Online Appendix

A New Spatial Hedonic Equilibrium in the Emerging Work-from-Home Economy?

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A1. Employment comparisons and proof of Proposition 3

Employment relationships $\widetilde{L}_s < N_s^*$ and $\widetilde{L}_d > N_d^*$ stated prior to Proposition 2 follow because $N_s^* > \overline{N} = \widetilde{L}_s$ and $N_d^* < \overline{N} = \widetilde{L}_d$. It then follows that $w(N_s^*, \overline{\alpha}) < w(\widetilde{L}_s, \overline{\alpha})$, with $w(N_d^*, \overline{\alpha}) > w(\widetilde{L}_d, \overline{\alpha})$ holding for city d, establishing Proposition 3 (ii). Therefore, the original residents of city s (city d) earn a higher (lower) wage under WFH.

When the only advantage of city s is higher productivity, the previous results yield $N_s^* > \widetilde{N}_s < \widetilde{L}_s$, which appears to imply that $w(N_s^*, \alpha_s)$ could be larger or smaller than $w(\widetilde{L}_s, \alpha_s)$, and similarly for $w(N_d^*, \alpha_d)$ and $w(\widetilde{L}_d, \alpha_d)$. However, further analysis dispels this ambiguity, as follows.

The first step is to note that the inequalities $N_s^* > \widetilde{L}_s$ and $N_d^* > \widetilde{L}_d$ cannot both hold nor can the reverse of these two inequalities both hold. Either set of inequalities violates the requirements that the city populations before WFH or the employment levels under WFH individually sum to $2\overline{N}$. Therefore, the inequalities

$$N_s^* \; < \; \widetilde{L}_s, \; N_d^* \; > \; \widetilde{L}_d \qquad \textit{or} \qquad N_s^* \; > \; \widetilde{L}_s, \; N_d^* \; < \; \widetilde{L}_d \tag{$a1$}$$

must be satisfied. The second set of inequalities implies

$$w(N_s^*, \alpha_s) \; < \; w(\widetilde{L}_s, \alpha_s), \quad w(N_d^*, \alpha_d) \; > \; w(\widetilde{L}_d, \alpha_d). \tag{$a2$}$$

Since $w(N_s^*, \alpha_s) > w(N_d^*, \alpha_d)$ holds when city s has only a productivity advantage, the inequalities in ($a2$) can be combined to yield

$$w(\widetilde{L}_s, \alpha_s) \; > \; w(N_s^*, \alpha_s) \; > \; w(N_d^*, \alpha_d) \; > \; w(\widetilde{L}_d, \alpha_d), \tag{$a3$}$$

which violates the condition of wage equality under WFH ($w(\widetilde{L}_s, \alpha_s) = w(\widetilde{L}_d, \alpha_d)$). Therefore, the first set of inequalities in ($a1$) must hold, establishing the claim made prior to Proposition

1, and they imply

$$w(N_s^*, \alpha_s) \; > \; w(\widetilde{L}_s, \alpha_s), \quad w(N_d^*, \alpha_d) \; < \; w(\widetilde{L}_d, \alpha_d), \tag{$a2$}$$

establishing Proposition 3 (*i*).

A2. Proof of Proposition 4

Focusing first on the differential-productivity case, after substitution of $N_d^* = 2\overline{N} - N_s^*$ and $A_s = A_d$ in (2), differentiation yields $\partial N_s^*/\partial \alpha_s > 0$, showing that higher productivity in city s raises its population in the absence of WFH. Since the population of city s in the WFH equilibrium ($\widetilde{N}_s$) is independent of α_s, being equal to $\overline{N}$, it follows that the change in the population of city s with the introduction of WFH, equal to $\widetilde{N}_s - N_s^*$ is smaller the larger is α_s. Thus, WFH yields a larger population decline in city s the higher its productivity. This larger population drop in turn implies that the WFH-induced housing-price decline in city s is larger the higher its productivity.

Turning to the differential-amenity case, after substituting $\alpha_s = \alpha_d = \overline{\alpha}$ and $N_s^* = 2\overline{N} - N_d^*$ in (2), differentiation yields $\partial N_d^*/\partial A_d > 0$, so that a higher amenity level in city d raises its population in the absence of WFH. However, in constrast to the differential-productivity case, the population of city d is still affected by A_d under WFH, with $\partial \widetilde{N}_d/\partial A_d > 0$. Although both amenity derivatives are positive, the derivative under WFH tends to be larger, so that $\partial(\widetilde{N}_d - N_d^*)/\partial A_d > 0$.[44] Thus, WFH yields a smaller population decline in city d the higher its amenity level. This smaller population decline in turn implies that the WFH-induced housing-price decline in city d is smaller the higher its amenity level.

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[44] Differentiating (2) yields $\partial N_d^*/\partial A_d = -1/(w_s' + H_s' + w_d' + H_d' > 0$, where the subscripts denote evaluation of the function in city s or city d and the prime on the wage functions denotes the population derivative. Differentiation of (3) yields $\partial \widetilde{N}_d/\partial A_d = -1/(\widetilde{H}_s' + \widetilde{H}_d') > 0$, where the tildes on the H functions denote evaluation at the WFH equilibrium. The wage terms tend to make first denominator larger in absolute value than the second, making the amenity's effect on N_d^* smaller than its effect on $\widetilde{N}_d$. However, the fact that the H' functions in the two expressions are evaluated at different equilibria means that this conclusion is likely but not guaranteed to hold (the likelihood grows if H'' is small in absolute value).

Table A1. Changes in House Prices and Rents, 2019-2020

	Dependent variable: Change in log home price or log rent, 2019–2020							
	Log home price				Log rent			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Low PROD × PROD × WFHPOT	0.178	0.156			−1.434***	−1.554***		
	(0.301)	(0.302)			(0.496)	(0.467)		
High PROD × PROD × WFHPOT	−0.653***	−0.713***			−0.438**	−0.537***		
	(0.208)	(0.211)			(0.209)	(0.162)		
Low QOL × QOL × WFHPOT	−0.878				−0.681			
	(0.702)				(0.834)			
High QOL × QOL × WFHPOT	0.327				−0.239			
	(0.479)				(0.437)			
PROD × WFHPOT			−0.481***	−0.527***			−0.420**	−0.512***
			(0.165)	(0.164)			(0.188)	(0.142)
QOL × WFHPOT			−0.256				−0.393	
			(0.253)				(0.459)	
High PROD × PROD	0.201*	0.209*			−0.230	−0.235		
	(0.110)	(0.114)			(0.163)	(0.159)		
High QOL × QOL	−0.561*				−0.208			
	(0.302)				(0.383)			
PROD	−0.036	−0.030	0.128**	0.141**	0.365**	0.399***	0.118*	0.145***
	(0.086)	(0.087)	(0.057)	(0.056)	(0.153)	(0.141)	(0.067)	(0.052)
QOL	0.318	−0.034	0.033	−0.046	0.108	−0.152***	−0.012	−0.144***
	(0.207)	(0.031)	(0.095)	(0.030)	(0.342)	(0.044)	(0.183)	(0.045)
WFHPOT	0.045	0.070***	0.040	0.041*	−0.127***	−0.114***	−0.116***	−0.110***
	(0.028)	(0.021)	(0.025)	(0.024)	(0.026)	(0.023)	(0.023)	(0.022)
Pct. pop. with a college education	−0.033***	−0.035***	−0.030**	−0.029**	−0.035***	−0.035***	−0.039***	−0.039***
	(0.011)	(0.011)	(0.012)	(0.012)	(0.010)	(0.010)	(0.010)	(0.010)
Pct. MSA land steeper than 15 degrees	−0.006	−0.025	−0.042	−0.042	−0.096	−0.106	−0.054	−0.065
	(0.092)	(0.092)	(0.094)	(0.094)	(0.170)	(0.173)	(0.171)	(0.175)
Wharton Residential Land-Use Regulation Index	0.006***	0.006***	0.006***	0.006***	−0.003	−0.003	−0.003	−0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
Bartik IV 2019-2020	0.007	0.007	0.017	0.012	0.185**	0.174**	0.180**	0.172**
	(0.053)	(0.055)	(0.058)	(0.057)	(0.077)	(0.075)	(0.075)	(0.074)
Observations	792	792	792	792	269	269	269	269
Adjusted R^2	0.154	0.142	0.127	0.128	0.511	0.514	0.510	0.510
Sample	metro	metro	metro	metro	metro	metro	metro	metro
SE cluster	MSA	MSA	MSA	MSA	MSA	MSA	MSA	MSA

Note: Outcomes are county-level changes in log annual home prices and log rents for all homes and condos/co-ops. Home prices and rents are based on the Zillow Home Value Index and Zillow Observed Rent Index, respectively. Control variables include census division fixed effects, WFH potential, percent of population with a college education, MSA productivity, MSA quality of life, percent of MSA land steeper than 15 degrees, the Wharton Residential Land-Use Regulation Index, and the 2019-2020 Bartik instrument. The metro county sample includes all counties that are part of an MSA. Standard errors are clustered at the MSA level. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A2. Change in Population Outflows, 2019-2020

	Dependent variable: *Change in log USPS outflows, 2019–2020*			
	(1)	(2)	(3)	(4)
Low PROD × PROD × WFHPOT	1.529	1.617		
	(1.139)	(1.149)		
High PROD × PROD × WFHPOT	1.862***	1.955***		
	(0.483)	(0.485)		
Low QOL × QOL × WFHPOT	−0.869			
	(1.797)			
High QOL × QOL × WFHPOT	1.335			
	(1.463)			
PROD × WFHPOT			1.866***	1.998***
			(0.477)	(0.448)
QOL × WFHPOT			0.734	
			(1.064)	
High PROD × PROD	−0.023	−0.028		
	(0.370)	(0.368)		
High QOL × QOL	−0.640	0.052		
	(0.733)	(0.208)		
PROD	−0.390	−0.414	−0.448***	−0.485***
	(0.326)	(0.328)	(0.140)	(0.131)
QOL	0.141**	0.182***	0.198***	0.197***
	(0.067)	(0.049)	(0.060)	(0.059)
WFHPOT	0.138***	0.134***	0.131***	0.129***
	(0.025)	(0.025)	(0.026)	(0.026)
Pct. pop. with a college education	−0.364	−0.371	−0.318	−0.318
	(0.274)	(0.277)	(0.268)	(0.268)
Pct. MSA land steeper than 15 degrees	−0.011*	−0.011*	−0.011*	−0.011*
	(0.006)	(0.006)	(0.006)	(0.006)
Wharton Residential Land-Use Regulation Index	−0.077	−0.063	−0.089	−0.073
	(0.109)	(0.108)	(0.108)	(0.106)
Observations	792	792	792	792
Adjusted R^2	0.387	0.387	0.387	0.387
Sample	metro	metro	metro	metro
SE cluster	MSA	MSA	MSA	MSA

Note: Outcomes are county-level changes in log USPS migration outflows. USPS population outflows are estimated using county-to-county U.S. Postal Service address changes. Control variables include census division fixed effects, WFH potential, percent of population with a college education, MSA productivity, MSA quality of life, percent of MSA land steeper than 15 degrees, the Wharton Residential Land-Use Regulation Index, and the 2019-2020 Bartik instrument. The metro county sample includes all counties that are part of an MSA. Standard errors are clustered at the MSA level. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

Table A3. Robustness Checks

	Change in log home price			*Change in log rent*		
	2019–2020		2018–2019	2019–2020		2018–2019
	(1)	(2)	(3)	(4)	(5)	(6)
PROD × WFHPOT	-0.500^{**}	-0.642^{**}	-0.284	-0.535^{**}	-0.659^{***}	0.067
	(0.198)	(0.289)	(0.180)	(0.238)	(0.241)	(0.119)
PROD	0.129^{*}	0.186^{*}	0.086	0.138^{*}	0.163^{*}	-0.023
	(0.072)	(0.097)	(0.059)	(0.082)	(0.083)	(0.048)
QOL	0.049	0.047	-0.021	-0.096^{***}	-0.177^{*}	0.007
	(0.032)	(0.045)	(0.022)	(0.030)	(0.097)	(0.018)
WFHPOT	-0.050^{***}	-0.045^{**}	-0.049^{***}	-0.037^{**}	-0.033	-0.046^{***}
	(0.017)	(0.022)	(0.013)	(0.015)	(0.042)	(0.010)
Pct. pop. with a college education	-0.062	0.062	0.180^{*}	-0.152	0.094	-0.097
	(0.115)	(0.095)	(0.099)	(0.137)	(0.106)	(0.154)
Pct. MSA land steeper than 15 degrees	0.006^{**}	0.006^{*}	0.003	-0.003	0.004	-0.002
	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)
Wharton Residential Land-Use Regulation Index	0.157	0.149		0.275^{***}	0.186	
	(0.096)	(0.107)		(0.072)	(0.128)	
Bartik IV 2019-2020			-0.212			-0.239
			(0.241)			(0.309)
Observations	378	236	792	165	83	269
Adjusted R^2	0.140	0.055	0.230	0.491	0.324	0.247
Sample	principal-city	MSA	metro	principal-city	MSA	metro
SE cluster	MSA	State	MSA	MSA	State	MSA

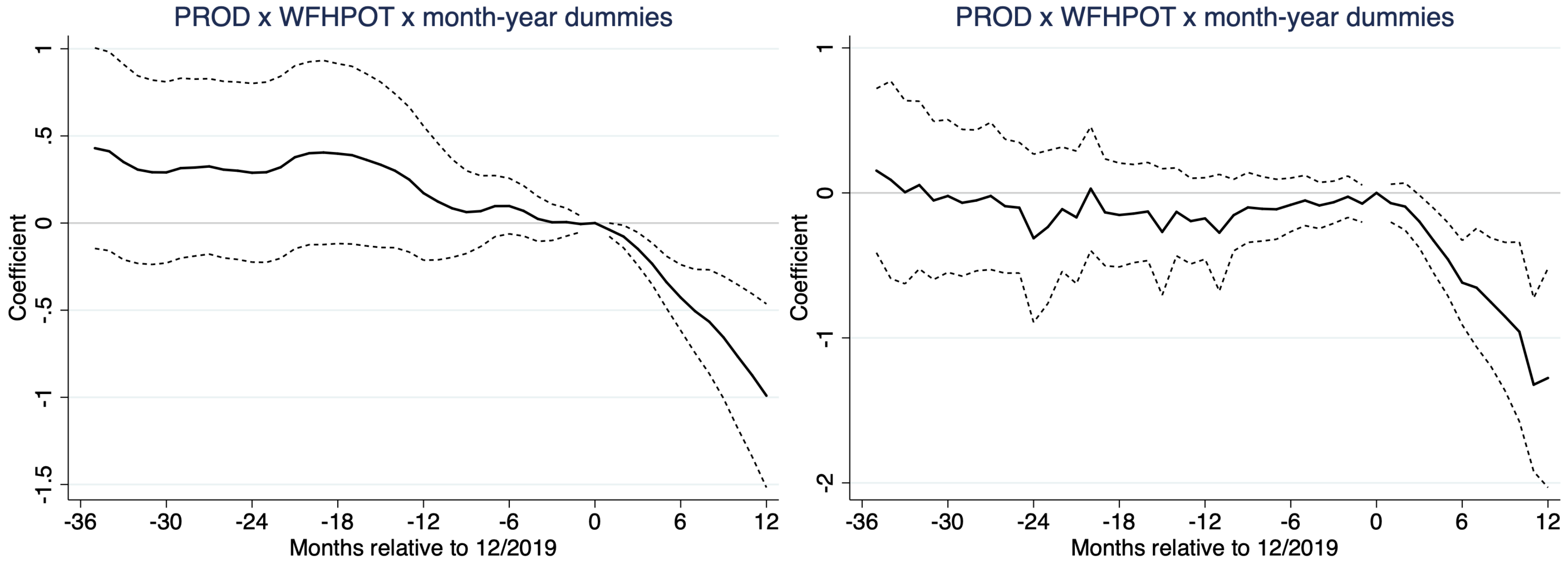
Note: Outcomes are county- or MSA-level changes in log annual home prices and log rents for all homes and condos/co-ops. Home prices and rents are based on the Zillow Home Value Index and Zillow Observed Rent Index, respectively. Control variables include WFH potential, percent of population with a college education, MSA productivity, MSA quality of life, percent of MSA land steeper than 15 degrees, and the Wharton Residential Land-Use Regulation Index, and Bartik instruments. Except for the regressions using the MSA sample (Columns 2 and 5), all regression include census division fixed effects. The metro county sample includes all counties that are part of an MSA. The principal-city county sample includes all counties that contain a principal city of an MSA. The MSA sample includes 236 MSAs with non-missing covariates. Standard errors are clustered at the MSA level, except for Columns 2 and 5, which are clustered at the state level. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A4. Intracity Zip-Code Home Price Gradients, All Metro Areas

	Dependent variable: Log home price	
	12/2019	12/2020
	(1)	(2)
Log dist. to CBD	-0.090^{***}	-0.087^{***}
	(0.021)	(0.020)
Log dist. to nearest river	0.014	0.014
	(0.017)	(0.016)
Log dist. to nearest lake	−0.010	−0.012
	(0.010)	(0.010)
Log dist. to nearest coastline	−0.018	−0.018
	(0.014)	(0.014)
Avg. annual precipitation 1971–2000	−0.0001	−0.00003
	(0.0001)	(0.0001)
Max temperature in July	-0.035^{***}	-0.033^{***}
	(0.006)	(0.006)
Minimum temperature in January	0.040^{**}	0.036^{**}
	(0.016)	(0.015)
Average slope	0.00005	−0.001
	(0.003)	(0.003)
Log population density	0.008	0.014
	(0.010)	(0.009)
Log avg. hhld. income	1.127^{***}	1.108^{***}
	(0.043)	(0.042)
Observations	12,792	12,792
Adjusted R^2	0.823	0.830

Note: The estimation equation is $\log P_{zt} = \alpha_m + \beta_t \log DistCBD_z + \gamma_t X_z + \varepsilon_{zt}$, where P_{zt} is the home price index of zip-code z, α_m are metro area fixed effects, $DistCBD_z$ is distance from zip-code z to the central business district, and X_z are zip-code covariates. Home price indices are based on the the zip-code-level Zillow Home Value Index for all homes and condos/co-ops. Zip-code covariates are based on census tract-level data from Lee and Lin (2018), which we map to zip-codes using a HUD crosswalk.

Figure A1. Home Price and Rental Rate Dynamics, Bootstrapped Standard Errors, 2017–2020

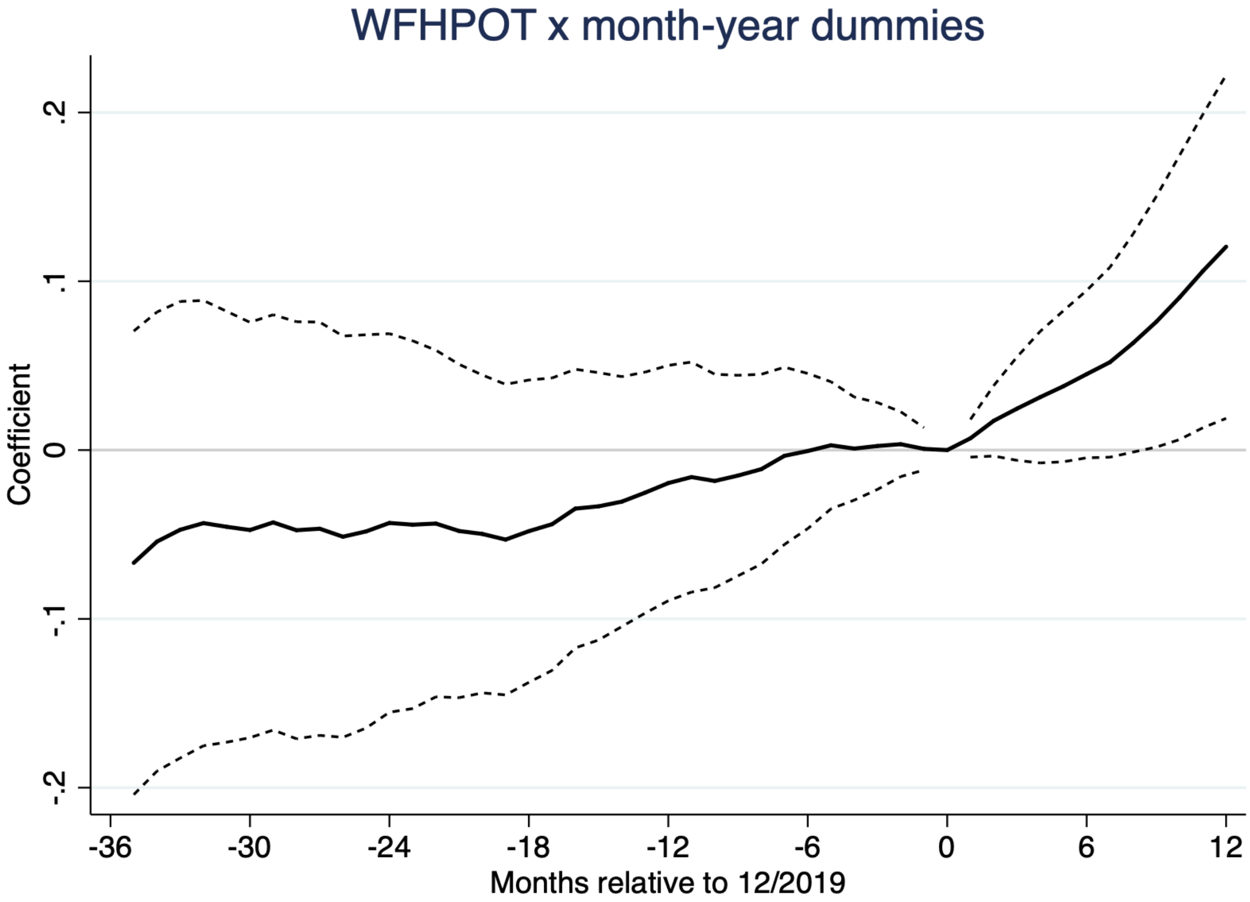


(a) Price

(b) Rent

Note: Figure plots the coefficients and 95 confidence intervals of the event study estimates. Outcomes are the Zillow Home Value Indices and Zillow Observed Rent Indices for all homes and condos/co-ops between January 2017 and December 2020. Control variables include county fixed effects, census division-month-year fixed effects, and the interactions between month-year dummies with a set of county covariates, including WFH potential, percent of population with a college education, MSA productivity, MSA quality of life, percent of MSA land steeper than 15 degrees, and the Wharton Residential Land-Use Regulation Index. Standard errors are estimated using nonparametric boostrap.

Figure A2. Intracity Home Price Gradients, Bootstrapped Standard Errors, 2017–2020



Note: Figure plots the coefficients and 95 confidence intervals of the event study estimates. Outcomes are intracity home price gradients based authors' calculations. In the first stage, we estimate the intracity home price gradient of each MSA with at least 30 zip-codes by separately regressing log zip-code-level Zillow Home Value Index on log distance to the central business district, a set of exogenous amenities (log distances to nearest lake, river, and coastline; the average annual precipitation 1971–2000, January minimum temperature, and July maximum temperature), average slope, and a set of proxies for endogenous amenities (log population density and log average household income). In the second stage, we estimate an event study equation by regressing the estimated intracity home price gradients on the interactions of month-year dummies and principal-city counties' WFH potential, controlling for MSA fixed effects and month-year fixed effects. Standard errors are estimated using nonparametric bootstrap.