Mixing by Patch & Age with Recurrent Mobility for COVID-19

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Motivation & Background

Research Question

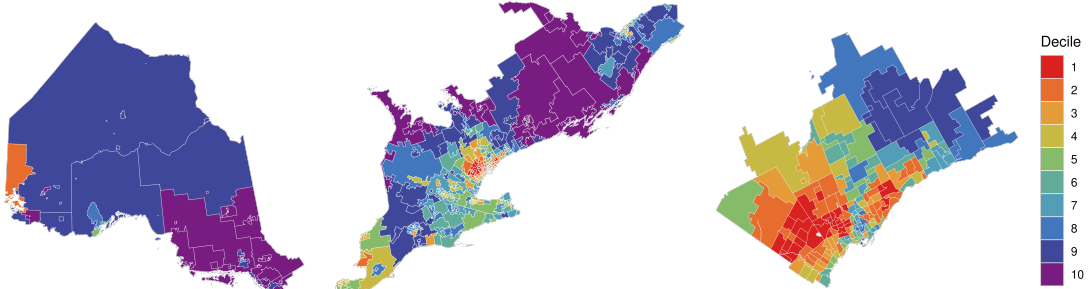
Research Question

Impact of **hotspot** vs **non-hotspot** COVID-19 vaccine prioritization in Ontario

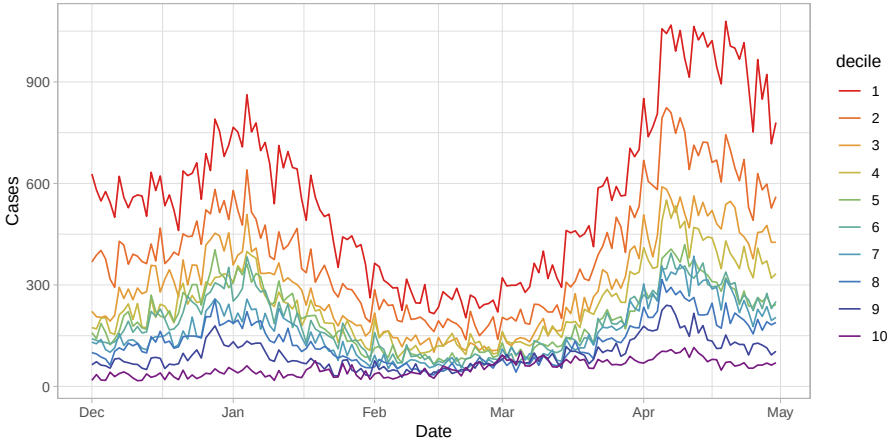
Transmission Model

- 513 FSA (first 3 postal code digits) $\rightarrow$ **10 deciles** by cumulative cases
- **12 age** groups: [0-11, 12-15, 16-39, 40-44, ..., 75-79, 80+]
- **4* contact types**: household, school, work, other
- COVID-19 stuff ...

Ontario FSA, stratified by deciles of cumulative COVID-19 incidence



Covid-19 incidence by deciles (FSA): consistent differences



Objective

Develop a **mixing matrix** (# contacts formed & with whom) stratified by:

- self decile, g
- self age, a
- other decile, g'
- other age, a'
- contact type, y
- calendar month, t

Dimensions: $10 \times 12 \times 10 \times 12 \times 4 \times t$

Methods Overview

1. Mobility Patterns: $gg't$
2. Age Mixing: $aa'y$
3. Integrated Age & Mobility Mixing: $gag'a'yt$

Mobility Matrix

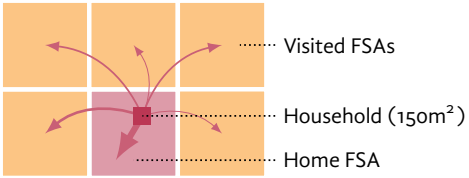
Mobility Data

~ 2 % Ontario devices, Jan–Dec 2020

Define:

- **Household**: ~ 150m² tile with most evening time per month
- **Home FSA**: FSA n containing Household
- **Visited FSA**: 2+ hours in another FSA n'
- **Away Time:** % time outside Household stratified by Home vs Visited FSA

Repeat for each month t



Mobility Metrics, by FSA n and Month t

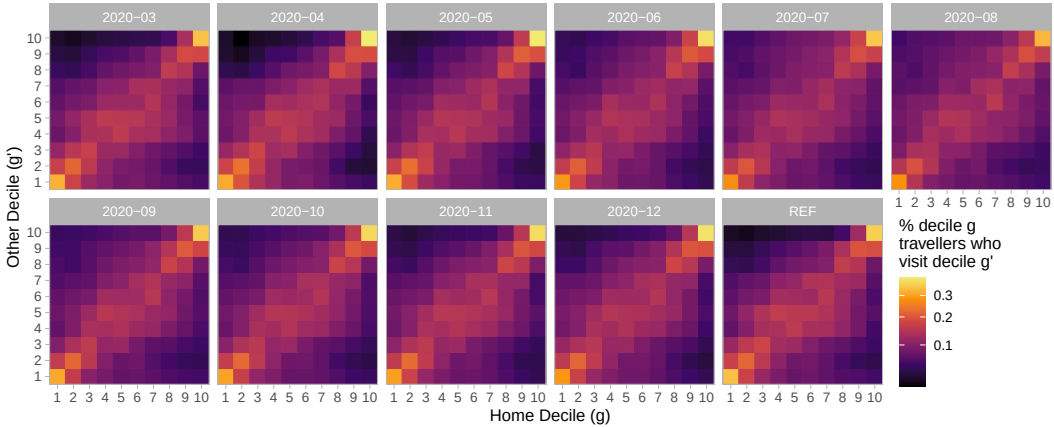
Inter-FSA Mobility, conditional probability of destination n': $B^c_{nn't} = \frac{V_{nn't}}{\sum_{n'} V_{nn't}}$

Relative Time Away (TA) from home, vs reference t_0: $\rho_{nt} = \frac{TA_{nt}}{TA_{nt_0}}$

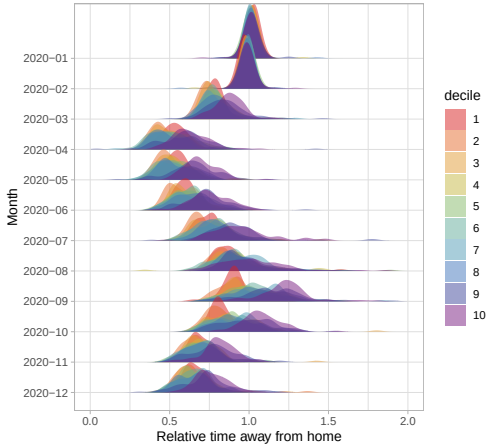
Proportion Time Away in Home FSA of total Time Away: $\phi_{nt} = \frac{TA^{(h)}_{nt}}{TA_{nt}}$

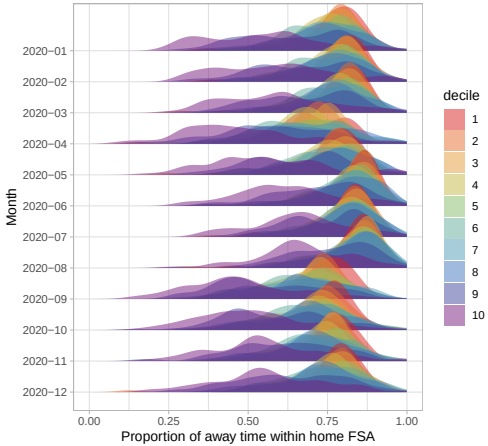
Later: aggregate from FSA $n \to$ decile g

Mobility Metrics: Inter-FSA Mobility



Mobility Metrics: Time Away

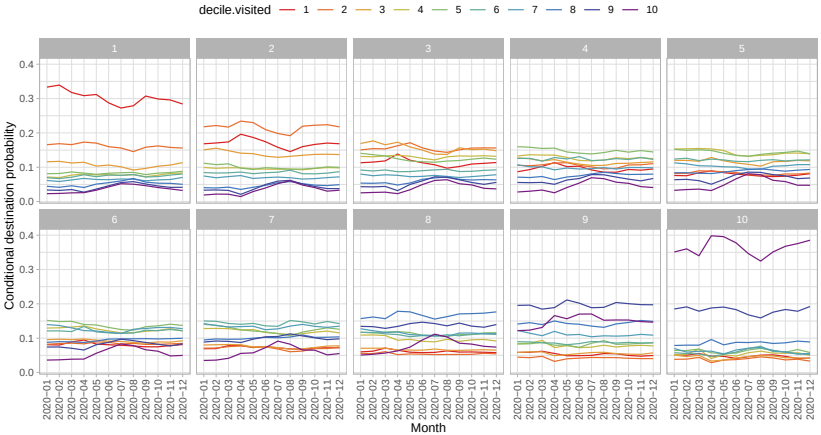




Mobility Matrix: Equation

$$B_{gg't} = \underbrace{\rho_{gt}}_{\text{overall mobility}} \Big[\underbrace{(\phi_{gt})\,\delta_{gg'}}_{\text{intra-decile}} + \underbrace{(1 - \phi_{gt}\,B^{c}_{gg't})}_{\text{inter-decile}} \Big]$$

Does inter-FSA mobility $B^c_{gg'}$ change by month?



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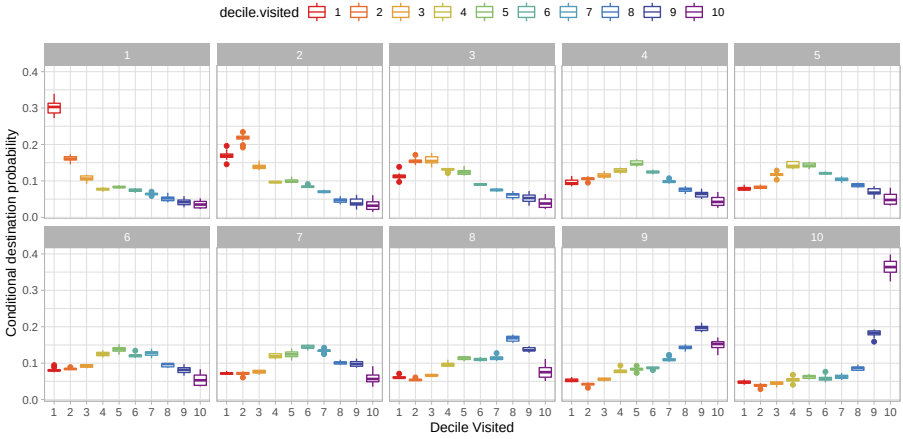
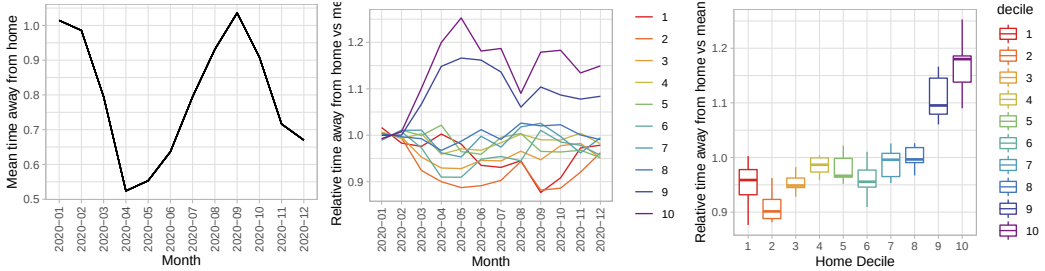
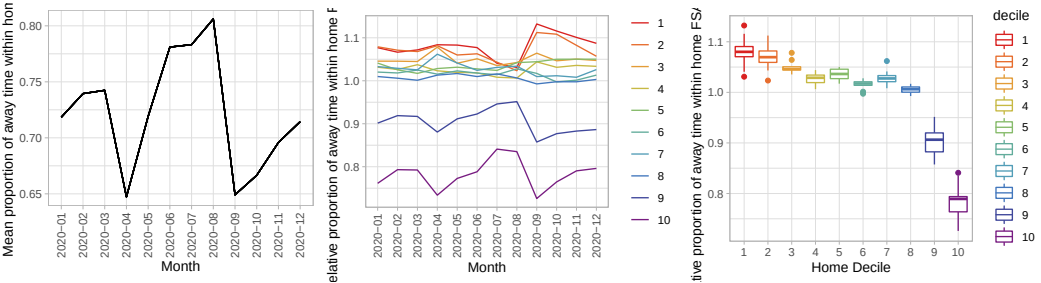


Does overall time away per decile ρ_g change by month?



Does % time away within home FSA per decile ϕ_g change by month?



Mobility Matrix: Equation with 1 (or 2) inputs: ρ_t (ϕ_t)

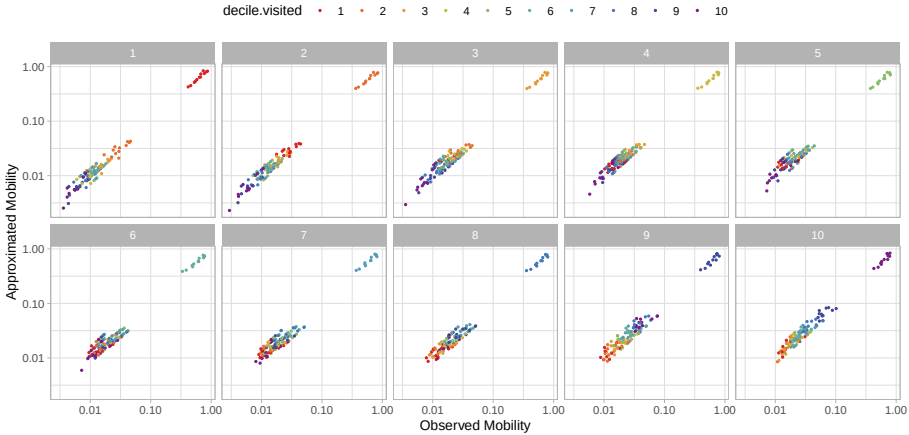
Required: ρ_t, mean overall population mobility (TA vs t_0)

Optional: ϕ_t, proportion of TA within home FSA

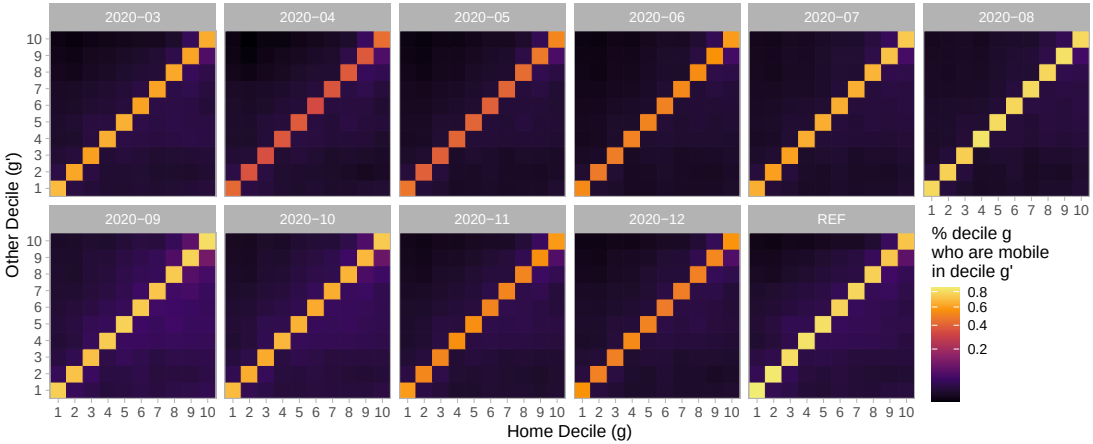
$$B_{gg't} = \rho_t \, R_g^{\rho} \Big[\left(\phi_t \, R_g^{\phi} \right) \delta_{gg'} + \left(1 - \phi_t \, R_g^{\phi} \, B_{gg'}^{c} \right) \Big]$$

$\rightarrow$ for projecting beyond available data

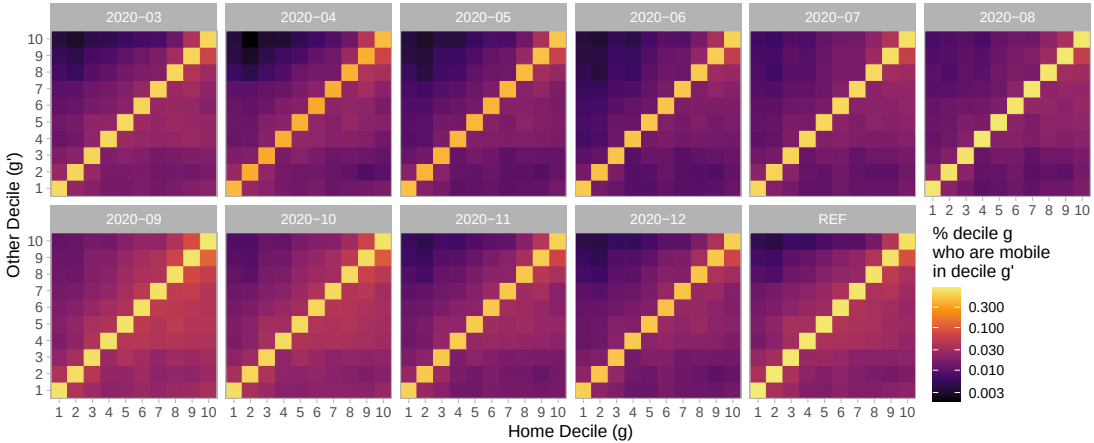
Mobility Matrix: 1-input Approximation vs Observed



Mobility Matrix



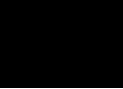
Mobility Matrix (log scale)



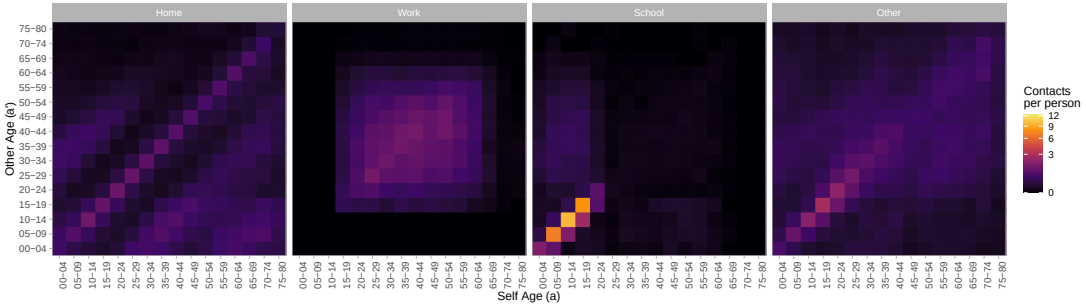
Mobility Matrix: Comment

- Inter-FSA mobility mainly with similar deciles ($B^c_{gg'}$, clustered near diagonal)
- Most % time away from household within Home FSA ($\phi \approx 0.7$)
- Lowest incidence deciles ($g = 9, 10$):
  - Least mobility reduction (largest R^ρ_g)
  - Most time outside Home FSA (smallest R^ϕ_g)

Age Mixing



Prem et al (2021): POLYMOD projected onto 177 countries, incl. Canada



Open source: `github.com/kieshaprem/synthetic-contact-matrices`

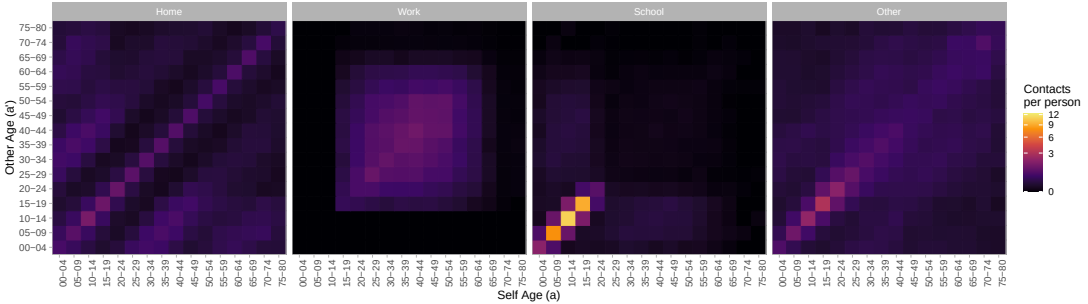
Age Mixing, Challenge 1: contacts don't "balance"

Solution

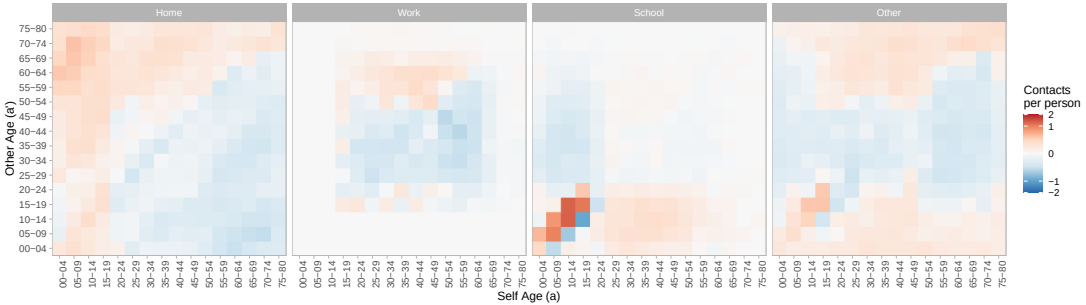
Un-weight by Prem 2021 age group sizes P_a: $C^u_{aa'y} = C_{aa'y}\frac{\bar{P}}{P_{a'}}$

Enforce Symmetry by averaging with transpose: $C^{ub}_{aa'y} = \frac{1}{2}\left[C^u_{aa'y} + {C^u_{aa'y}}^T\right]$

Age Mixing, Challenge 1: balancing contacts



Age Mixing, Challenge 1: balancing contacts



Age Mixing, Challenge 2: age stratifications don't align

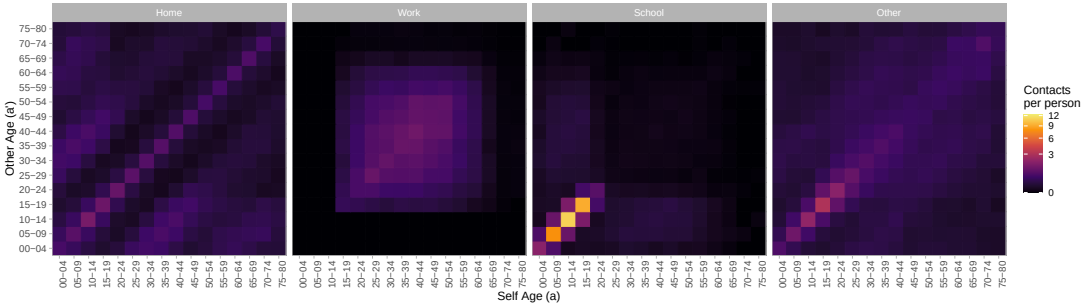
Solution

Linear Upsample from 5-year → 1-year age groups

Diagonally Pad edges for 80+ age groups

Aggregate 1-year → target age groups

Age Mixing, Challenge 2: re-stratify



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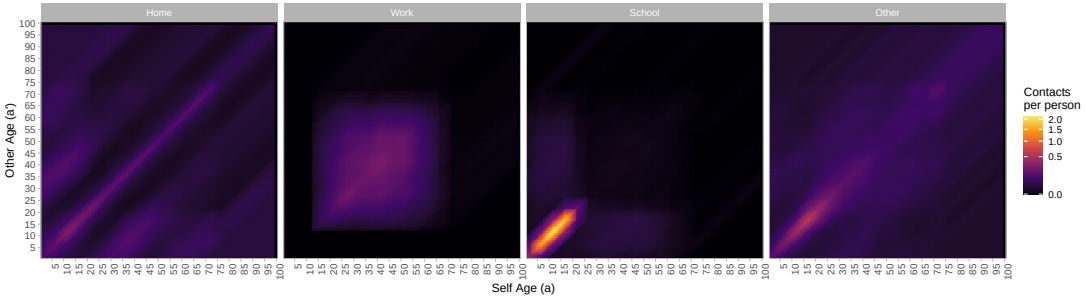

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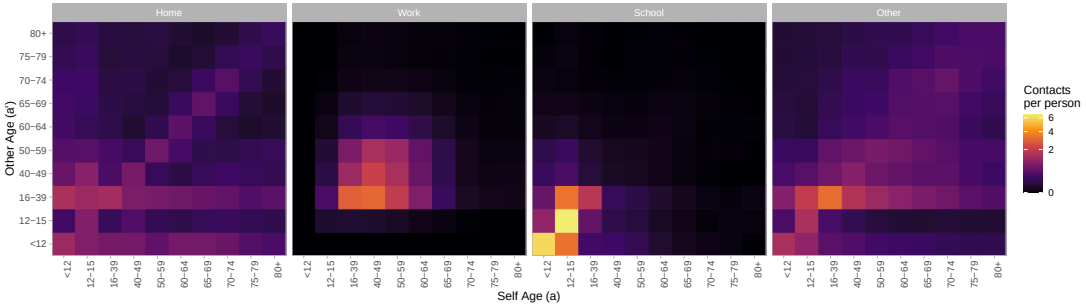
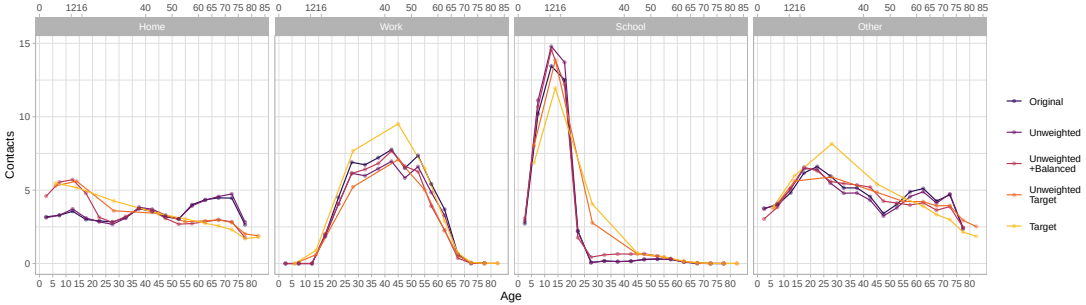


Age Mixing: total contacts by age group



Mobility Matrix: Comment

- Adapting to different demographic structure: like Arregui et al. (2018)
- New contributions: re-sampling strategy & diagonal padding
- Horizontal streaks are expected: due to unequal age groups

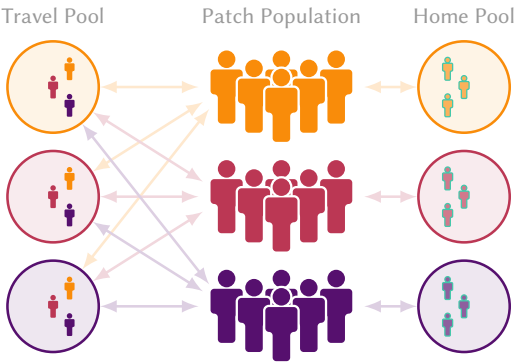
Combined Mixing

Mixing Pools: Definitions

Home Pools: contacts with Home FSA only
$(h_y)\delta_{gg'}$

Travel Pools: contacts with other mobile

- **Mobile at Home**: within Home FSA
  $(1-h_y)B_{g=g'}$
- **Mobile Away**: outside Home FSA
  $(1-h_y)B_{g\neq g'}$



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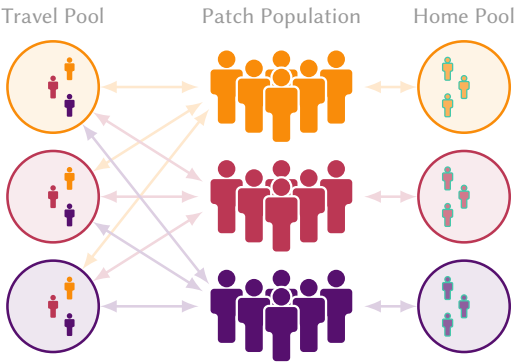

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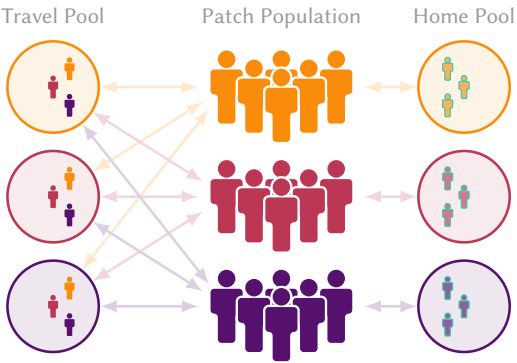

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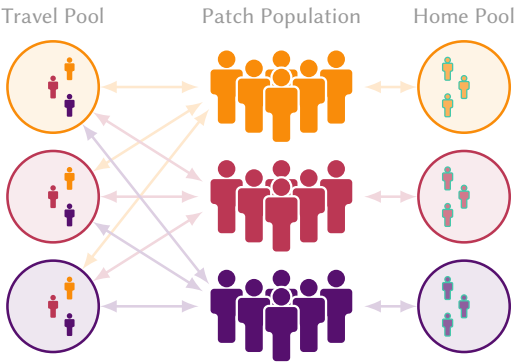

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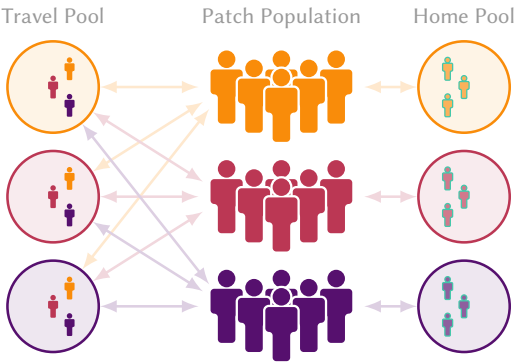


Mixing Pools as microcosms: Travel pool g^*

Who is here: $P^{g^*}_{gay} = (1 - h_y) B_{gg^*} P_{ga}$

Proportionate mixing of groups: $X^{g^* r}_{gag'a'y} = \frac{P^{g^*}_{gay} \otimes P^{g^*}_{g'a'y}}{\sum_{g'a'} P^{g^*}_{g'a'y}}$

Contacts by age applied on top: $X^{g^*}_{gag'a'y} = X^{g^* r}_{gag'a'y} C^{ub}_{aa'y} w^{-1}_{a'}$

Home pool g^*: same, except $(1 - h_y) B_{gg^*} \to (h_y) \delta_{gg^*}$

Total contacts across mixing pools

Total # Contacts

$$X_{gag'a'y} = \underbrace{X^{h}_{gag'a'y}}_{\text{home pool}} + \underbrace{\sum_{g^*} X^{g^*}_{gag'a'y}}_{\text{travel pools}}$$

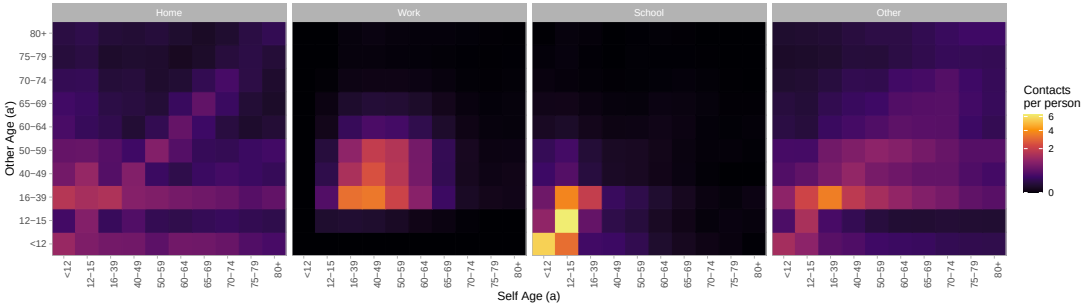
$\longrightarrow$

```
g, g',  a, a',         y,   t,     C
1,  1, <4, <4, household, Jan, 0.592
1,  1, <4, <4, household, Feb, 0.541
1,  1, <4, <4, household, Mar, 0.604
...
```

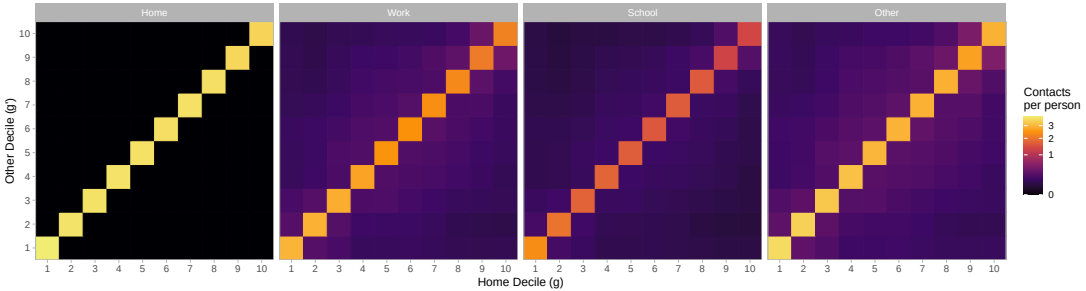
 # Contacts per Person

$$C_{gag'a'y} = \frac{X_{gag'a'y}}{P_{ga}}$$

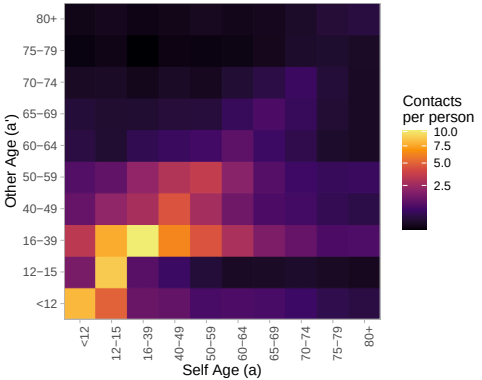
Contacts per person: age vs age (a, a')

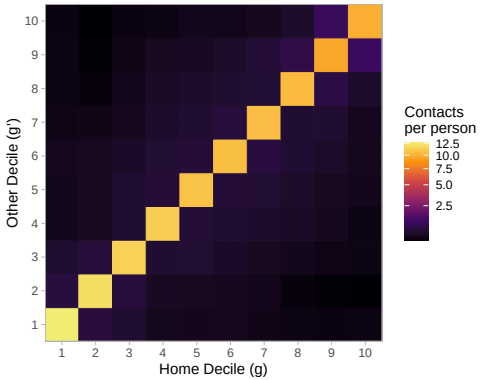


Contacts per person: decile vs decile (g, g')



Contacts per person: all types (y)





Combined Mixing: Comment

- Recurrent mobility approach: like Arenas et al. (2020)
- Recurrent mobility allows people from A & B to mix in C
  $\rightarrow$ connectivity is greater than mobility would suggest
- New contributions: home vs travel pools, combined age mixing, balancing

Next Steps

- Validation of # contacts with COVID-19 surveys (BC Mix, CONNECT)
- Scaling contacts by decile for model fitting

Thanks

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Ontario

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