The Environmental Impact of Working from Home

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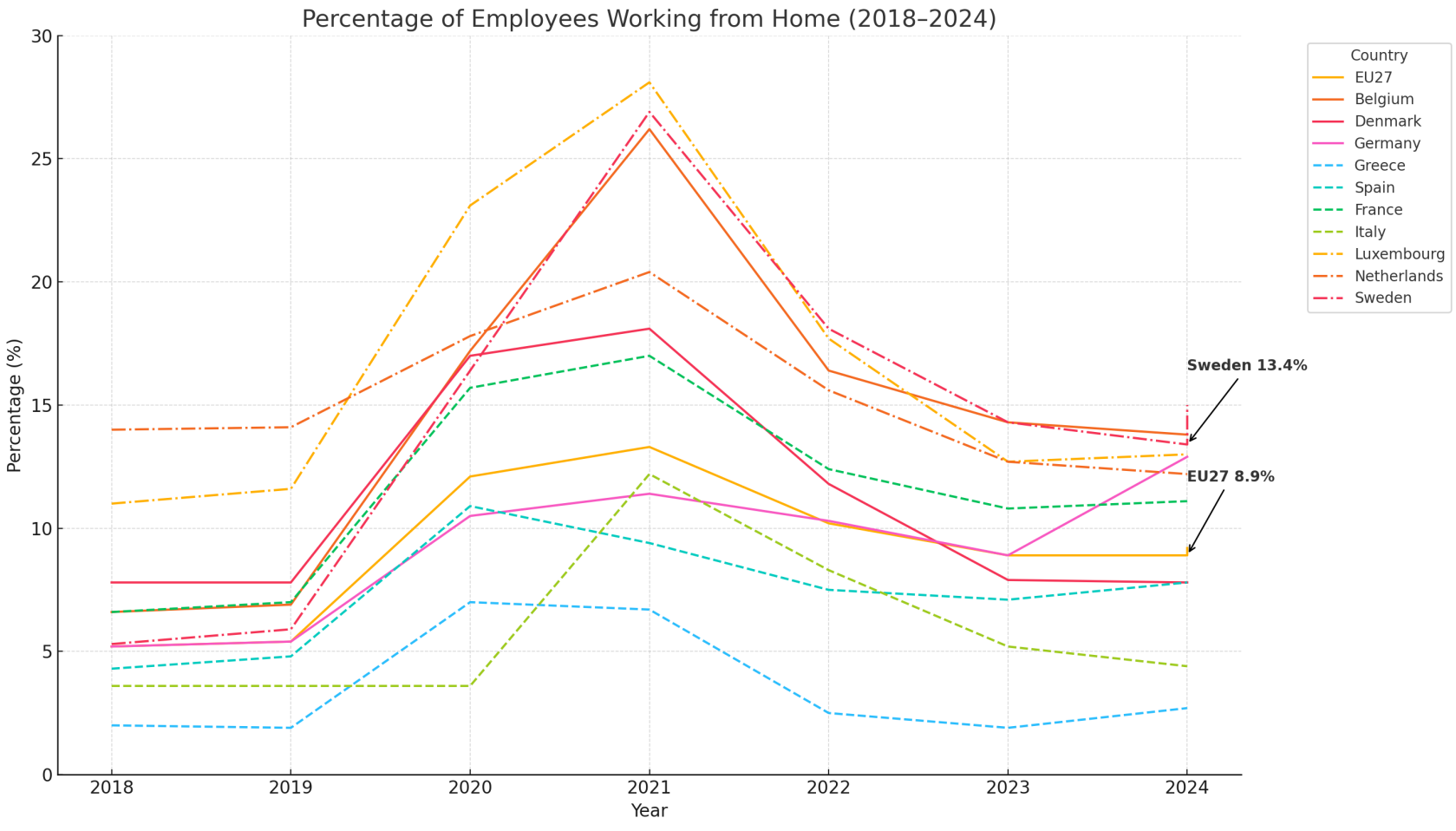
Working from home



Source of data: Eurostat – https://ec.europa.eu/eurostat/databrowser/view/lfsa_ehomp/default/table?lang=en

Purpose

- Investigation of the impact of remote work on the environment
- We look at **commuting emissions & floorspace energy consumption**.

Transport:

- less frequent commuting $\rightarrow$ lower emissions;
- commuting distances increase $\rightarrow$ higher emissions;
- WFH may also affect transport mode choices!

Energy:

- smaller office space in commercial buildings;
- larger houses, because of office space at home;
- denser areas are often more energy efficient...

The aggregate effect is an empirical question.

This paper....

Build a **quantitative spatial model** with:

- heterogeneous workers;
  - who choose: residence, workplace, commuting modes;
- freely tradable goods and multiple sectors;
- sector-specific WFH shares;
- firms production decisions (inputs and location);
- land developers & spatial externalities (amenities & productivities).

Estimate and calibrate for Sweden.

Counterfactual exercise: Sector-specific increases in remote work.

Overview of the results

- Commuting emissions >> Residential/Commercial emissions
- Small effect on housing consumption
- Rebound effect: WFH increases distance more than it reduces frequency
- This leads to an increase in carbon emissions
- Negative impact on welfare (at CO2 price=120 EUR)

Literature

- WFH and urban structure
  - Reduced commuting costs and demand for larger homes, central rents fall and suburban rents rise (Behrens et al. 2021; Monte et al. 2023; Brueckner 2024; Kyriakopoulou and Picard 2023)
- COVID-19 empirical studies
  - Flatter housing/rent gradients; effect on house prices and rents in high-productivity areas; weaker agglommeration economies (Liu and Su 2021, Brueckner et al. 2023, Gupta et al. 2022)
  - Demand for suburban housing (Mondragón and Wieland 2022 and Guglielminetti et al. 2023)

Literature

- Quantitative spatial models
  - Jobs concentration and resident spread (Los Angeles, Delventhal et al. 2022)
  - Welfare improvement for remote workers (US, Delventhal and Parkhomenko 2023)
  - Multiple equilibria: permanent jump (US, Monte, Porcher, Rossi-Hansberg 2025)
- Environmental implications of remote work
  - Commuting frequency, commuting distance, office space, home space, transport mode, sector, WFH feasibility
  - 30-80% emission reduction (Tao et al. 2023, Navaratnam et al. 2022)
  - Rebound effects (Marz and Şen 2022, Cerqueira et al. 2020)
  - Sprawl/decentralization (Larson and Zhao (2016)
  - WFH increased PM2.5 levels in France (Briole and Lavaine, 2025)
  - Germany (Borck et al. 2024)

Roadmap

1. Structural framework
2. Data
3. Quantification
4. Preliminary results

Individuals

- Work a fraction θ of their time at the office, and $1-\theta$ at home
- Need extra floorspace at home $g(\theta)$ when they work from home
- Choose housing floorspace h and a composite good c to maximize their utility

$$U(c,h) = z\frac{X}{d(t,\theta)}\left(\frac{c}{1-\beta}\right)^{1-\beta}\left(\frac{h}{\beta}\right)^{\beta},$$

  - spatial residential amenities X
  - idiosyncratic preference parameter z
- Commuting disutility

$$d(t,\theta) = \theta e^{\kappa t} + (1-\theta)$$

  - travel time t (by mode)
- Budget constraint $c + qh[1+g(\theta)] = w$
  - floorspace price q and wage w

Individuals

- Choose residence locations i, job places j, sectors s, and transport modes m
- Idiosyncratic Fréchet i.d.d. preference shock ξ_{ij}, φ_s and ζ_m
- WFH depends on sector as θ_s
- Indirect utility

$$V_{ijsm} = \xi_{ij}\zeta_m\varphi_s \; v_{ijsm}$$

where

$$v_{ijsm} = \frac{X_i}{d(t_{ijm}, \theta_s)} \frac{w_{js}}{[q_i(1 + g(\theta_s))]^\beta}.$$

Optimal choices

- Fréchet's choices probability $\pi_{ijsm} = \pi_{ij}\,\pi_{s|ij}\,\pi_{m|ijs}$ where

$$\pi_{m|ijs} = \left[\frac{v_{ijsm}}{v_{ijs}}\right]^{\nu} \quad \text{with} \quad v_{ijs} = \left[\sum_{m} v_{ijsm}^{\nu}\right]^{1/\nu},$$

$$\pi_{s|ij} = \left[\frac{v_{ijs}}{v_{ij}}\right]^{\rho} \quad \text{with} \quad v_{ij} = \left[\sum_{s} v_{ijs}^{\rho}\right]^{1/\rho},$$

$$\pi_{ij} = \left[\frac{v_{ij}}{v}\right]^{\gamma} \quad \text{with} \quad v = \left[\sum_{i}\sum_{j} v_{ij}^{\gamma}\right]^{1/\gamma}.$$

Production

- Competitive CRS sectors s with production function in location j

$$Y_{js} = A_{js} \left(\frac{M_{js}}{\alpha_s} \right)^{\alpha_s} \left(\frac{H_{js}}{1-\alpha_s} \right)^{1-\alpha_s}$$

  - local producticity A_{js}
  - office floor units H_{js}
  - effective labor units $M_{js} = \xi_s N_{js}$
    - number of workers N_{js}
    - WFH productivity $\xi_s \equiv \theta_s + \overline{\xi}_s (1-\theta_s)$ $(<> 1)$

- Firms choose effective labor and floorspace to maximize their profits.
- Equilibrium payments for labor at location j and sector s

$$w_{js} = \xi_s A_{js}^{\frac{1}{\alpha_s}} \left(\frac{1}{q_j} \right)^{\frac{1-\alpha_s}{\alpha_s}} . \tag{1}$$

Competitive developers

- Produce and sell floorspace using land l_i and good c_i:

$$H_i = \left(\frac{\phi_i l_i}{\eta}\right)^{\eta} \left(\frac{c_i}{1-\eta}\right)^{1-\eta}$$

  - land-productivity ϕ_i (geography, regulation)
- Pay cost $r_i l_i + c_i$ where r_i is the land unit price
- In equilibrium, land demand equals land supply Λ_i
- Equilibrium floorspace and land price

$$H_i = \frac{\phi_i \Lambda_i}{\eta} q_i^{\frac{1-\eta}{\eta}} \tag{2}$$

$$r_i = \phi_i q_i^{\frac{1}{\eta}}. \tag{3}$$

Externalities

- Residential spillovers

$$X_i = x_i \left[\frac{1}{\Lambda_i} \sum_j \sum_s N_{ijs} \right]^{\chi} \tag{4}$$

- Productivity spillovers

$$A_{js} = a_{js} \left[\frac{1}{\Lambda_j} \sum_i \sum_s [\theta_s + \psi(1 - \theta_s)] N_{ijs} \right]^{\lambda}, \tag{5}$$

  - $\psi = 0, 1$ is the contribution of remote workers to productivity externalities

Equilibrium

- A spatial equilibrium consists of allocations of workers to sectors, residences, workplaces, and transport modes, N_{ijsm}; productivities, A_{js}; residential amenities, X_i; wages, w_{js}; floorspace prices, q_i and land prices, l_i, that satisfy in every location i:
  - markets for goods, labor, floorspace and land, residential and productivity spillover identites, Frèchet population flows.
- Using results from Allen, Arkolakis, and Li (2024), we prove the existence and uniqueness of the spatial equilibrium.

Equilibrium full definition

- Labor market clearing

$$N_{ijsm} = \pi_{ijsm}. \tag{6}$$

- Floorspace market clearing

$$H_i = H_i^R + H_i^{WFH} + H_i^C, \tag{7}$$

with:

$$q_i H_i^R = \beta \sum_j \sum_s \frac{1}{1 + g(\theta_s)} w_{js} N_{ijs}, \tag{8}$$

$$q_i H_i^{WFH} = \beta \sum_j \sum_s \frac{g(\theta_s)}{1 + g(\theta_s)} w_{js} N_{ijs}, \tag{9}$$

$$q_j H_j^C = \sum_s \frac{1 - \alpha_s}{\alpha_s} w_{js} \sum_i N_{ijs}. \tag{10}$$

Emissions of GHG

- Related to commuting, i.e., travel distance d_{ijm}

$$Z_m^T = \varepsilon^m \sum_{i,j,s,m} \theta_s d_{ijm} N_{ijsm}$$

  - emission intensity ε^m

- Related to floorspace

$$Z_i^H = \varepsilon_i^R (H_i^R + H_i^{WFH}) + \varepsilon_i^C H_i^C,$$

  - emission intensities $\varepsilon_i^R, \varepsilon_i^C$
  - taller buildings exhibit greater energy efficiency (Borck Brueckner 2018, Kyriakopoulou et al. 2025)

Data

- 1,990 locations from RegSO areas (1600) and municipalities (390) (4.7 million workers)
- 12 sector s from Swedish Labor Survey (AKU)
- 3 commuting mode from Trafik Analys (2019 report on Swedish travel habits)
- WFH shares $1 - \theta_s$ from 2022 Swedish Labor Survey (AKU) (Corona pandemic).
- Commuting flows N_{ijs} and wages w_{js} from Swedish longitudinal integrated database for individual and workplaces (LISA) (trimmed $5\% - 95\%$, aggregated in location i)
- Travel time, distance, and mode from Open Route Services (car+cycle) and TravelTime (public transport)

Data

- Residential floorspace $H_i^R + H_i^{WFH}$ from Swedish housing register (*Lägenhetsregistret*)
- Annual individual wages (LISA)
- Total residential and commercial floorspace.
- Greenhouse gas emissions from National Emissions Database (Swedish Meteorological and Hydrological Institut, SMHI, 1 km^2 resolution). Residential and commercial heating + combustion of fossil fuels and biomass for space and water heating

Parameters

Param.	Description	Value	Comments
β	Housing expend. share	0.291	Household budget survey
λ	Elast. productivity/employ. density	0.04	Ahlfeldt et al. 2019
χ	Elast. amenity/pop. density	0.172	Heblich et al. 2020
$1-\bar{\alpha}_s$	Floorspace cost share	$\{.09, .15, .21, .32\}$	Valentinyi et al 2008
γ	Fréchet elast. work-residence	8.20	estimated
ν	Fréchet elast. mode	2.13	estimated
ρ	Fréchet elast. sector	.54	estimated
$\nu\kappa$	elast. commuting time	$\{1, 2.14, .54\}$	estimated
η	Elast. price/floorspace supply	.39	estimated
μ^k	Elast. floorspace emission/density	$\{-.19, -1.70\}$	estimated
δ	Elast. floorspace/WFH	$\{0, .5\}$	counterfactuals
ψ	WFH productivity externalities	$\{0, 1\}$	counterfactuals
$\bar{\xi}$	WFH productivity	$\{.9, 1, 1.1\}$	counterfactuals
$g(\theta)$	home work space	$\{0, 0.2\}$	counterfactuals

- Carbon gCO2/km: car=133, public=25; foot/cycle=0
- 250 working days/year (Sweden).

Baseline Sweden

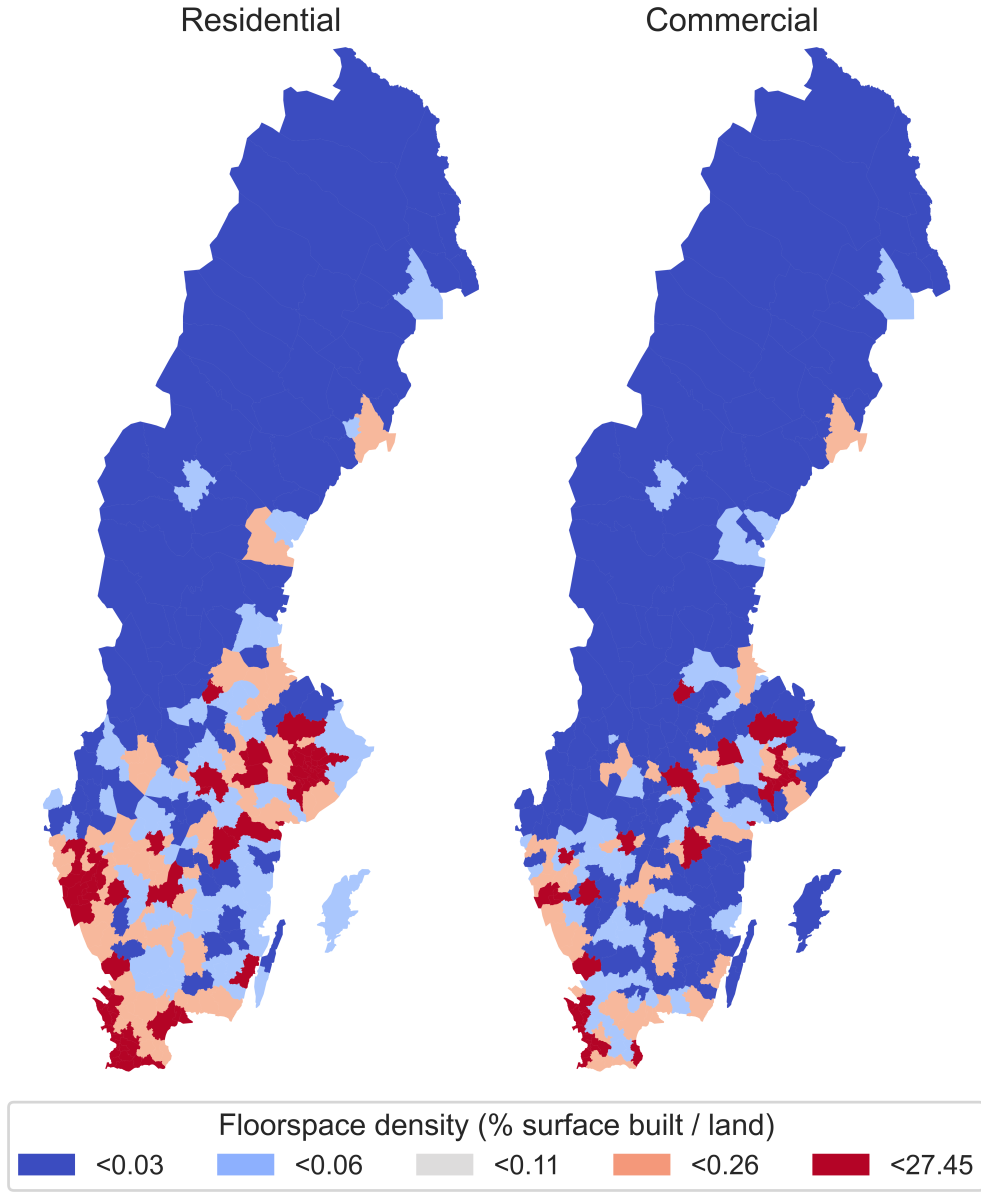


Figure: Baseline floorspace density in Sweden

Baseline Sweden

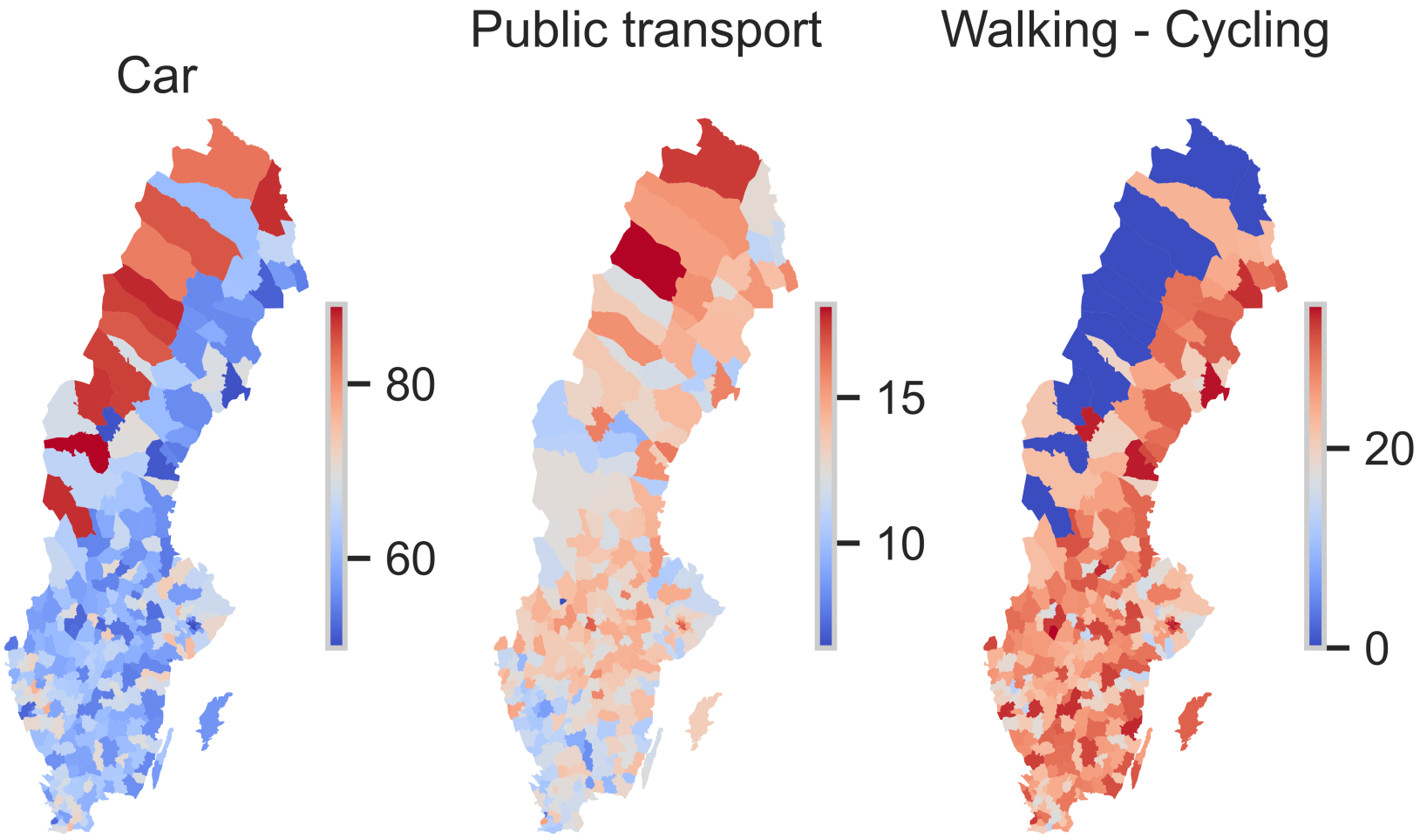


Figure: Commuting mode shares across Sweden

Counterfactual WFH

- Exogeneous changes in WFH

Sector	θ	θ'	**Sector share**
Agriculture	100%	70%	1.7%
Artothers	100%	68%	5.1%
Construction	100%	90%	7.2%
Education	100%	79%	11.5%
Finance	100%	49%	15.0%
Healthsocial	100%	90%	15.5%
Hotelrestau	100%	100%	4.8%
Infocomm	100%	18%	3.7%
Manufenergy	100%	77%	12.0%
Publicadmin	100%	44%	6.0%
Trade	100%	76%	12.4%
Transport	100%	90%	5.1%
All	100%	72%	100.0%

Population and Employment Changes - Sweden

- Move from high to low density

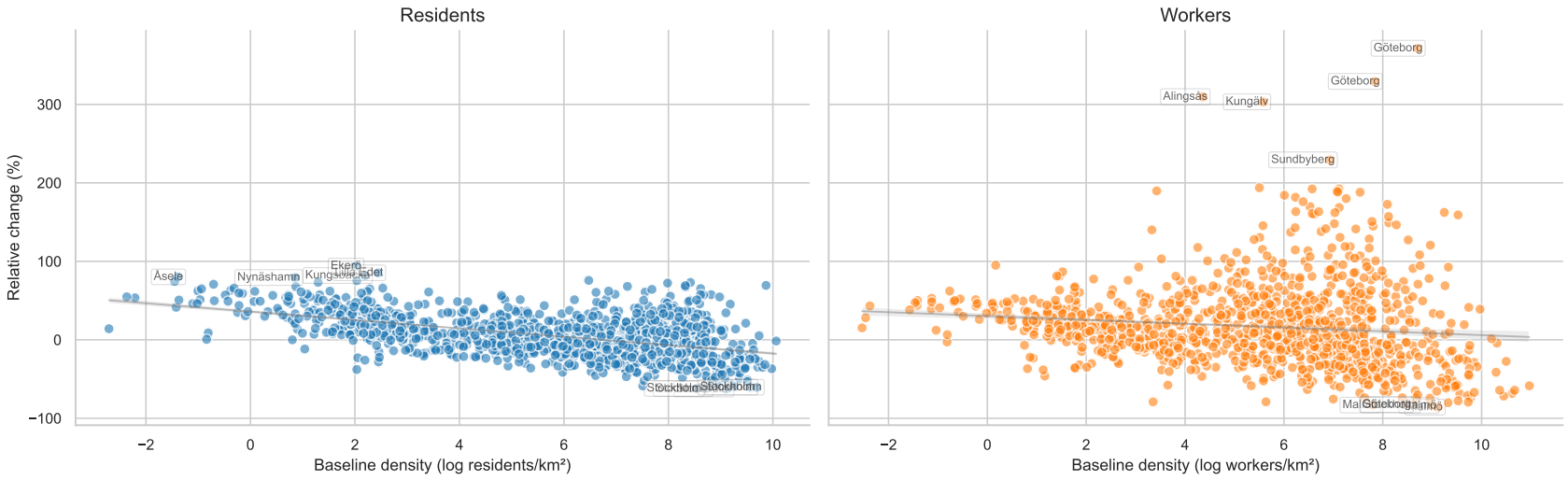


Figure: Population/employment reallocation across municipalities

Population and Employment Changes - Stockhom

- Move from high to low density

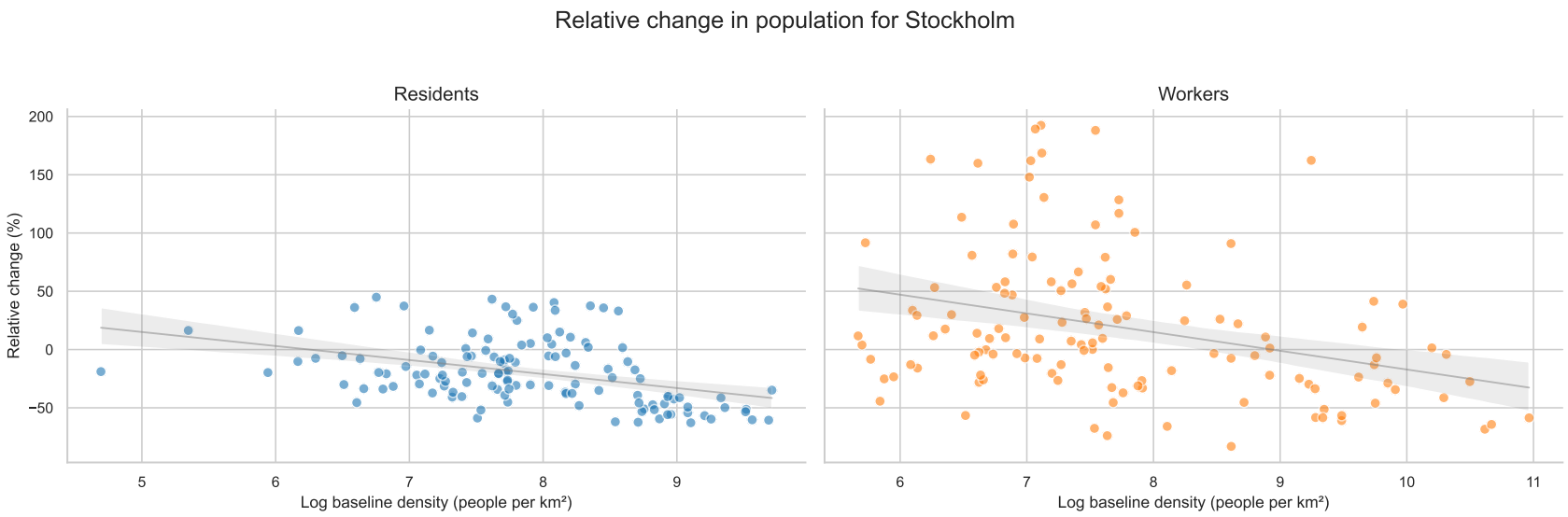


Figure: Population/employment reallocation across RegSO Stockholm

WFH composition effect- Sweden

- residence: uniform reduction of θ_s
- office: lower θ_s in more dense areas

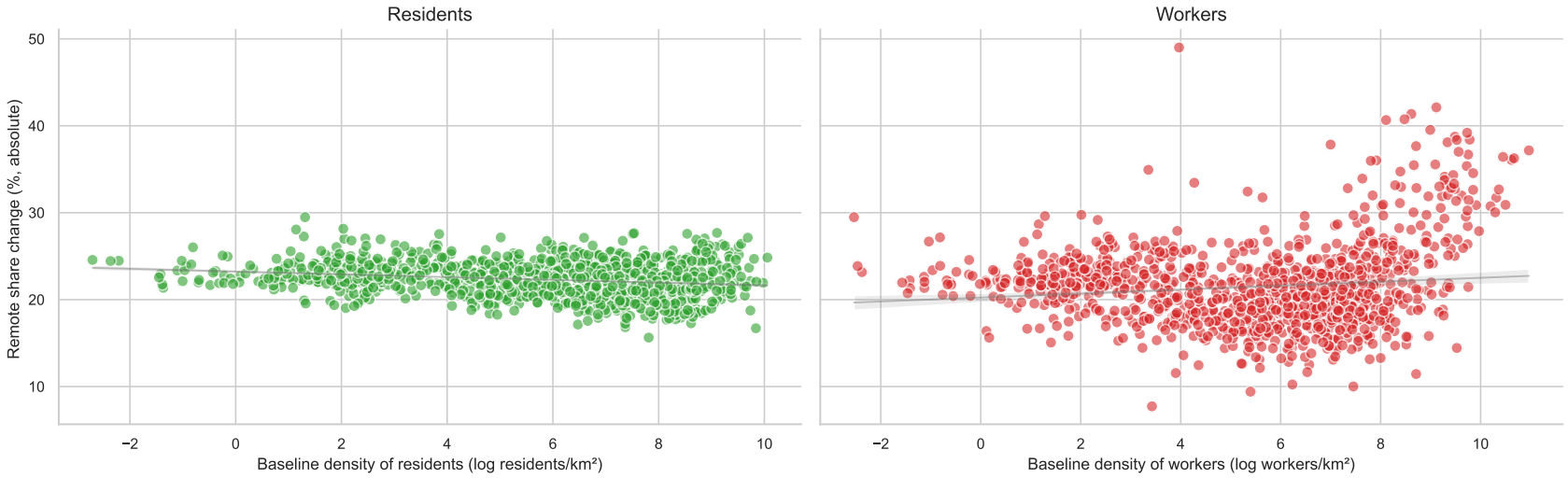


Figure: Spatial variation in the WFH share change

CO2 Emissions - Sweden

- Rebound effect in commuting; small effect from floorspace

	Baseline (1)	**Change** (2)
Emissions from Commuting	**5.68**	**0.96**
– Cars	5.56	0.92
– Public Transports	0.12	0.04
Emissions from floorspace	**0.675**	**-0.019**
– Residential	0.305	-0.010
– Commercial	0.370	-0.009
Total	**6.36**	**0.94**

CO2 Breakdown - Commuting

	Baseline (1)	**Change** (2)
Cars	**5.56**	**0.92**
– *Lower travel frequency* (θ_s)		-1.53
– *Longer trips* (t_{ij})		3.00
– *Interaction*		-0.55
Public transports	**0.12**	**0.04**
– *Lower travel frequency* (θ_s)		-0.03
– *Longer trips* (t_{ij})		0.12
– *Interaction*		-0.05
All modes	**5.68**	**0.96**

- Magnitudes of rebound effect: distance/frequency 2 for car, 4 for public transport

CO2 Breakdown - Floorspace

	Baseline (1)	**Change** (2)
Commercial emissions	**0.370**	**-0.009**
– *Space* (H_i^k)		-0.082
– *Efficiency* (μ^k)		0.054
– *Composition* ($\{H_i^k\}$)		-0.025
– *Interaction*		0.043
Residential emissions	**0.305**	**-0.010**
– *Space* ($hg(\theta)$)		-0.028
– *Efficiency* (μ^k)		0.003
– *Composition* ($\{H_i^k\}$)		0.016
– *Interaction*		-0.001
Total	**0.675**	**-0.019**

- small uniform CO2 reductions for residential and commercial
- space effect mitigated by efficiency and composition effects

Conclusion

- Impact of **WFH on carbon emissions**.
- Multiple tradeoffs: commuting frequency/distance, space at office/home, transport mode choice.
- General equilibrium effect (markets for goods, labor, floorspace, and land).
- Additional: agglomeration effect, efficiency effects, composition effects.
- Own estimation of many parameters.
- Consideration of 3 transport modes.
- Important rebound effect.
- Quantitative spatial equilibrium applied to Swedish cities.

Thank you!

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Sectorial breakdown

Sector	π	π'	w	w'	θ	θ'	α	α'	ξ	ξ'
Agriculture	1%	2%	181.8	183.6	100%	70%	68%	68%	1.00	1.00
Artothers	5%	4%	212.5	161.9	100%	68%	79%	82%	1.00	1.00
Construction	7%	9%	307.5	305.2	100%	90%	91%	91%	1.00	1.00
Education	11%	11%	277.3	235.0	100%	79%	79%	81%	1.00	1.00
Finance	14%	10%	269.7	167.2	100%	49%	79%	85%	1.00	1.00
Healthsocial	15%	20%	263.5	272.9	100%	90%	79%	79%	1.00	1.00
Hotelrestau	4%	5%	163.1	166.7	100%	100%	79%	79%	1.00	1.00
Infocomm	3%	2%	357.0	145.5	100%	18%	79%	91%	1.00	1.00
Manufenergy	11%	12%	333.7	288.6	100%	77%	85%	86%	1.00	1.00
Publicadmin	6%	4%	335.1	194.6	100%	44%	79%	86%	1.00	1.00
Trade	12%	11%	257.7	209.2	100%	76%	79%	81%	1.00	1.00
Transport	5%	5%	275.2	255.3	100%	90%	79%	80%	1.00	1.00

Sensitivity analysis

Scenario	GHG Emissions Changes			Total SCC	Equivalent Variation
	Commuting	Residential	Commercial		
	MtonsCO2 (%)			BnSEK (%)	
	(1)	(2)	(3)	(4)	(5)
$\gamma = 8.2$, $\Psi = 0$, & $\bar{\xi} = 1$	+0.96	-0.01	-0.01	-1.13	-204.35
	+17.0%	*-3.3%*	*-2.6%*	*-0.1%*	*-15.0%*
$\gamma = 4$, $\Psi = 0$, & $\bar{\xi} = 1$	-0.52	-0.02	-0.02	+0.67	-201.47
	-9.2%	*-5.3%*	*-4.6%*	*+0.0%*	*-14.8%*
$\gamma = 8.2$, $\Psi = 0$, & $\bar{\xi} = 1.1$	+0.99	-0.01	-0.01	-1.16	-176.44
	+17.3%	*-2.0%*	*-3.6%*	*-0.1%*	*-13.0%*
$\gamma = 4$, $\Psi = 0$, & $\bar{\xi} = 1.1$	-0.53	-0.01	-0.02	+0.68	-174.54
	-9.4%	*-4.1%*	*-4.7%*	*+0.0%*	*-12.9%*
$\gamma = 8.2$, $\Psi = 0$, & $\bar{\xi} = 1.2$	+1.02	-0.00	-0.02	-1.20	-148.80
	+17.9%	*-0.7%*	*-4.5%*	*-0.1%*	*-11.0%*
$\gamma = 4$, $\Psi = 0$, & $\bar{\xi} = 1.2$	-0.54	-0.01	-0.02	+0.68	-147.78
	-9.5%	*-2.8%*	*-4.9%*	*+0.1%*	*-10.9%*
$\gamma = 8.2$, $\Psi = 0$, & $\bar{\xi} = 2$	+1.40	+0.03	-0.02	-1.69	+61.54
	+24.7%	*+9.7%*	*-6.5%*	*-0.1%*	*+4.5%*
$\gamma = 4$, $\Psi = 0$, & $\bar{\xi} = 2$	-0.55	+0.02	-0.02	+0.66	+61.08
	-9.7%	*+7.3%*	*-6.0%*	*+0.0%*	*+4.5%*
$\gamma = 8.2$, $\Psi = 0$, & $\bar{\xi} = 0.9$	+0.95	-0.01	-0.01	-1.12	-232.53
	+16.8%	*-4.6%*	*-1.4%*	*-0.1%*	*-17.1%*
$\gamma = 4$, $\Psi = 0$, & $\bar{\xi} = 0.9$	-0.51	-0.02	-0.02	+0.66	-228.56
	-9.0%	*-6.5%*	*-4.4%*	*+0.0%*	*-16.8%*
$\gamma = 8.2$, $\Psi = 1$, & $\bar{\xi} = 1$	+0.98	-0.01	-0.01	-1.16	-189.13
	+17.3%	*-2.5%*	*-2.6%*	*-0.1%*	*-13.9%*
$\gamma = 4$, $\Psi = 1$, & $\bar{\xi} = 1$	-0.53	-0.01	-0.02	+0.67	-186.56
	-9.3%	*-4.5%*	*-4.5%*	*+0.0%*	*-13.7%*

Commuting shares

Table: Commuting Mode Share by Area Type (in million trips and %)

Area Type	**Walk/Bike**	**Car**	**Public Transp.**	**Total Trips**
Number of Trips (in millions)				
City over 200,000	1 318.98	1 245.47	759.00	3 323.44
Commuter suburb to a city	739.84	1 896.17	397.94	3 033.95
Larger town (50,000–200,000)	2 203.90	3 749.51	430.37	6 383.78
Other	2 044.55	5 134.56	241.36	7 420.48
Share of Trips (%)				
City over 200,000	39.7%	37.5%	22.8%	100%
Commuter suburb to a city	24.4%	62.5%	13.1%	100%
Larger town (50,000–200,000)	34.5%	58.7%	6.7%	100%
Other	27.6%	69.2%	3.3%	100%

Speed

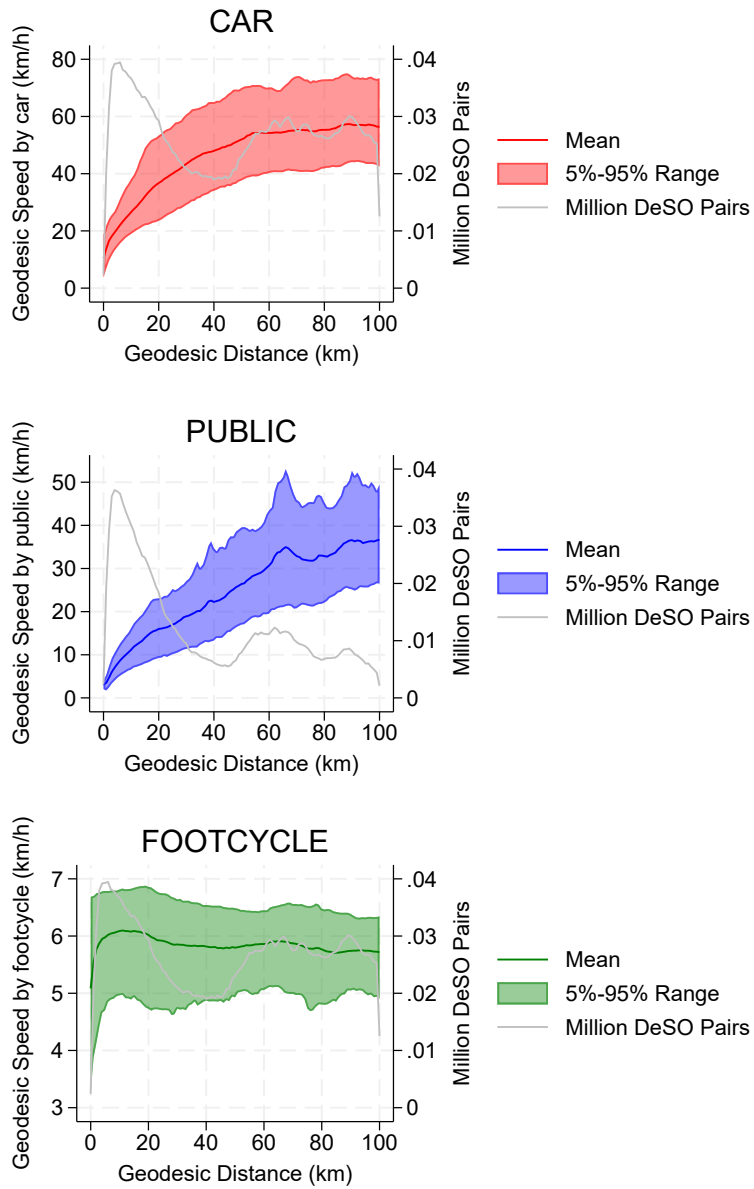

Figure: Speed per commuting mode up to 100km