THE HEBREW UNIVERSITY OF JERUSALEM

Modelling the effect of remote and hybrid working on the urban equilibrium

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Increase of remote work changes residents' expectations for home location

In 2022 **29%** of Full Paid workdays were performed at home according to the OECD and CHP US Survey.

Consequences of remote work for urban equilibrium

- Higher requirements for home conditions
- Decreased significance of commute time to work
- Local accessibility matters - 15 min city

Evidence from academic papers

9% of population and 16% of businesses have moved out of the centers of large cities over the first two years of the pandemic on top of pre-pandemic trends

- Ramani A, Bloom N. (2021). The Donut Effect of Covid-19 on Cities. NBER, Working Papers 28876, National Bureau of Economic Research, Inc

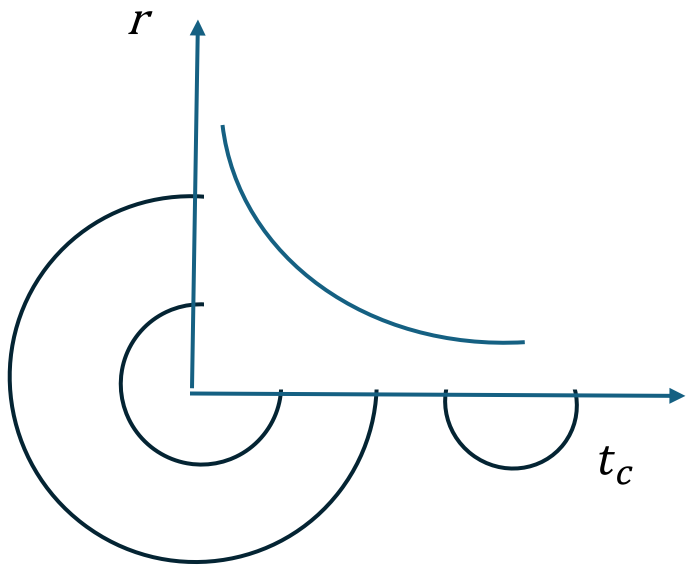
Research Question

- What are the effects of remote and hybrid working on the urban equilibrium and how can different neighborhoods adapt to this change to ensure long-term economic prosperity?

Theoretical background

Monocentric model in agglomeration

With distance from the CBD, rent decreases and commute cost increases



Individual utility function

$$U_i = f(s_i, q_i, t_c)$$

s_i – *composite good,*

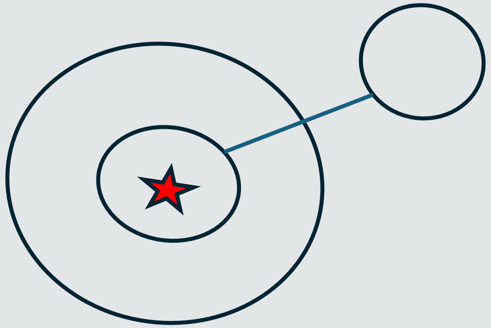
q_i – *size of housing, sq.foot*

t_c – *time to CBD*

r – *rent per sq. foot*

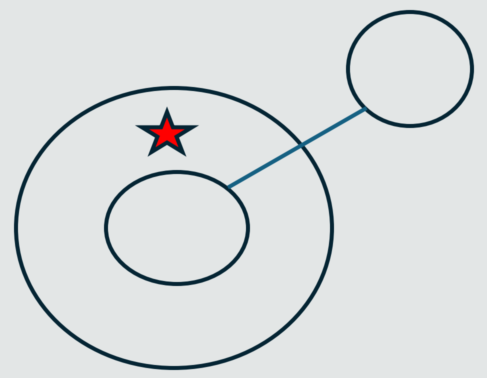
Central business district, N1

- Residents don't commute, t_c^1=0
- Large diversity of amenities (A^1)
- More workers than residents, $z_1 > g_1$
- High rent price per sq m (r^1)
- Small-sized apartments (q^1)

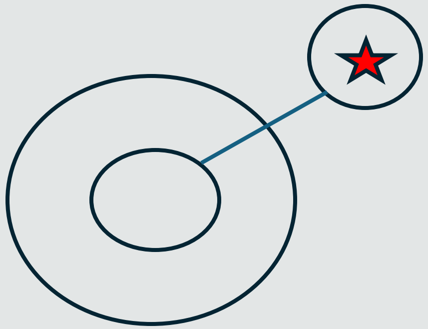


Residential neighborhood with limited local accessibility, N2

- Low rent price per sq m (r^2)
- Large-sized apartments (q^2)
- No white-collar workers
- Average accessibility to CBD (t_c^2)
- Few amenities available (A^2)



Small urban locality – satellite city, N3



- Low rent price per sq m (r^3)
- Average sized apartments (q^3)
- Average availability of amenities (A^3)
- Less white-collar workers than residents, $z_3 < g_3$
- Low accessibility to CBD (t_c^3)

Normal conditions

- **Implementing amenities into individual budget constraint**

Accessibility of amenities

$$\underset{\text{Income}}{Y_i} = \underset{\text{Disposable income}}{S} + q_i * \exp\underbrace{\left(\alpha + x_1 A_n + x_2 \left(A_{CBD} * \left((1-h)t_c\right)^{-k}\right)\right.}_{\text{Hedonic rent }(R)}\Big)_n + \underset{\text{Commuting cost}}{C_n}$$

- **Spending is explained through disposable income and time constraint**

$$\underset{\text{Spending}}{K} = \underbrace{(T - t_c(1-h_n) - t_w)}_{\text{Leisure time }(t_l)} * \underset{\text{cost of amenity per hour}}{\left(\frac{p}{f}\right)}$$

- **Demand for local services equals supply in the neighborhood**

$$\underbrace{z^n(1-h^n)K_W^n}_{\text{Workers total spending}} + \underbrace{g^n h K_H^n}_{\text{Residents total spending}} = \underset{\text{Number of amenities}}{A_n} * p$$

$n \in (1,2,3)$ – *neighborhood index*

Y_i = *income*

S_i = *disposable income*

p = *price of LCS(amenity)*

k, α - *coefficients*

C = *weekly commuting cost*

$(1-h)t_c$ = *weekly commute time*

K_i = *amenities spending*

B^n = *total spending on amenities*

z^n = *number of workplaces*

g^n = *number of residents*

WFH consequences

WFH assumptions

- Work time and office location do not change: $t_w = t_w^{WFH}, Y^{WFH} = Y$
- New commuting time approaches 0: $\lim_{h_{WFH} \to 1} t_c * (1 - h_{WFH}) = 0,$
  $\Delta h = h_{WFH} - h > 0$

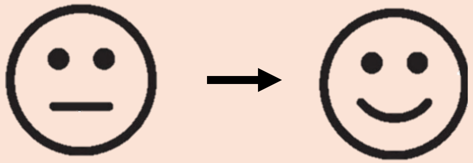
$* \; h = avg\ share\ of\ workdays\ performed\ at\ home\ per\ week$

With lower commuting time, there is a new urban equilibrium with a higher individual's utility that can be reached within the same budget

$$U^{WFH} = f(s, q, t - \Delta t) > U$$

$$\Delta U = U - U^{WFH} > 0$$

People should become happier!



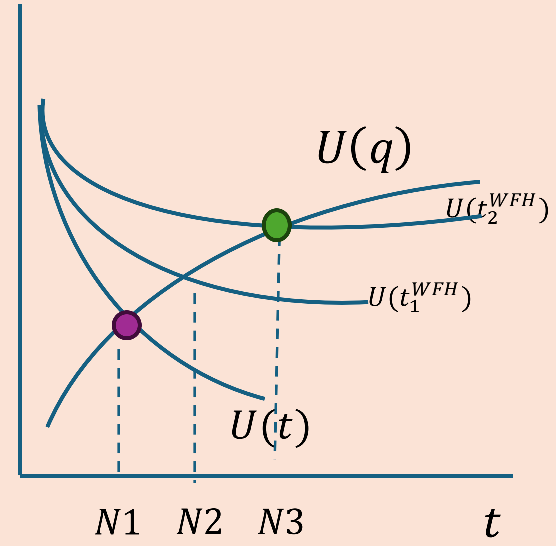
Outcomes for Residents of different neighborhoods

Neighborhood	Changes	Reaction
N1	$t_c = t_c^{WFH} \Rightarrow \Delta U = 0$	Move to neighborhoods 2-3: $r_n^{WFH} < r_n \mid t_c^{WFH} = t_c = 0$
N2	$t_c^{WFH} < t_c \Rightarrow \left\{ \begin{matrix} t_l^{WFH} > t_l \\ (A_{CBD} * t_c < (A_{CBD} * t_c^{WFH}) \end{matrix} \right\}$	Move to neighborhood 3: $r_n^{WFH} < r_n$ $\Delta A_N = A_{CBD} * \Delta t_c$
N3	$t_c^{WFH} < t_c \Rightarrow \left\{ \begin{matrix} K_i^{WFH} < S^{WFH} \\ A_N^{WFH} \sim A_N^n \end{matrix} \right\}$	Stay in the neighborhood 3: $r_n^{WFH} < r_n$ $K^{WFH} > K$

K – spendings
S – Disposable income
r - rent per sq. foot

$*$ *h - avg share of workdays performed at home per week*

Simulation of new residential choice



$$h_1^{WFH} < 1 \Rightarrow N2$$

$$h_2^{WFH} = 1 \Rightarrow N3$$

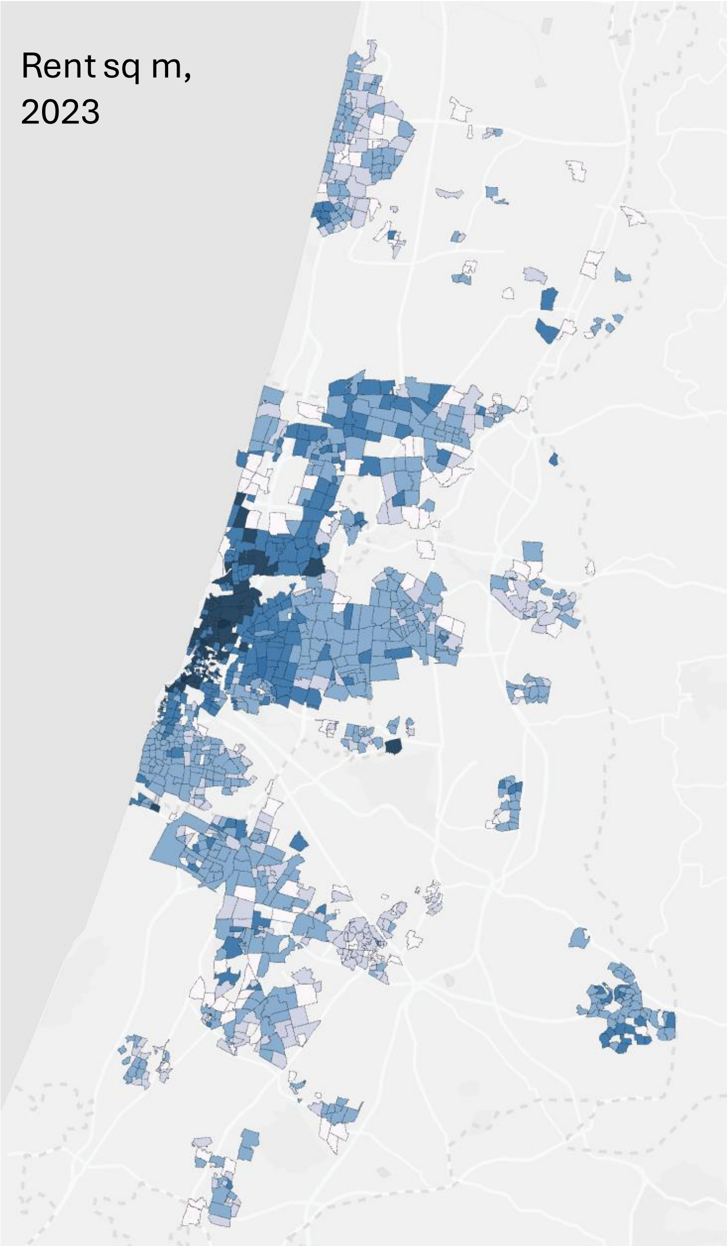
Outcomes of WFH for neighborhoods

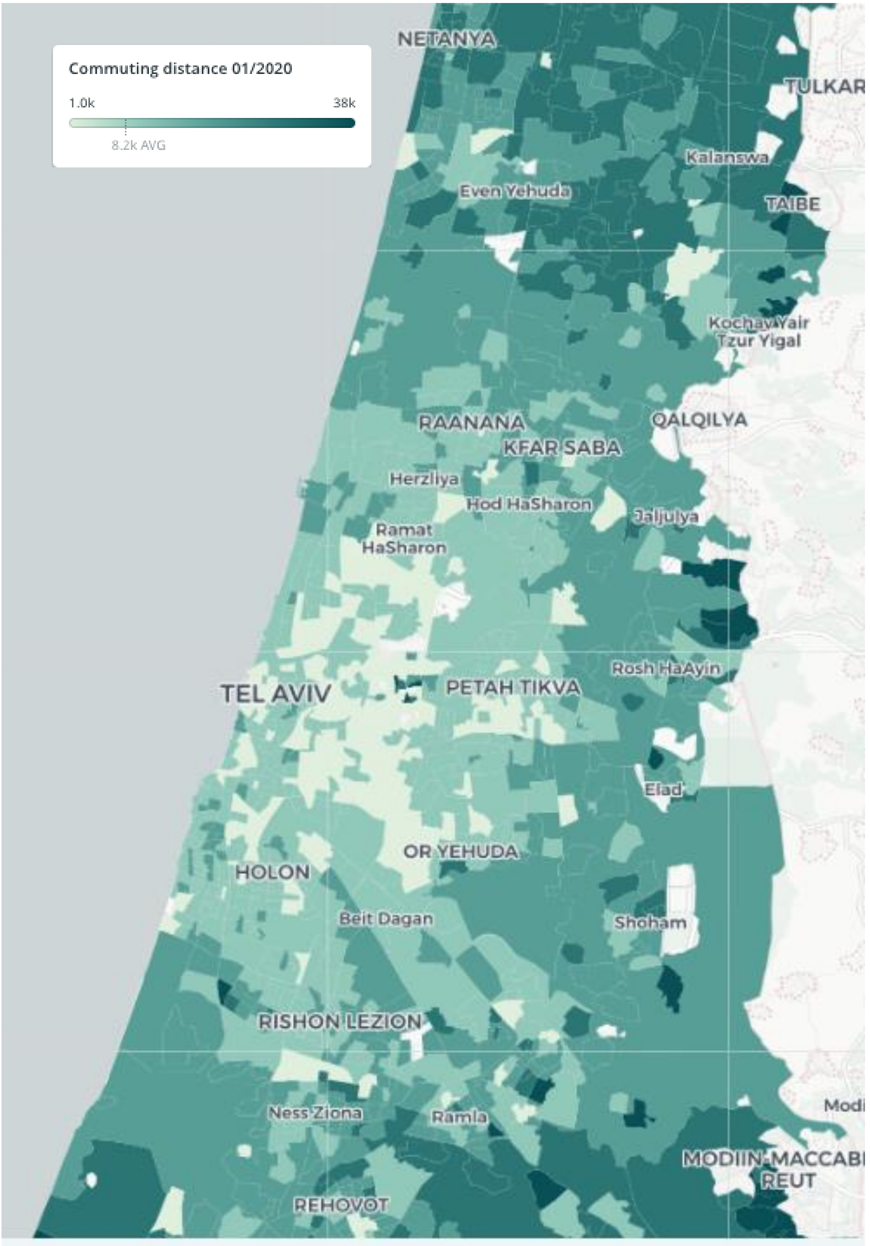
VARIABLE	NEIGHBORHOOD I	NEIGHBORHOOD II	NEIGHBORHOOD III
RENT	high impact	low impact	low impact
HOUSING CONDITIONS	high impact	low impact	high impact
AMENITIES	low impact	high impact	average **impact**

Empirical study

Part I. Estimating remote working level

Gush Dan has monocentric structure



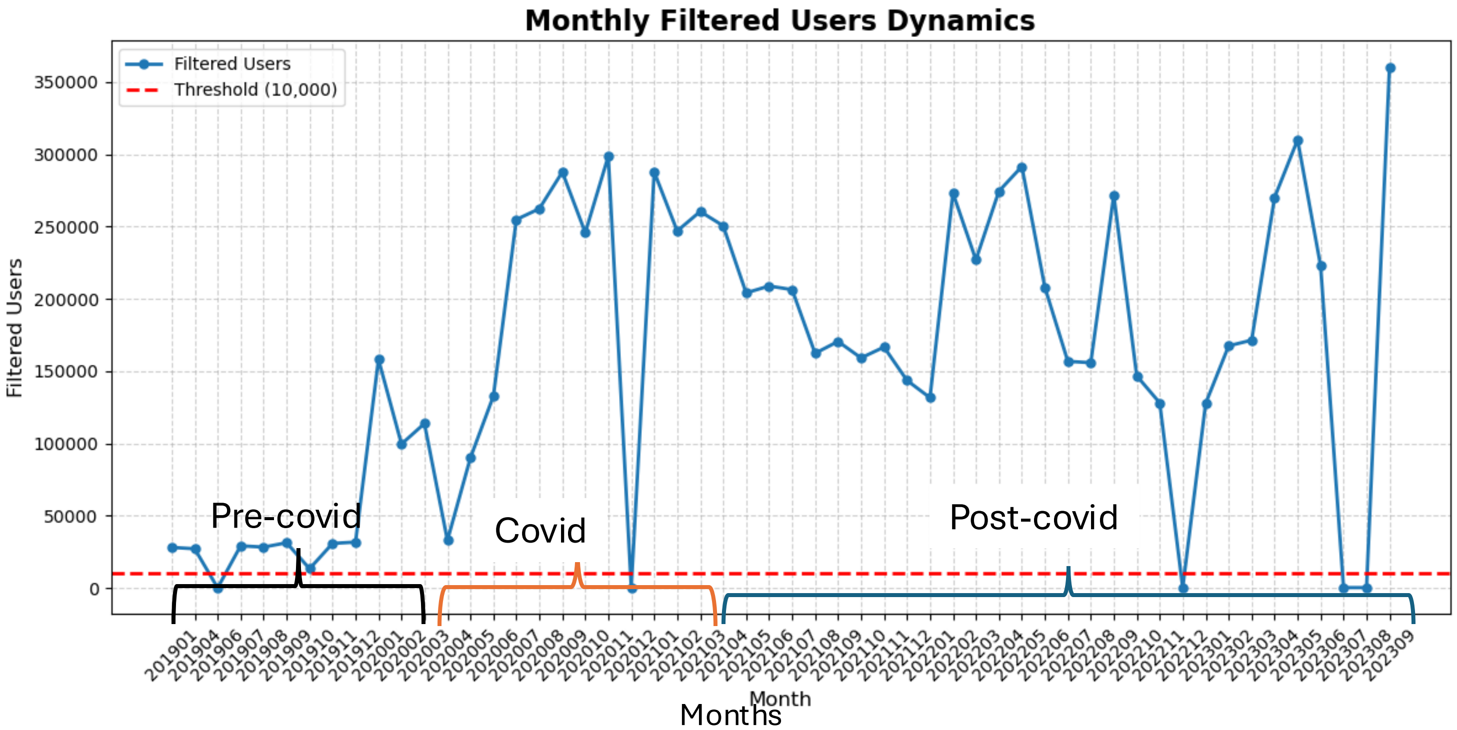


The commuting matrix, together with rental prices in Gush Dan, reveals its monocentric structure

Mobility data by Habidatum

identifier	identifier_type	local_date_time	classification	duration_seconds	centroid_latitude	centroid_longitude	bump_count
69cfacfa-d63c-4ae4-a5a8-d5a24a5b1019	IDFA	2020-01-03 17:43:43	AREA_DWELL	12314.0	31.787835	34.720584	9
6808df5f-741d-42bc-a9cf-62d51ff2a5f2	GAID	2020-01-15 13:24:47	AREA_DWELL	1540.0	31.801218	34.760400	13
7f1a74df-41c0-4463-98f7-34c46bbbe20b	GAID	2020-01-15 19:37:12	AREA_DWELL	1550.0	31.799680	34.760477	5
bf725105-a026-4c90-bafa-a098a3818213	IDFA	2020-01-15 15:16:43	AREA_DWELL	10372.0	31.779110	34.702775	60

Monthly number of users in pre-filtered dataset



Sample description

Size: 120M rows (64 GB)

Time interval: 01/2019 -09/2023

Penetration: 5% of population (2022)

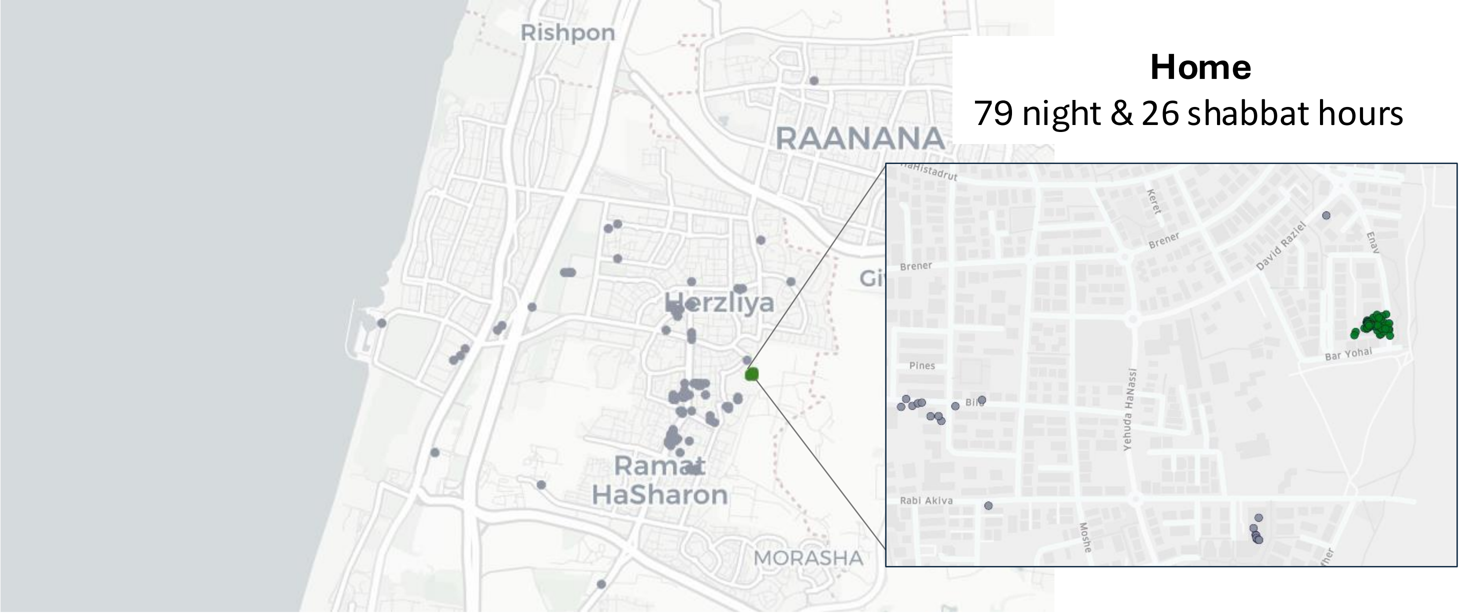
Basic filters (monthly)

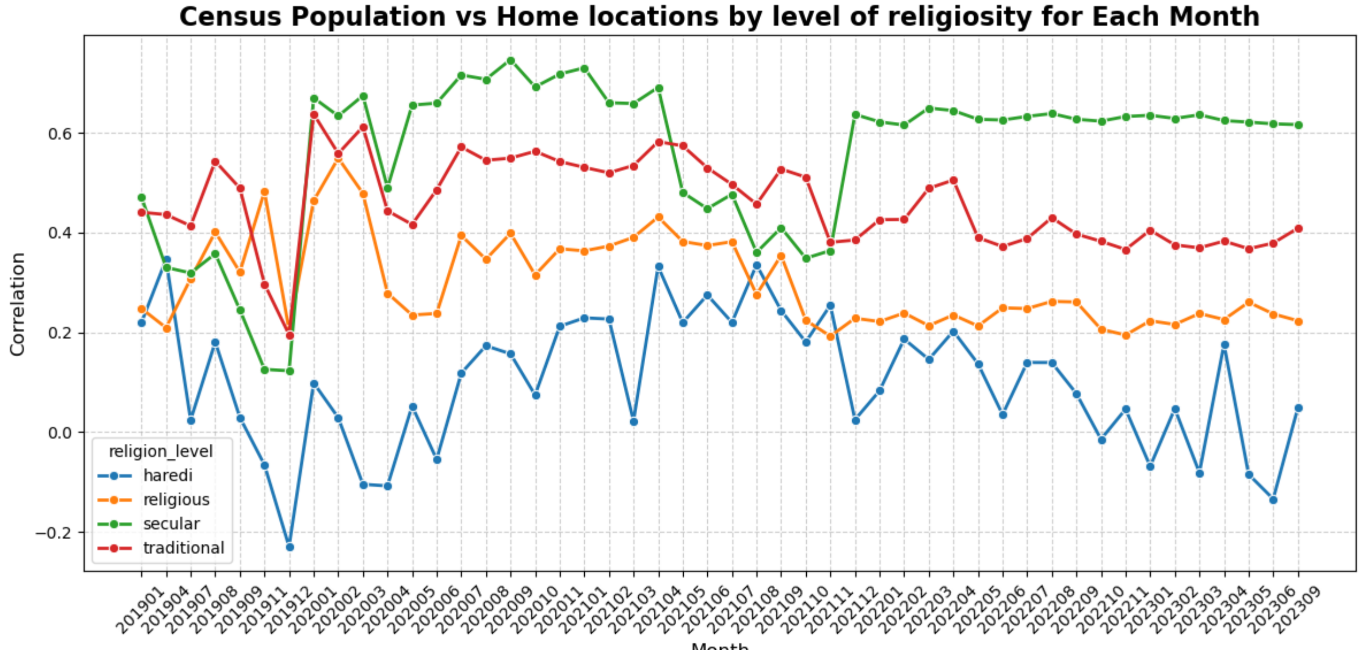
- ✓ User occurs at least 4 times
- ✓ Dwells coordinates are inside GushDan
- ✓ At least 20 K users after applying two first filters

Approach I

Remote work – staying at home during work hours

Identification of home locations





Home location detection

- At least 2 hours between 8pm and 9 am
- At least 1 signal on Shabbat
- Place with the highest number of night + Shabbat signals that satisfy these criteria

Validation

- Monthly correlation between census population and home locations across statistical areas is **0.57**
- The probability of a home being attributed to a non-residential building is less than **2%.**

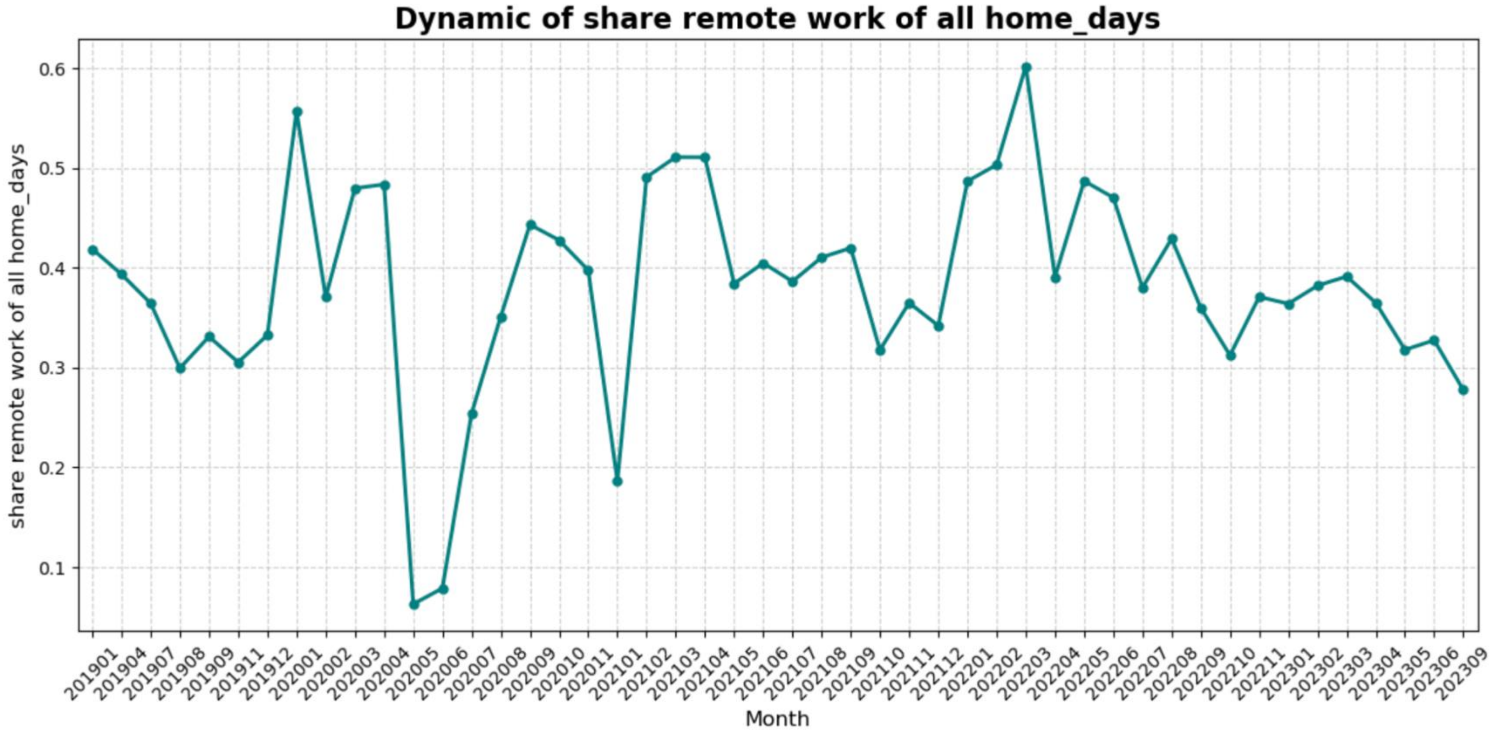
Identification of remote work using only home location. Bad results ☹

Expected:

In Covid Lockdown periods number of days with work hours at home increase significantly

Reality:

May 2020(1st Lockdown) and January 2021 (3rd lockdown) show the lowest level of days with work hours at home

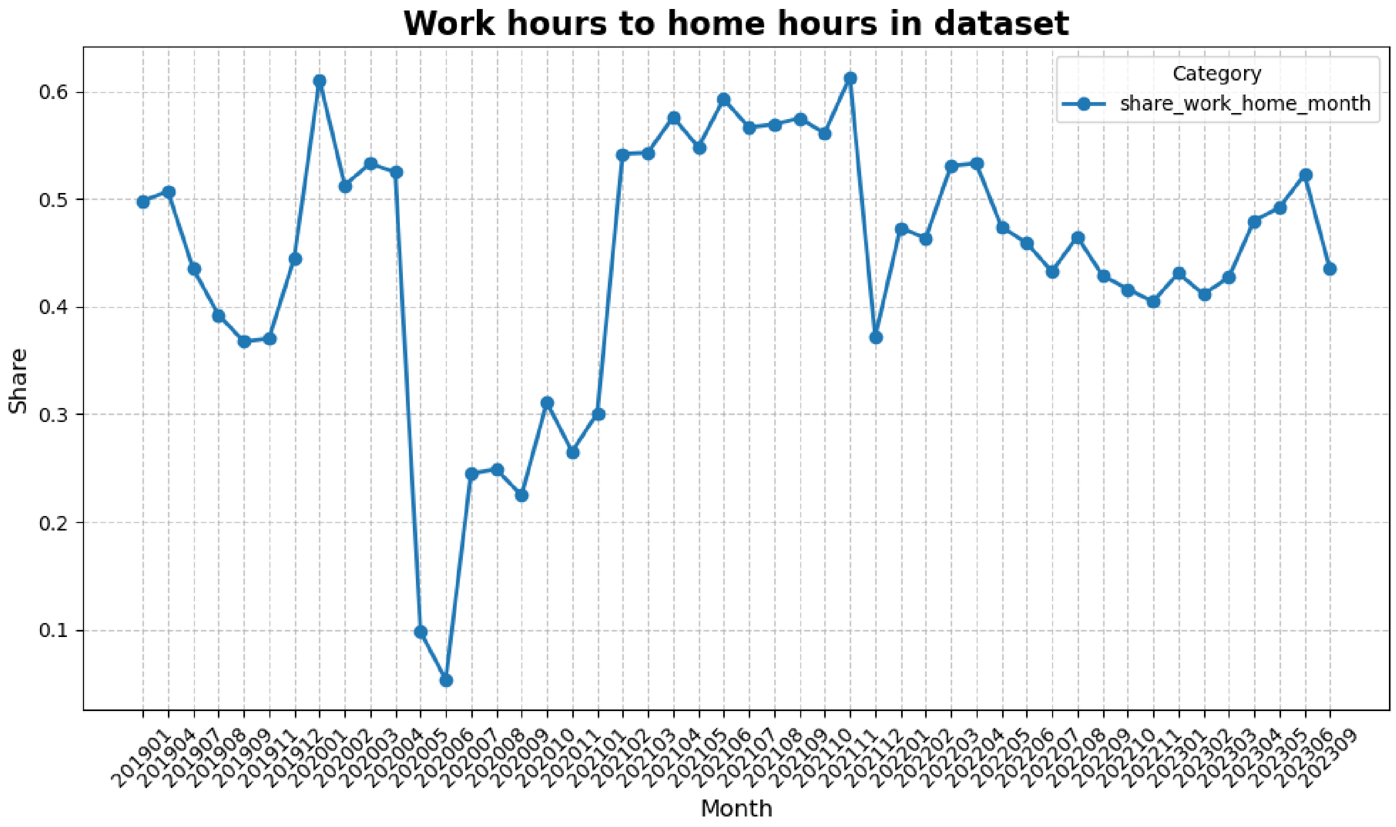


$$Remote\ Work\ ratio =$$

$$avg\left(\frac{\sum(1_{work\ hours} * 1_{home\ location})}{\sum(1_{home\ location})}\right)$$

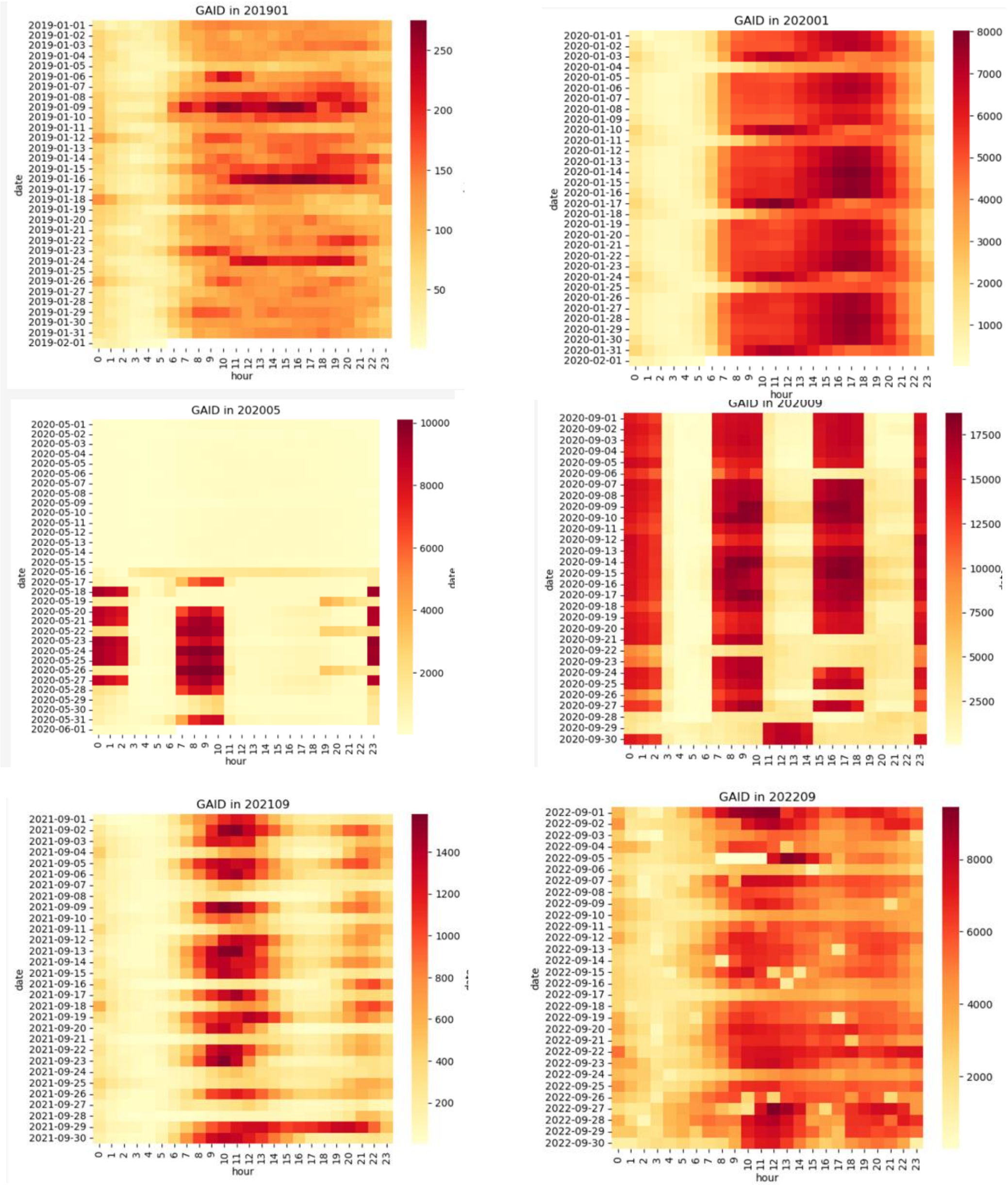
$$Work\ hours\ - 09:00 - 19:00$$

Wrong assumption: we believe that ratio of work hours to home hours is constant



In some months, especially, during the Covid-19 lockdowns we have only home hours signals

Wrong assumption: we believed that each month have similar signals distribution across days and hours



Frequency of signals changes between months, days and hours

Approach II

Remote work – staying at home during times when the probability of being at work is higher than at any other place on days when they do not come to the office."

Steps

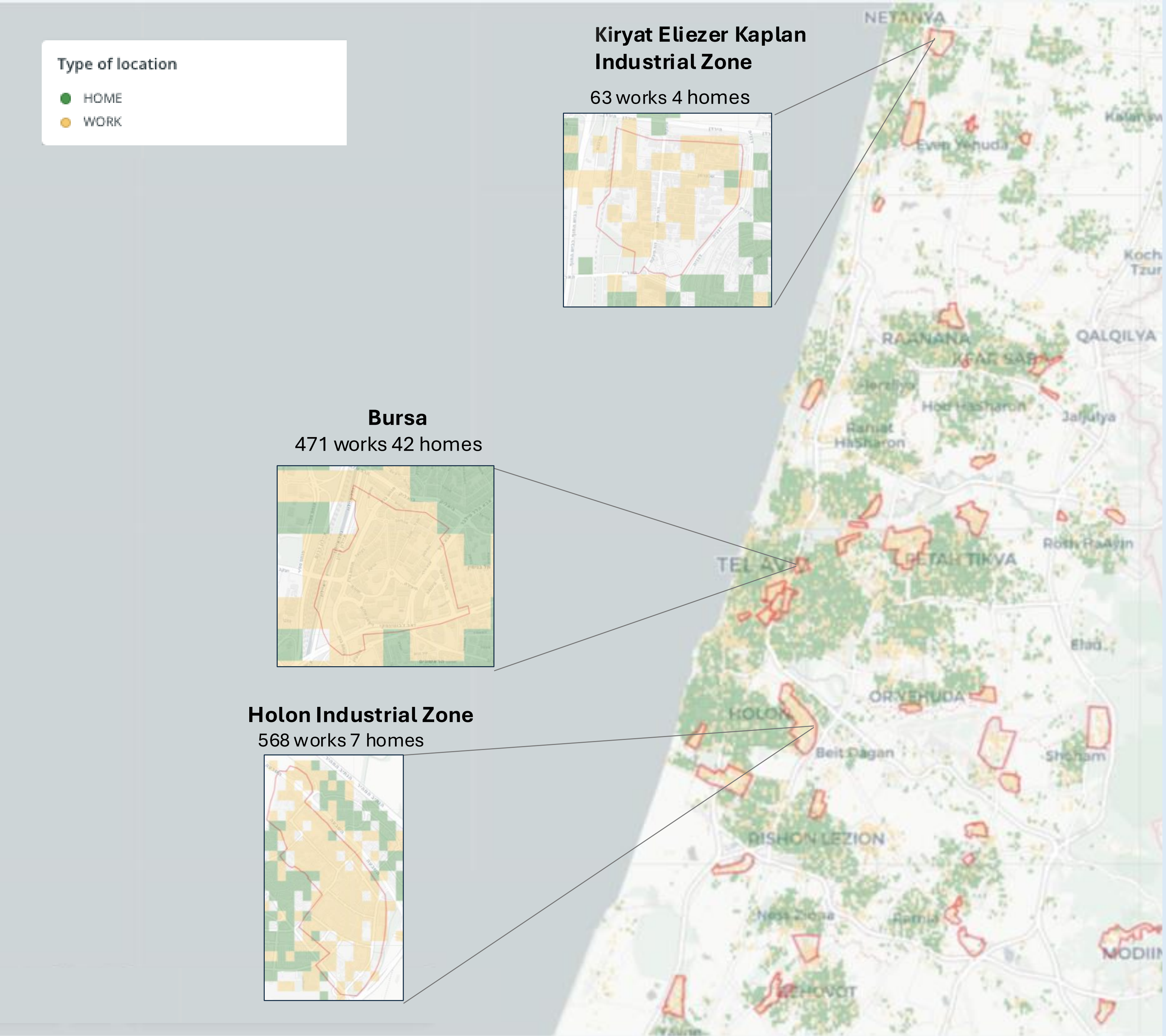
1. Exclude months with distorted signals distribution

2. Find work locations in each month

3. For each hour and individual find probability to be at work, home and 3rd place

4. Conclude WFH for each day and user

5. Calculate monthly share of remote work days



Work location detection

- No signals on weekends
- At least 3 hours and two days
- At least 1km from home
- Place with the highest number of signals that satisfy these criterias

Work location vs real work zones

Real work zone	Estimated work location	Share
	FALSE	69%
FALSE	TRUE	31%
	TRUE	96%
TRUE	FALSE	4%

Identifying remote work at a specific hour using conditional probability

P(O|h) = (P(O)*P(h|O))|P(h) - probability to be at office at exact hour between 8 am and 7 pm

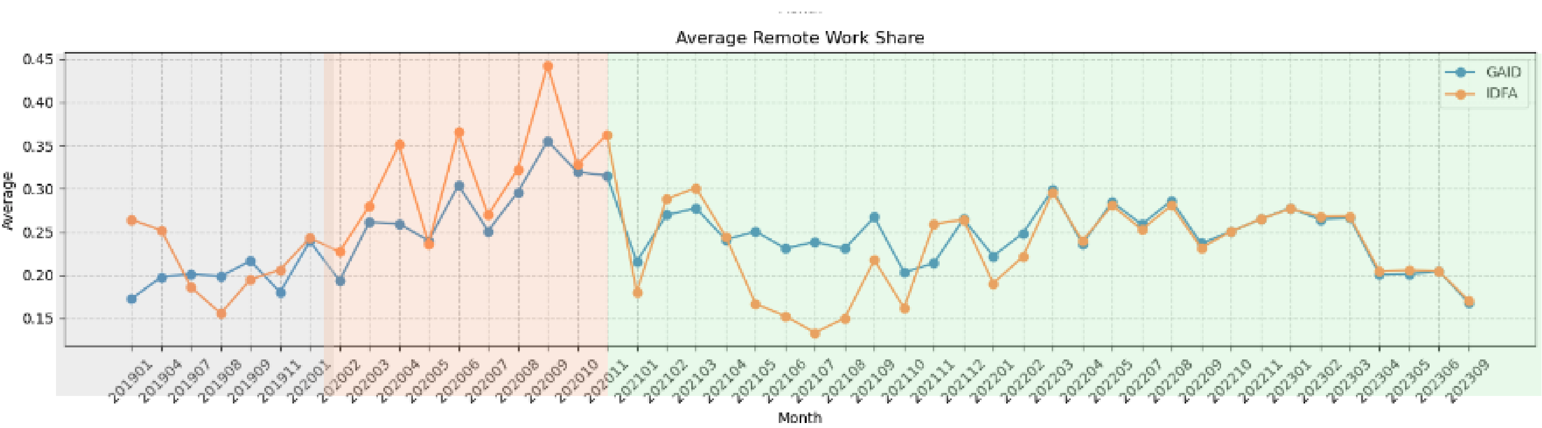
- P(O) - share of office location hours in the office days
- P(h) - share of exact hour in the office days.
- P(h|O) - share of exact hour at office location in the office_days

P(H|h), P(oth|h) are calculated by analogy

$$\textbf{Flag Remote work} = \frac{\sum(\mathbf{1}_{P(O|h)>P(H|h)} \cdot \mathbf{1}_{P(O|h)>P_{oth|h}} \cdot \mathbf{1}_{home\ location})}{\sum(\mathbf{1}_{home\ location})}$$

Monthly share of remote work days

$$Remote\ Work\ ratio = avg(\frac{\sum(1_{remote\ work\ day})}{\sum(1_{work\ day})})$$



Individual's remote work day $(1_{work\ day})$ **:**

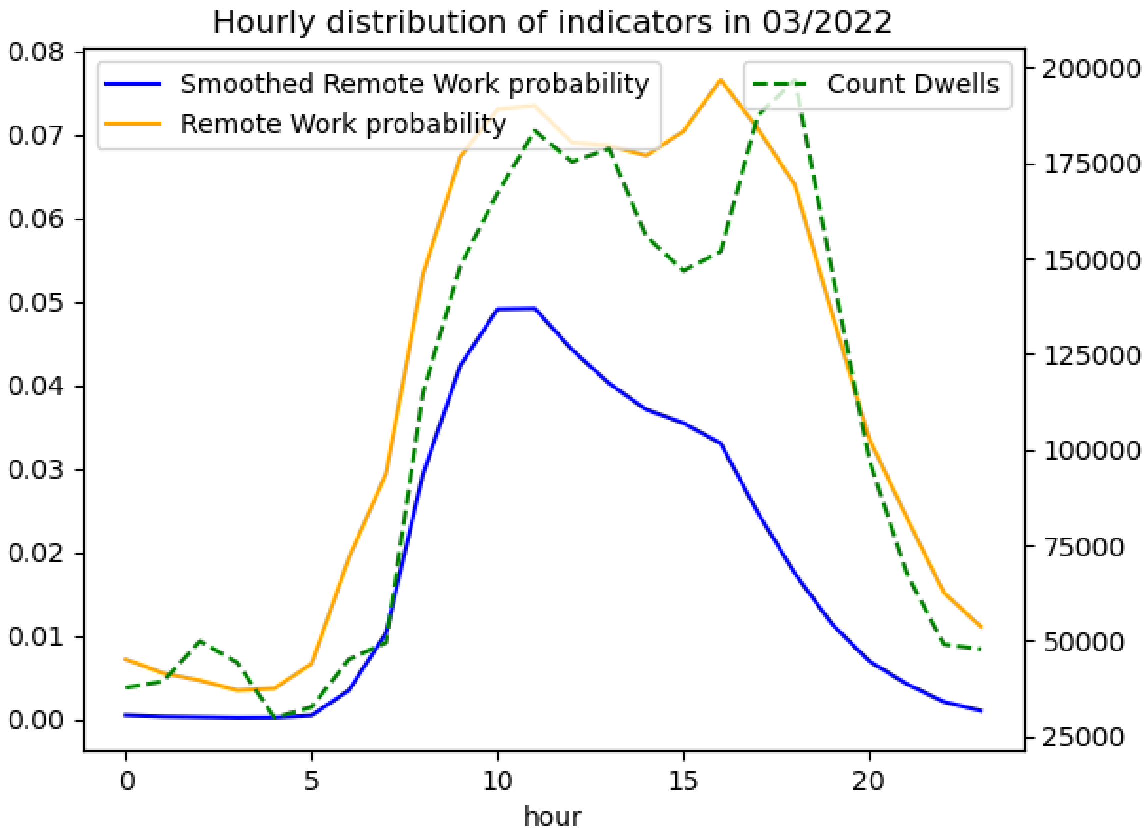
- Day where at least for one hour flag remote work =1
- Non weekend/holiday
- Day with 0 office signals

Individual's Work day $(1_{remote\ work\ day})$ **:**

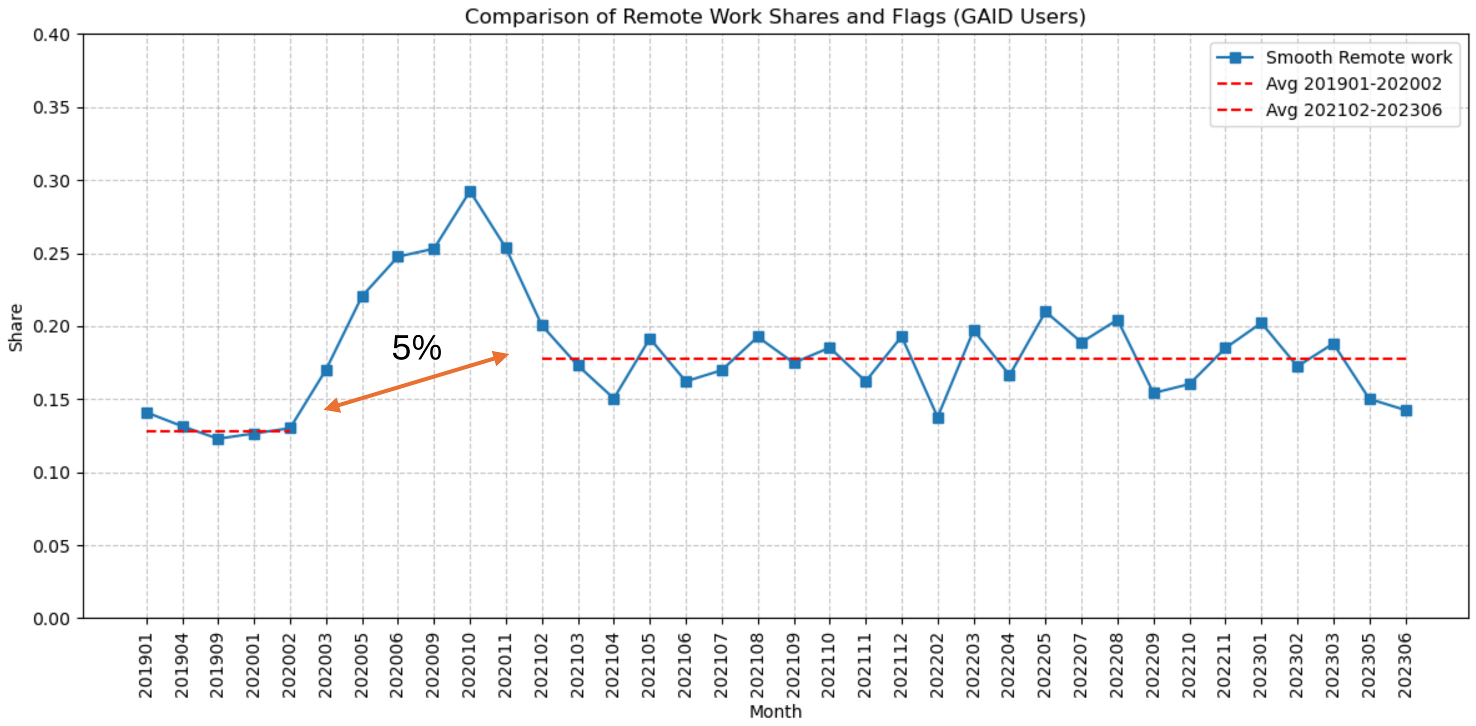
- Day where $\sum(\mathbf{1}_{P_w>P_H} \cdot \mathbf{1}_{P_w>P_{oth}}) > \mathbf{0}$
- Non weekend/holiday day

Improvement: Smoothing conditional probability

Smoothed remote work = Flag Remote work * P (W)



Monthly share of smoothed remote work days



Additional evidence of correct identification

False “remote work” days