



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

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Motivation & Background



Research Question

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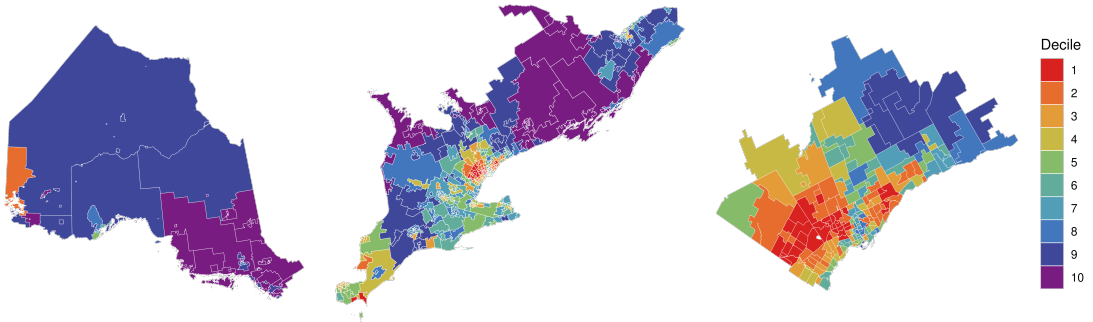
Impact of **hotspot** vs **non-hotspot** COVID-19 vaccine prioritization in Ontario

Transmission Model

- ▶ 513 FSA (first 3 postal code digits) → **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 ...

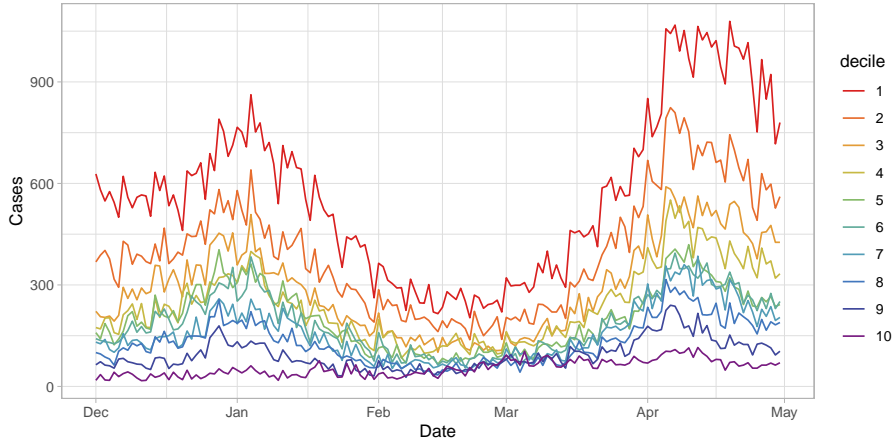


Ontario FSA, stratified by deciles of cumulative COVID-19 incidence





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





Objective

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

- ▶ self decile, g
- ▶ other decile, g'
- ▶ contact type, y
- ▶ self age, a
- ▶ other age, a'
- ▶ 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



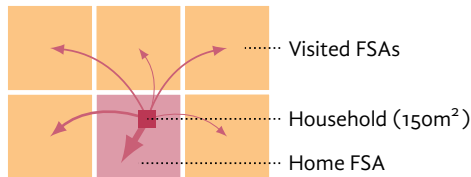
Mobility Data

~ 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' : $B_{nn't}^c = \frac{V_{nn't}}{\sum_{n'} V_{nn't}}$

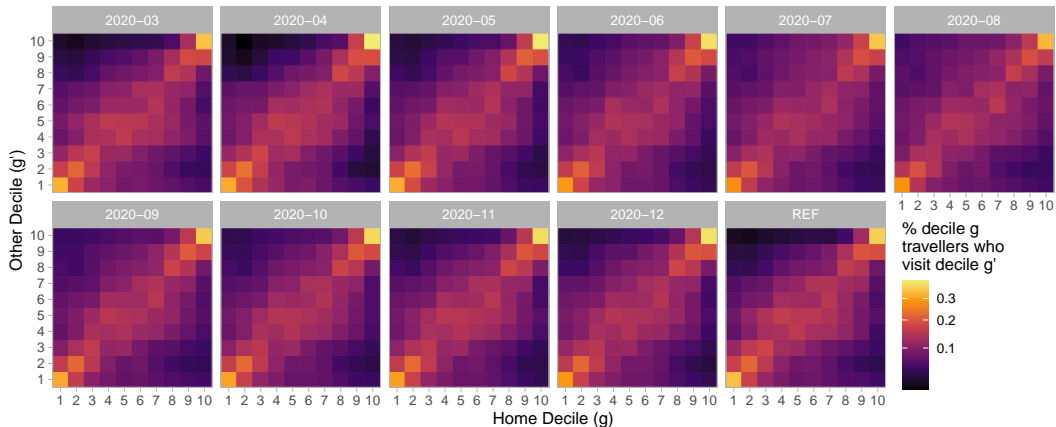
Relative Time Away (TA) from home, vs reference t_o : $\rho_{nt} = \frac{TA_{nt}}{TA_{nt_o}}$

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

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

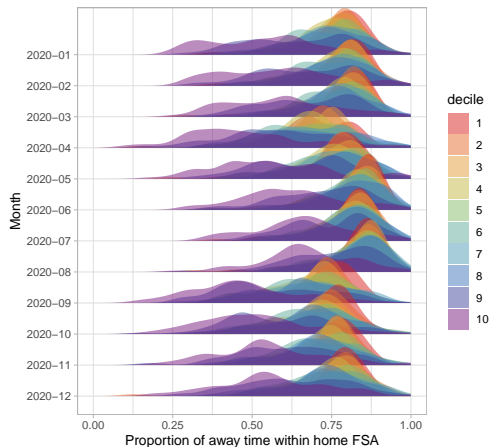
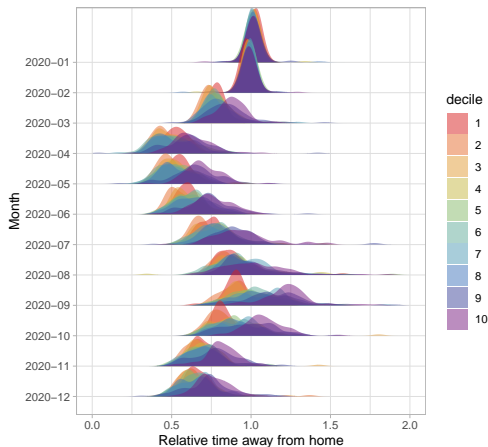


Mobility Metrics: Inter-FSA Mobility





Mobility Metrics: Time Away



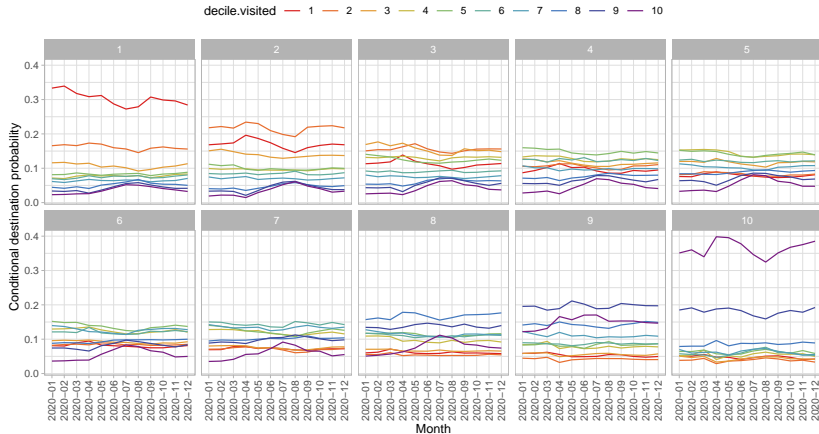


Mobility Matrix: Equation

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

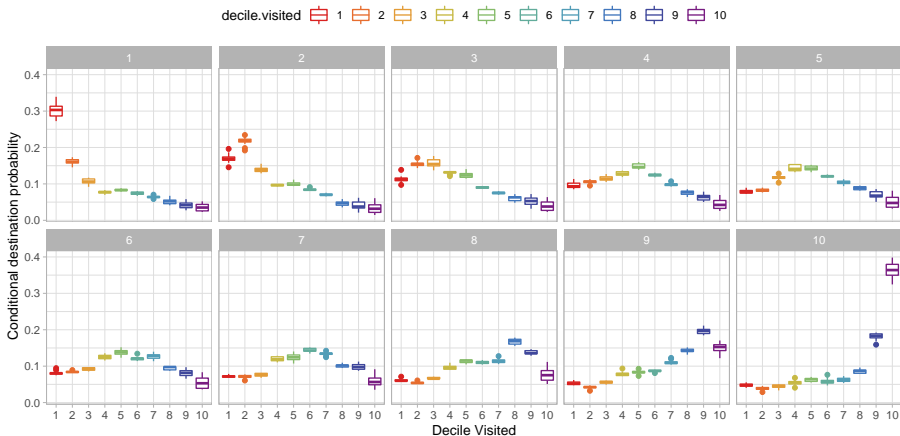


Does inter-FSA mobility $B_{gg'}^c$ change by month?



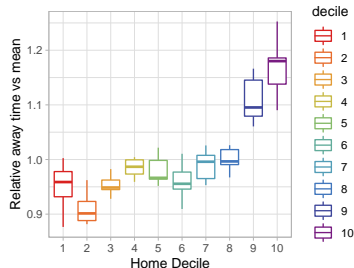
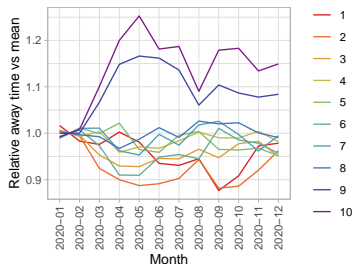
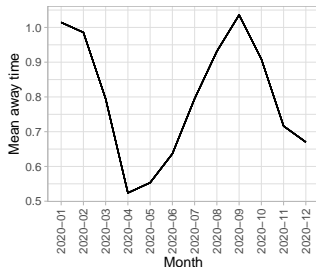


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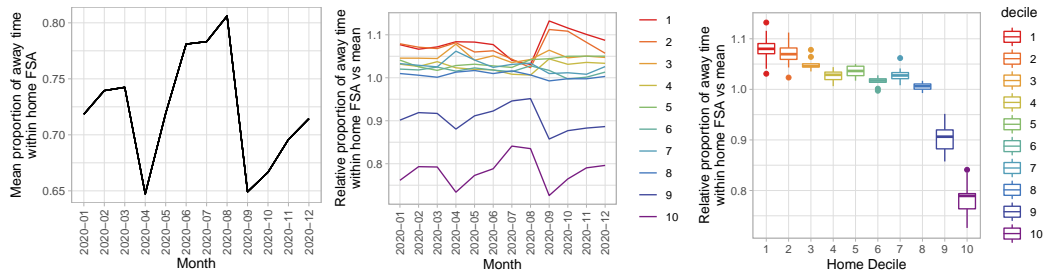


Does overall time away per decile ρ_g change by month?





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)

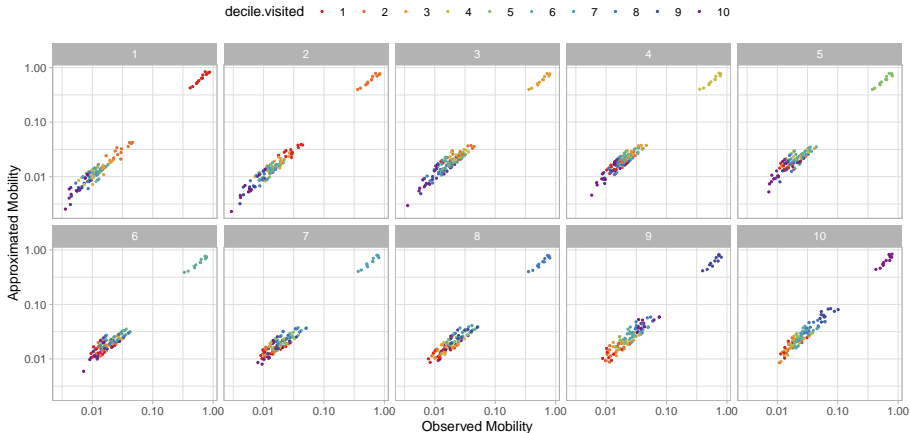
Optional: ϕ_t , proportion of TA within home FSA

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

→ for projecting beyond available data

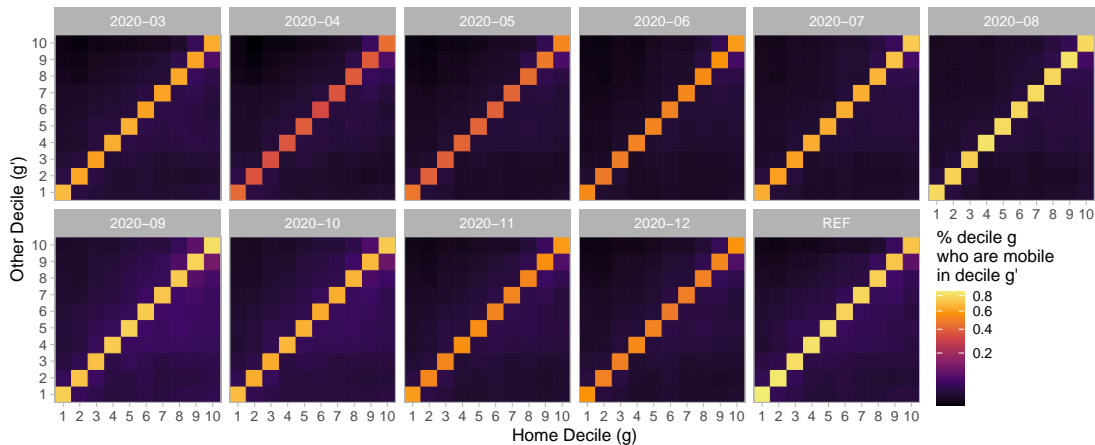


Mobility Matrix: 1-input Approximation vs Observed



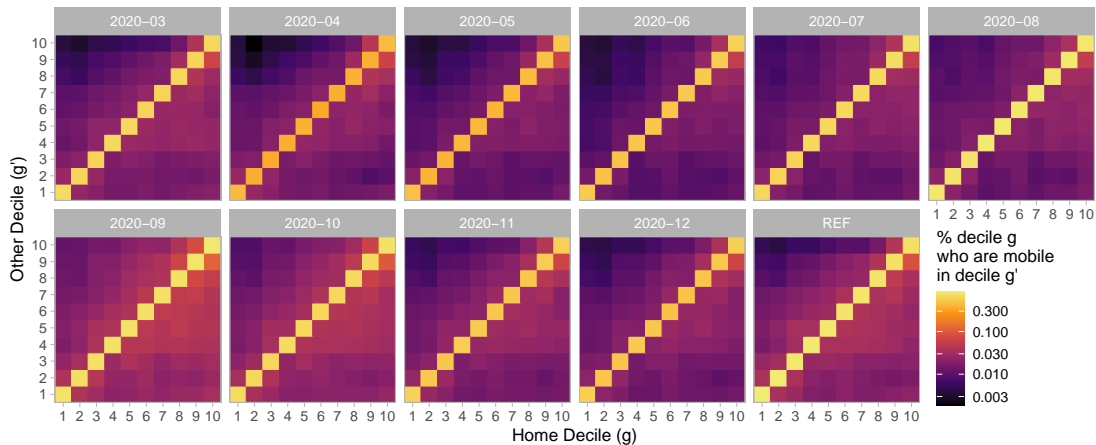


Mobility Matrix





Mobility Matrix (log scale)





Mobility Matrix: Comment

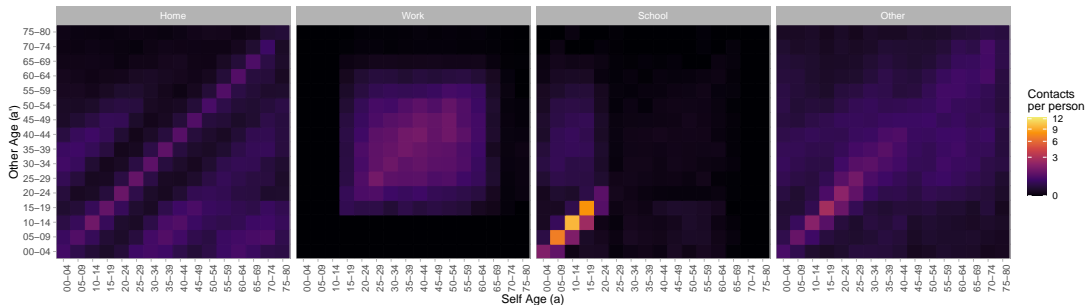
- ▶ Inter-FSA mobility mainly with similar deciles ($B_{gg'}^c$, clustered near diagonal)
- ▶ Most % time away from household within Home FSA ($\phi \approx 0.7$)
- ▶ Lowest incidence deciles ($g = 9, 10$):
 - ▶ Least mobility reduction (largest R_g^ρ)
 - ▶ Most time outside Home FSA (smallest R_g^ϕ)



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”

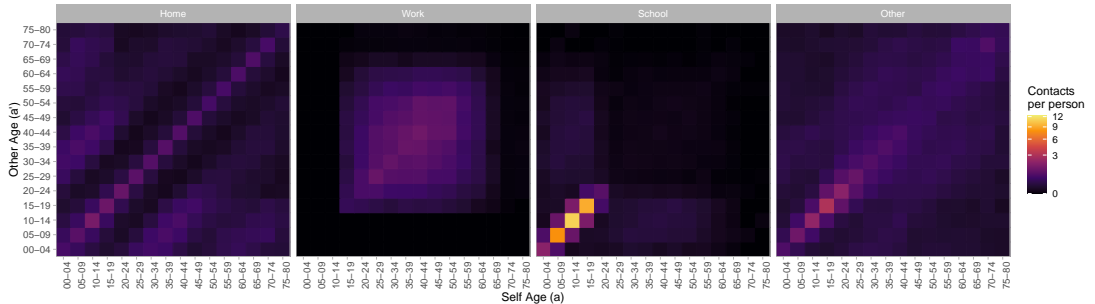
Solution

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

Enforce Symmetry by averaging with transpose: $C_{aa'y}^{ub} = \frac{1}{2} \left[C_{aa'y}^u + C_{aa'y}^{uT} \right]$

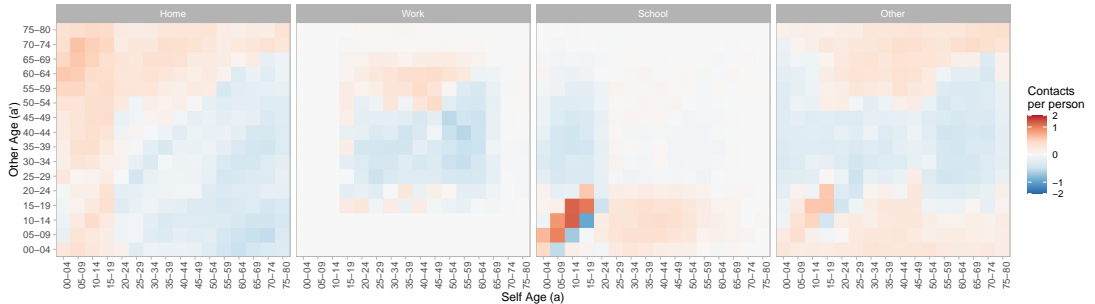


Age Mixing, Challenge 1: balancing contacts





Age Mixing, Challenge 1: balancing contacts





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

Solution

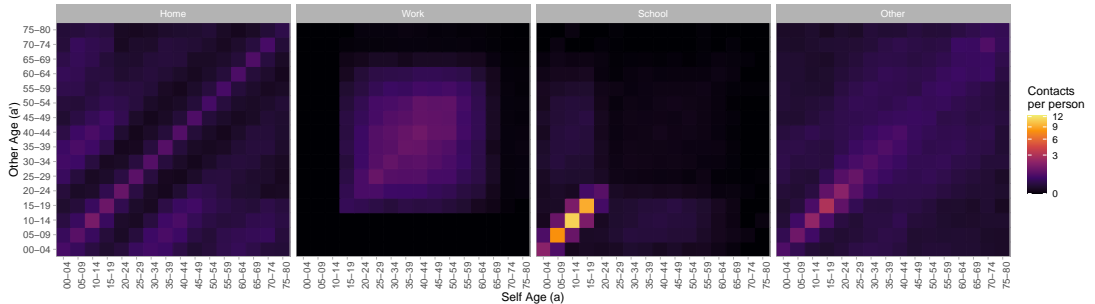
Linear Upsample from 5-year \rightarrow 1-year age groups

Diagonally Pad edges for 80+ age groups

Aggregate 1-year \rightarrow target age groups

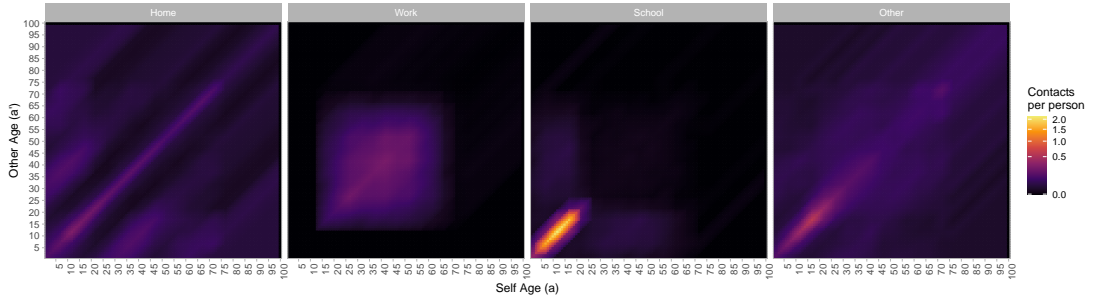


Age Mixing, Challenge 2: re-stratify



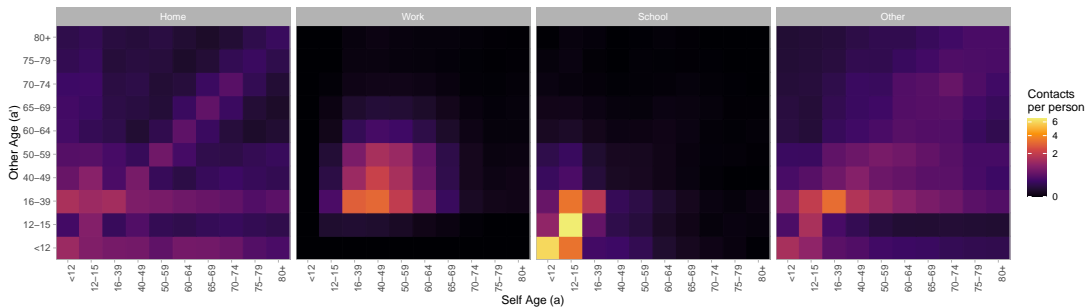


Age Mixing, Challenge 2: re-stratify



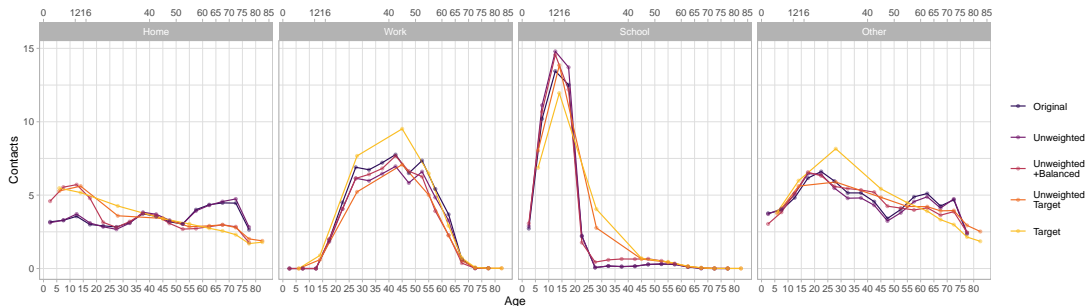


Age Mixing, Challenge 2: re-stratify





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

$$(h_y)\delta_{gg'}$$

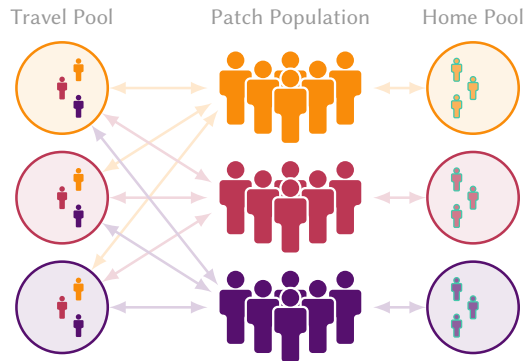
Travel Pools: contacts with other mobile

- ▶ **Mobile at Home:** within Home FSA

$$(1 - h_y)B_{g=g'}$$

- ▶ **Mobile Away:** outside Home FSA

$$(1 - h_y)B_{g \neq g'}$$



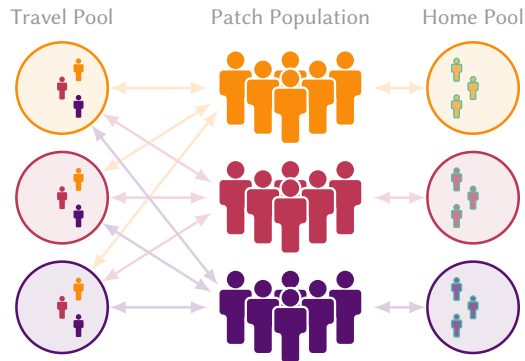


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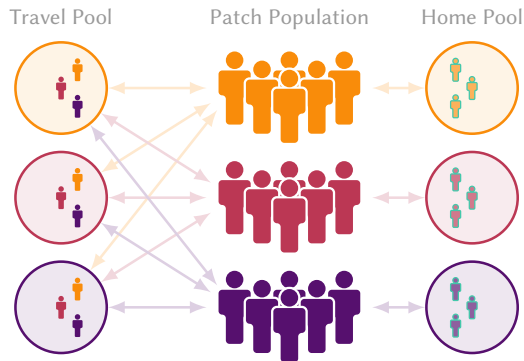
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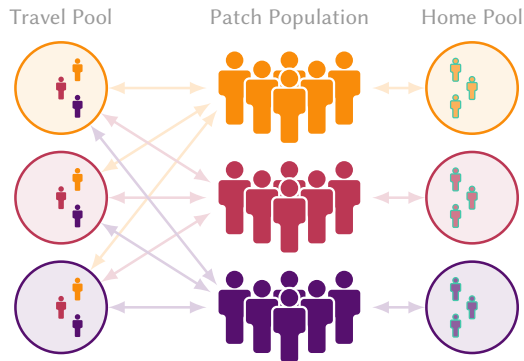
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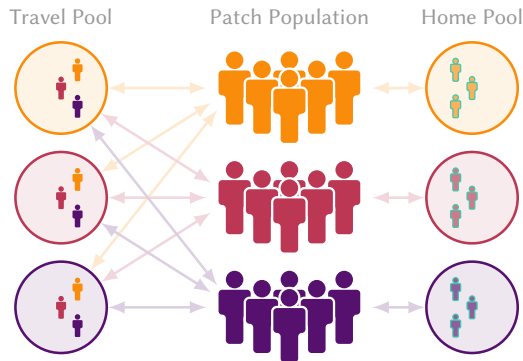


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Mixing Pools as microcosms: Travel pool g^*

Who is here:

$$P_{gay}^{g^*} = (1 - h_y)B_{gg^*}P_{ga}$$

Proportionate mixing of groups:

$$X_{gag'a'y}^{g^*r} = \frac{P_{gay}^{g^*} \otimes P_{g'a'y}^{g^*}}{\sum_{g'a'} P_{g'a'y}^{g^*}}$$

Contacts by age applied on top:

$$X_{gag'a'y}^{g^*} = X_{gag'a'y}^{g^*r} C_{aa'y}^{ub} w_{a'}^{-1}$$

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



Total contacts across mixing pools

Total # Contacts

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

→

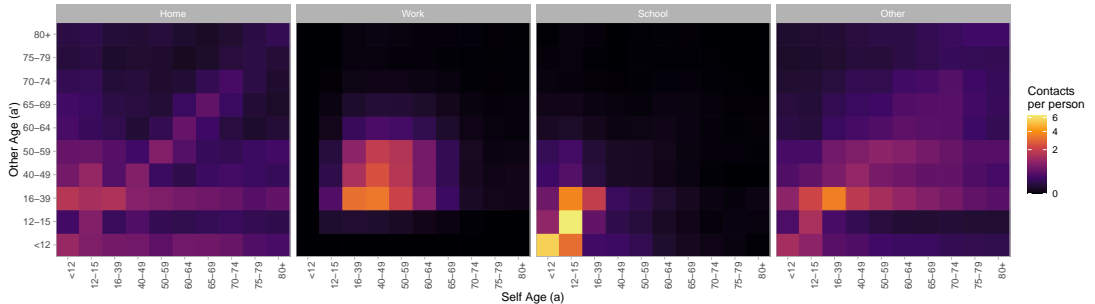
| g, | g', | a, | a', | y, | t, | C |
|-----|-----|-----|-----|------------|------|-------|
| 1, | 1, | <4, | <4, | household, | Jan, | 0.592 |
| 1, | 1, | <4, | <4, | household, | Feb, | 0.541 |
| 1, | 1, | <4, | <4, | household, | Mar, | 0.604 |
| ... | | | | | | |

Contacts per Person

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

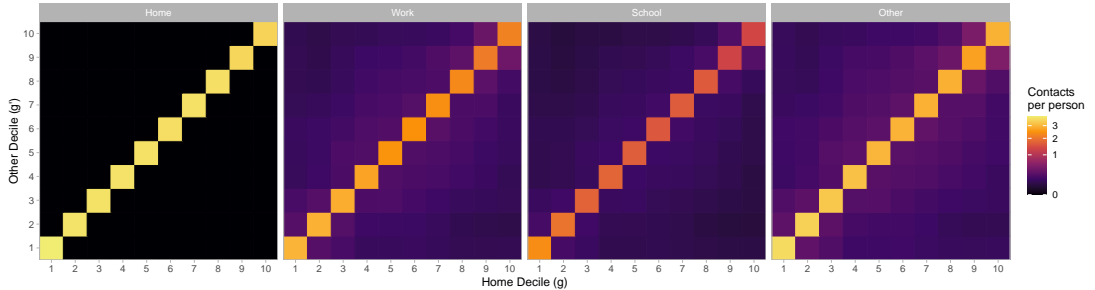


Contacts per person: age vs age (a, a')



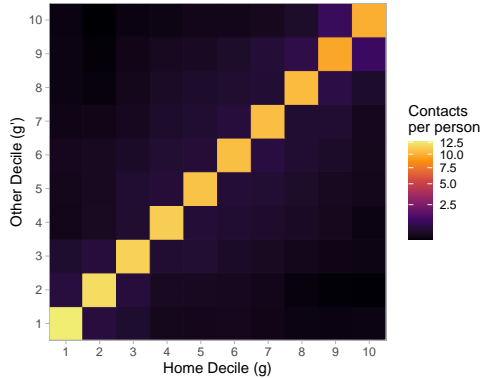
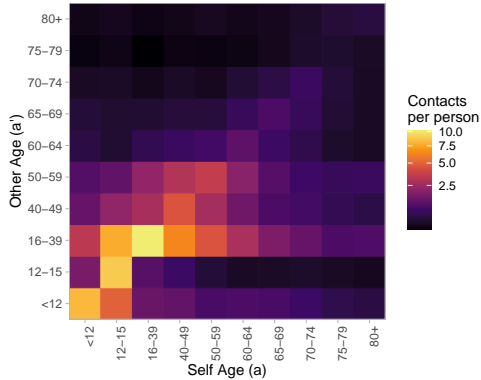


Contacts per person: decile vs decile (g, g')





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
→ 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

Kristy Yiu, Gary Moloney, Linwei Wang

