, ϵ_{is}^f), I solve for socially optimal expenditure ($\widetilde{I}_{is}^o, \widetilde{I}_{is}^h, \widetilde{I}_{is}^f$), employment ($L_{is}^o, L_{is}^h, L_{is}^f$), and the share of time hybrid workers spend working onsite (θ_{is}) using the following algorithm:

1. Guess L_{is}^o, L_{is}^h, and L_{is}^f such that $\sum_s(L_{is}^o + L_{is}^h + L_{is}^f) = \bar{L}_i$. Guess expenditure $\widetilde{I}_{is}^o, \widetilde{I}_{is}^h, \widetilde{I}_{is}^f$, and the share of time hybrid workers spend working onsite θ_{is}.

2. Calculate the marginal product of labor, the shadow price of goods, the housing price and the city welfare index:

$$\frac{\partial Y_i}{\partial L_{is}^m} = \bar{y}_{is}\left(\frac{Y_i}{y_{is}}\right)^{\frac{1}{\eta}} \frac{\partial y_{is}}{\partial L_{is}^m}, \tag{G.24}$$

The sectoral employment derivative is

$$\frac{\partial y_{is}}{\partial L_{is}^m} = \frac{\partial A_{is}^o}{\partial L_{is}^m} L_{is}^o + \bar{a}_{is}^h L_{is}^h \left(\frac{\partial A_{is}^h(\theta_{is})}{\partial A_{is}^f} \frac{\partial A_{is}^f}{\partial L_{is}^m} + \frac{\partial A_{is}^h(\theta_{is})}{\partial A_{is}^o} \frac{\partial A_{is}^o}{\partial L_{is}^m} \right) + \frac{\partial A_{is}^f}{\partial L_{is}^m} L_{is}^f + y_{is}^m, \qquad \forall m.$$

The associated onsite and remote productivity derivatives are

$$\frac{\partial A_{is}^o}{\partial L_{is}^o} = \frac{\lambda A_{is}^o}{L_{is}^O}, \qquad \frac{\partial A_{is}^o}{\partial L_{is}^f} = \frac{\tau_{ro} A_{is}^o}{L_{is}^R}, \qquad \frac{\partial A_{is}^o}{\partial L_{is}^h} = A_{is}^o \left[\frac{\lambda \theta_{is}}{L_{is}^O} + \frac{\tau_{ro}(1-\theta_{is})}{L_{is}^R} \right],$$
$$\frac{\partial A_{is}^f}{\partial L_{is}^o} = \frac{\tau_{or} A_{is}^f}{L_{is}^O}, \qquad \frac{\partial A_{is}^f}{\partial L_{is}^f} = \frac{\lambda^R A_{is}^f}{L_{is}^R}, \qquad \frac{\partial A_{is}^f}{\partial L_{is}^h} = A_{is}^f \left[\frac{\tau_{or} \theta_{is}}{L_{is}^O} + \frac{\lambda^R(1-\theta_{is})}{L_{is}^R} \right].$$

The hybrid productivity derivatives are

$$\frac{\partial A_{is}^h(\theta_{is})}{\partial A_{is}^o} = \left(\frac{A_{is}^h(\theta_{is})}{A_{is}^o} \right)^{\frac{1}{\rho}} (\theta_{is})^{\frac{\rho-1}{\rho}}, \qquad \frac{\partial A_{is}^h(\theta_{is})}{\partial A_{is}^f} = \left(\frac{A_{is}^h(\theta_{is})}{A_{is}^f} \right)^{\frac{1}{\rho}} (1-\theta_{is})^{\frac{\rho-1}{\rho}}.$$

$$\widetilde{P}_i = \frac{(\alpha + \gamma(1-\alpha)) \sum_s \sum_m \widetilde{I}_{is}^m L_{is}^m}{Y_i}, \tag{G.25}$$

$$\widetilde{q}_i = \left(\frac{\widetilde{P}_i}{\gamma} \right)^{\gamma} \left(\frac{(1-\alpha) \sum_s \sum_m \widetilde{I}_{is}^m L_{is}^m}{\bar{H}_i} \right)^{1-\gamma},^{22} \tag{G.26}$$

$$U_i = \frac{1}{\widetilde{P}_i^{\alpha} \widetilde{q}_i^{1-\alpha}} \left[\sum_s \sum_m \left(\frac{\widetilde{I}_{is}^m \epsilon_{is}^m}{d_{is}^m(\theta_{is}^m)} \right)^{\sigma} \right]^{\frac{1}{\sigma}}. \tag{G.27}$$

3. Update expenditure:

$$\widetilde{I}_{is,new}^m = \max \left\{ 0, \frac{\sigma}{\sigma+1} \left(\widetilde{P}_i \frac{\partial Y_i}{\partial L_{is}^m} - e_i \right) \right\}, \tag{G.28}$$

$$\text{where } e_i = \widetilde{P}_i \sum_s \sum_m \left(\frac{L_{is}^m}{\bar{L}_i} \frac{\partial Y_i}{\partial L_{is}^m} \right) - \frac{\sigma+1}{\sigma} U_i. \tag{G.29}$$

[22] I normalize the land endowment to $\bar{H}_i = 1$. To see why this does not affect the allocation, consider $\bar{H}_i' = \xi_i \bar{H}_i$ and let $\chi_i = \xi_i^{(1-\alpha)(1-\gamma)}$. The corresponding levels satisfy $U_i' = \chi_i U_i$, $\widetilde{P}_i' = \chi_i \widetilde{P}_i$, $e_i' = \chi_i e_i$, and $\widetilde{I}_{is}^{m\prime} = \chi_i \widetilde{I}_{is}^m$. These common city-level changes cancel from $\widetilde{I}_{is}^m / \widetilde{P}_i$, from the employment shares in equation (D.21), and from the first-order condition for θ_{is}, leaving L_{is}^m and θ_{is} unchanged. They also cancel from each city's social-market welfare ratio, $U_i^{\mathrm{S}} / U_i^{\mathrm{M}}$. The reported average welfare gain is therefore calculated as $\sum_i \frac{\bar{L}_i}{\sum_j \bar{L}_j} \left(\frac{U_i^{\mathrm{S}}}{U_i^{\mathrm{M}}} - 1 \right)$, which is invariant to this normalization.

4. Update employment:

$$L_{is,new}^{m*} = \left(\frac{\widetilde{\phi}_{is}^{m}}{\widetilde{\widetilde{\Phi}}_i} \right)^{\sigma} \bar{L}_i, \tag{G.30}$$

where $\widetilde{\phi}_{is}^{m} = \frac{\widetilde{I}_{is}^{m} \epsilon_{is}^{m}}{d_{is}^{m}(\theta_{is}^{m})}$, $\widetilde{\widetilde{\Phi}}_i = \left(\sum_s \sum_m \left(\widetilde{\phi}_{is}^{m} \right)^{\sigma} \right)^{\frac{1}{\sigma}}$.

5. For each city-sector cell with hybrid workers ($L_{is}^{h} > 0$), update the onsite time share θ_{is} using the first-order condition in equation (D.33). Define $R(\theta_{is})$ as the residual of the first-order condition (D.33) (i.e. The first-order condition is $R(\theta_{is}) = 0$) :

$$R(\theta_{is}) = \widetilde{P}_i \frac{\partial Y_i}{\partial \theta_{is}} - \widetilde{I}_{is}^{h} L_{is}^{h} \frac{\partial d_{is}^{h}(\theta_{is}) / \partial \theta_{is}}{d_{is}^{h}(\theta_{is})}. \tag{G.31}$$

Define the conditional objective function as the integral of the first-order condition residual $R(\theta_{is})$ without the constant term:

$$J(\theta_{is}) = \widetilde{P}_i Y_i(\theta_{is}) - \widetilde{I}_{is}^{h} L_{is}^{h} \log d_{is}^{h}(\theta_{is}). \tag{G.32}$$

Seperate the range of θ_{is} into a rough grid of 9 points in the interval (10^{-6}, $1-10^{-6}$), including the interior points and the corner points[23]. Evaluate the residual $R(\theta_{is})$ at each grid point and find the interior $\theta_{is,new}$ that satisfies the FOC using the bisection method and corner solutions satisfying the Karush–Kuhn–Tucker (KKT) conditions.

When multiple solutions for θ_{is} are available[24], select the candidate closest to the previous iteration's proposed $\theta_{is,new}$ by default to prevent repeated switching between candidates that could keep the iteration from converging. Switch to another candidate only if it yields a higher conditional objective $J(\theta_{is})$ over several subsequent iterations.

If the FOC residual $R(\theta_{is})$ is close to zero at every tested grid point or it cannot be evaluated on the grid, mark this city-sector cell as unsolved and set θ_{is} at the

[23] A finner grid check will be used in the final check.

[24] For each senarior presented in table 3, less than 1 % of the city-sector cells with hybrid workers have multiple solutions for θ_{is}.

current iteration value without updating ($\theta_{is,new} = \theta_{is}$).

6. If the error

$$\max\left\{ \left|\theta_{is,new} - \theta_{is}\right|, \left|\frac{\widetilde{I}^m_{is,new}}{\widetilde{I}^m_{is}} - 1\right|, \left|\frac{L^m_{is,new}}{L^m_{is}} - 1\right|, \left|\frac{\sum_s \sum_m \widetilde{I}^m_{is} L^m_{is}}{U_i \bar{L}_i} - 1\right|, \left|\frac{\sum_s \sum_m L^m_{is,new}}{\bar{L}_i} - 1\right| \forall i, s, m \right\}$$

is larger than a sufficiently small number, update the variables as follows and go back to step 2: $x = \omega x + (1-\omega)x_{new}, x \in \{\widetilde{I}^m_{is}, L^m_{is}\}$, ω is the adaptive damping weight[25]. $\theta_{is} = \tilde{\omega}_{\theta_{is}}\theta_{is} + (1 - \tilde{\omega}_{\theta_{is}})\theta_{is,new}$, $\tilde{\omega}_{\theta_{is}}$ is the cell-specific adaptive damping weight[26]. Otherwise, stop and obtain the solution for $\theta_{is}, \widetilde{I}^m_{is}, L^m_{is}$ in the inner iteration.

7. During the inner iteration, mark θ_{is} in city-sector cells as unsettled if $\theta_{is,new}$ repeatedly jumps between low and high values, or if heavy damping keeps θ_{is} nearly unchanged while $\theta_{is,new}$ remains different from θ_{is} for 200 iterations.

8. After the inner iteration converges, repeat step 5 again without the switching constraints and mark the city-sector cell as unreached if this extra step yields a $\theta_{is,new}$ that is different from the solution θ_{is} from the inner iteration.

9. Evaluate conditional objective $J(\theta_{is})$ in equation (G.32) with values of θ_{is} in a finer grid of its range. Flag a city for re-solving if any of its cells[27]:

   (a) the finer-grid check finds a higher conditional objective $J(\theta_{is})$;

[25] The error of θ_{is} is measured in levels because the relative error approaches infinity when θ_{is} is close to zero. Let $\mathscr{E}^{(r)}$ be the error in iteration r and $\omega^{(r)}$ be the damping weight in iteration r. $\omega^{(0)} = 0.5$ and $\mathscr{E}^{(0)} = +\infty$. For $r \geq 1$, if $\mathscr{E}^{(r)} < \mathscr{E}^{(r-1)}$, $\omega^{(r)} = \max\{0.2, \omega^{(r-1)} - 0.05\}$; if $\mathscr{E}^{(r)} \geq \mathscr{E}^{(r-1)}$, $\omega^{(r)} = \min\{0.95, \omega^{(r-1)} + 0.15\}$.

[26] For hybrid worker's onsite time, the adaptive damping weight is $\tilde{\omega}_{\theta_{is}} = \max\{\omega, \omega_{\theta_{is}}\}$, where $\omega_{\theta_{is}}$ is the cell-specific damping weight for θ_{is}, which is updated as follows: When the direction of the proposed change in θ_{is} reverses ($\theta_{is,new} - \theta_{is}$ in this iteration has different sign compared to the previous iteration), increase $\omega_{\theta_{is}}$ by 0.1, up to a maximum of 0.98. A larger weight keeps θ_{is} closer to its previous-iteration $\theta_{is,new}$, so repeated reversals can make its adjustment substantially slower than that of the other variables. When the proposed change continues in the same direction as in the previous iteration, decrease $\omega_{\theta_{is}}$ by 0.02, allowing θ_{is} to move further toward $\theta_{is,new}$. Once $\omega_{\theta_{is}}$ falls below the common damping weight ω, update θ_{is} using the common weight.

[27] In Table 3, the model is re-solved for 11 of 338 cities (3.3%) in the baseline scenario, 2 of 338 cities (0.6%) in the scenario with no spillovers from remote labor, and 12 of 338 cities (3.6%) in the scenario with no cross-mode spillovers.

(b) marked as unresolved in step 5, or unsetteled in step 7, or unreached in step 8.

Re-solve each flagged city from multiple initial values of θ_{is} using the inner iteration in steps 1 to 6. The multiple initial values include the incumbent solution $\theta_{\text{incumbent}}$ from the initial inner iteration, $1 - \theta_{\text{incumbent}}$, the observed value in the data, 0.5, and the best point identified by the finer grid. Among the converged solutions, retain the one with the highest city welfare.

H Mapping Onsite and Remote Spillovers into Sectoral Productivity Elasticities

Sectoral agglomeration elasticities are commonly measured by the response of average wages or productivity to sector employment (Wheeler (2006); Kemeny and Storper (2014); Rossi-Hansberg et al. (2021)). This appendix expresses the local elasticity λ_{is} as a function of the model's spillovers $\lambda, \lambda^R, \tau_{or}, \tau_{ro}$.

In the model, within and cross-mode productivity spillovers measure the elasticity of productivity to aggregated labor, which can be writen as the elasticity of work-mode level wages excluding the unit wage w_{is} to labor: $\lambda = \frac{\partial lnA^o_{is}}{\partial lnL^O_{is}} = \frac{\partial (ln(W^o_{is}/w_{is}))}{\partial lnL^O_{is}}$,$\lambda^R = \frac{\partial lnA^f_{is}}{\partial lnL^R_{is}} = \frac{\partial (ln(W^f_{is}/w_{is}))}{\partial lnL^R_{is}}$,$\tau_{or} = \frac{\partial (ln(W^f_{is}/w_{is}))}{\partial lnL^O_{is}}$,$\tau_{ro} = \frac{\partial (ln(W^o_{is}/w_{is}))}{\partial lnL^R_{is}}$.

Define the sectoral productivity externality as the elasticity of average wages excluding w_{is} to sector employment. This is equivalent to the elasticity of average sectoral productivity to employment:[28]

$$\lambda_{is} = \frac{\partial \ln(W_{is}/w_{is})}{\partial \ln L_{is}} = \frac{\partial \ln(y_{is}/L_{is})}{\partial \ln L_{is}} = \frac{L_{is}}{y_{is}} \frac{\partial y_{is}}{\partial L_{is}} - 1 \tag{H.1}$$

where $W_{is} = \frac{\sum_m L^m_{is} W^m_{is}}{L_{is}} = w_{is} \frac{y_{is}}{L_{is}}$, $y_{is} = A^o_{is} L^o_{is} + \bar{a}^h_{is} A^h_{is} L^h_{is} + A^f_{is} L^f_{is}$.

Assume the work-mode employment shares $\bar{s}^m_{is} = L^m_{is}/L_{is}$ are fixed, so $L^m_{is} = \bar{s}^m_{is} L_{is}$

[28] The unit wage w_{is} is determined by supply and demand in sector s and other sectors within the city. $w_{is} = P\bar{y}_{is}(Y_i/y_{is})^{1/\eta}$. The quantity y_{is} measures the output produced by sector s in city i.

and $\partial L_{is}^m / \partial L_{is} = \bar{s}_{is}^m$ for $m \in \{o, h, f\}$. Differentiating sector production gives

$$\frac{\partial y_{is}}{\partial L_{is}} = \frac{y_{is}}{L_{is}} + L_{is}^o \frac{\partial A_{is}^o}{\partial L_{is}} + \bar{a}_{is}^h L_{is}^h \frac{\partial A_{is}^h}{\partial L_{is}} + L_{is}^f \frac{\partial A_{is}^f}{\partial L_{is}}. \tag{H.2}$$

Productivity in the three work arrangements can be expressed as a function of sector employment L_{is}:

$$A_{is}^o(L_{is}) = \bar{a}_{is}^o (\bar{s}_{is}^o + \theta_{is}\bar{s}_{is}^h)^{\lambda} [\bar{s}_{is}^f + (1-\theta_{is})\bar{s}_{is}^h]^{\tau_{ro}} L_{is}^{\lambda+\tau_{ro}}, \tag{H.3}$$

$$A_{is}^f(L_{is}) = \bar{a}_{is}^f [\bar{s}_{is}^f + (1-\theta_{is})\bar{s}_{is}^h]^{\lambda^R} (\bar{s}_{is}^o + \theta_{is}\bar{s}_{is}^h)^{\tau_{or}} L_{is}^{\lambda^R+\tau_{or}}, \tag{H.4}$$

$$A_{is}^h(L_{is}) = \left[(\theta_{is} A_{is}^o(L_{is}))^{\frac{\rho-1}{\rho}} + ((1-\theta_{is}) A_{is}^f(L_{is}))^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}. \tag{H.5}$$

Define the onsite time elasticity with respect to sector employment as

$$\chi_{is} = \frac{\partial \ln \theta_{is}}{\partial \ln L_{is}} = \frac{L_{is}}{\theta_{is}} \frac{\partial \theta_{is}}{\partial L_{is}}.$$

Differentiating the onsite and remote productivity functions gives

$$\frac{\partial A_{is}^o}{\partial L_{is}} = \frac{A_{is}^o}{L_{is}} \left[\lambda + \tau_{ro} + \bar{s}_{is}^h \theta_{is} \chi_{is} \left(\frac{\lambda}{\bar{s}_{is}^o + \theta_{is}\bar{s}_{is}^h} - \frac{\tau_{ro}}{\bar{s}_{is}^f + (1-\theta_{is})\bar{s}_{is}^h} \right) \right], \tag{H.6}$$

$$\frac{\partial A_{is}^f}{\partial L_{is}} = \frac{A_{is}^f}{L_{is}} \left[\lambda^R + \tau_{or} + \bar{s}_{is}^h \theta_{is} \chi_{is} \left(\frac{\tau_{or}}{\bar{s}_{is}^o + \theta_{is}\bar{s}_{is}^h} - \frac{\lambda^R}{\bar{s}_{is}^f + (1-\theta_{is})\bar{s}_{is}^h} \right) \right], \tag{H.7}$$

$$\frac{\partial A_{is}^h}{\partial L_{is}} = \frac{A_{is}^h}{d_{is}^h(\theta_{is})} \left[\frac{e^{kt_i}\theta_{is}}{A_{is}^o} \frac{\partial A_{is}^o}{\partial L_{is}} + \frac{\zeta_{is}(1-\theta_{is})}{A_{is}^f} \frac{\partial A_{is}^f}{\partial L_{is}} + (e^{kt_i} - \zeta_{is}) \frac{\partial \theta_{is}}{\partial L_{is}} \right]. \tag{H.8}$$

Differentiate the allocation condition (29) directly with respect to sector employment:

$$\frac{1}{(1-\theta_{is})^2} \frac{\partial \theta_{is}}{\partial L_{is}} = (\rho - 1) \left(\frac{\zeta_{is}}{e^{kt_i}} \right)^{\rho} \left(\frac{A_{is}^o}{A_{is}^f} \right)^{\rho-2} \left(\frac{1}{A_{is}^f} \frac{\partial A_{is}^o}{\partial L_{is}} - \frac{A_{is}^o}{(A_{is}^f)^2} \frac{\partial A_{is}^f}{\partial L_{is}} \right). \tag{H.9}$$

Using equation (29) to simplify gives

$$\frac{\partial \theta_{is}}{\partial L_{is}} = (\rho - 1)\theta_{is}(1-\theta_{is}) \left(\frac{1}{A_{is}^o} \frac{\partial A_{is}^o}{\partial L_{is}} - \frac{1}{A_{is}^f} \frac{\partial A_{is}^f}{\partial L_{is}} \right). \tag{H.10}$$

Substituting equation (H.10) into equation (H.8) gives

$$\frac{\partial A_{is}^h}{\partial L_{is}} = A_{is}^h \left(\frac{\kappa_{is}^o}{A_{is}^o} \frac{\partial A_{is}^o}{\partial L_{is}} + \frac{\kappa_{is}^f}{A_{is}^f} \frac{\partial A_{is}^f}{\partial L_{is}} \right), \tag{H.11}$$

where

$$\kappa_{is}^o = \frac{\theta_{is}[e^{kt_i} + (\rho - 1)(1 - \theta_{is})(e^{kt_i} - \zeta_{is})]}{d_{is}^h(\theta_{is})}, \tag{H.12}$$

$$\kappa_{is}^f = \frac{(1 - \theta_{is})[\zeta_{is} - (\rho - 1)\theta_{is}(e^{kt_i} - \zeta_{is})]}{d_{is}^h(\theta_{is})}. \tag{H.13}$$

They sum to one but can be negative.

Substituting equations (H.6) and (H.7) into equation (H.10) and collecting terms yields

$$\begin{aligned} &\left[1 - (\rho - 1)\theta_{is}(1 - \theta_{is})\bar{s}_{is}^h \left(\frac{\lambda - \tau_{or}}{\bar{s}_{is}^o + \theta_{is}\bar{s}_{is}^h} + \frac{\lambda^R - \tau_{ro}}{\bar{s}_{is}^f + (1 - \theta_{is})\bar{s}_{is}^h} \right) \right] \chi_{is} \\ &\quad = (\rho - 1)(1 - \theta_{is})(\lambda + \tau_{ro} - \lambda^R - \tau_{or}). \end{aligned} \tag{H.14}$$

We can solve for χ_{is} as:

$$\chi_{is} = \frac{L_{is}}{\theta_{is}} \frac{\partial \theta_{is}}{\partial L_{is}} = \frac{(\rho - 1)(1 - \theta_{is})(\lambda + \tau_{ro} - \lambda^R - \tau_{or})}{1 - (\rho - 1)\theta_{is}(1 - \theta_{is})\bar{s}_{is}^h \left(\frac{\lambda - \tau_{or}}{\bar{s}_{is}^o + \theta_{is}\bar{s}_{is}^h} + \frac{\lambda^R - \tau_{ro}}{\bar{s}_{is}^f + (1 - \theta_{is})\bar{s}_{is}^h} \right)}. \tag{H.15}$$

Substituting the three productivity derivatives back into equation (H.2) gives

$$\frac{\partial y_{is}}{\partial L_{is}} = \frac{y_{is}}{L_{is}} + L_{is} \left(\bar{s}_{is}^o + \bar{a}_{is}^h \bar{s}_{is}^h \frac{A_{is}^h}{A_{is}^o} \kappa_{is}^o \right) \frac{\partial A_{is}^o}{\partial L_{is}} + L_{is} \left(\bar{s}_{is}^f + \bar{a}_{is}^h \bar{s}_{is}^h \frac{A_{is}^h}{A_{is}^f} \kappa_{is}^f \right) \frac{\partial A_{is}^f}{\partial L_{is}}. \tag{H.16}$$

Hence, the sectoral externality in equation (H.1) is

$$\lambda_{is} = w_1 \lambda + w_2 \tau_{ro} + w_3 \lambda^R + w_4 \tau_{or}, \tag{H.17}$$

where

$$
\begin{aligned}
w_1 &= \frac{1}{y_{is}}(L_{is}^o A_{is}^o + \bar{a}_{is}^h L_{is}^h A_{is}^h \kappa_{is}^o)\left(1 + \frac{L_{is}^h \theta_{is}\chi_{is}}{L_{is}^o + \theta_{is} L_{is}^h}\right), \\
w_2 &= \frac{1}{y_{is}}(L_{is}^o A_{is}^o + \bar{a}_{is}^h L_{is}^h A_{is}^h \kappa_{is}^o)\left(1 - \frac{L_{is}^h \theta_{is}\chi_{is}}{L_{is}^f + (1-\theta_{is}) L_{is}^h}\right), \\
w_3 &= \frac{1}{y_{is}}(L_{is}^f A_{is}^f + \bar{a}_{is}^h L_{is}^h A_{is}^h \kappa_{is}^f)\left(1 - \frac{L_{is}^h \theta_{is}\chi_{is}}{L_{is}^f + (1-\theta_{is}) L_{is}^h}\right), \\
w_4 &= \frac{1}{y_{is}}(L_{is}^f A_{is}^f + \bar{a}_{is}^h L_{is}^h A_{is}^h \kappa_{is}^f)\left(1 + \frac{L_{is}^h \theta_{is}\chi_{is}}{L_{is}^o + \theta_{is} L_{is}^h}\right).
\end{aligned}
$$

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