

# Spatio-temporal estimates of HIV risk group proportions for adolescent girls and young women across 13 priority countries in sub-Saharan Africa

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# Background

- In sub-Saharan Africa, adolescent girls and young women (AGYW) aged 15-29 are disproportionately at risk of HIV infection
  - 28% of population and 44% of new infections
- This disparity is because of:
  1. Younger age at first sex
  2. Age patterns of sexual mixing
  3. Structural vulnerabilities and power imbalances
  4. Increased susceptibility to HIV infection



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An adolescent girl or young woman acquired HIV every two minutes in 2021.

Read about the devastating impact HIV has on women and girls in the new Global AIDS Update 2022 [indanger.unaids.org](https://indanger.unaids.org)

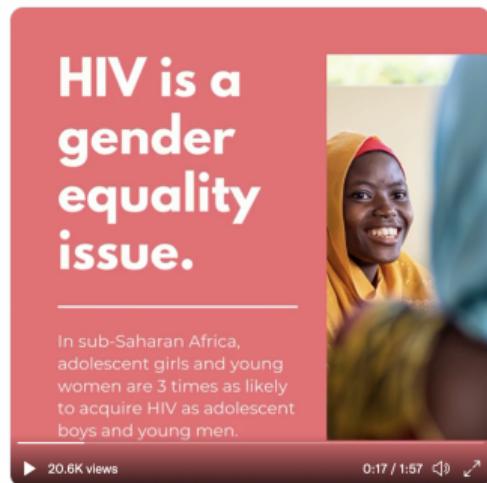


Figure 1: Tweet from UNAIDS

# Prevention packages

- Prevention options can be divided into two:
  1. Core package
  2. Intensified interventions
- There are not enough resources to offer the more costly intensified interventions to all AGYW, so it's important to prioritise those at highest risk

# Stratified prevention

- The Global AIDS strategy 2021-2026 proposed stratifying HIV prevention for AGYW based upon
  1. Population-level HIV incidence
  2. Individual-level sexual risk behaviour
- Takes into account the two most proximal drivers of sexual transmission



Figure 2: Global AIDS strategy

# Scope for our work

## Goals

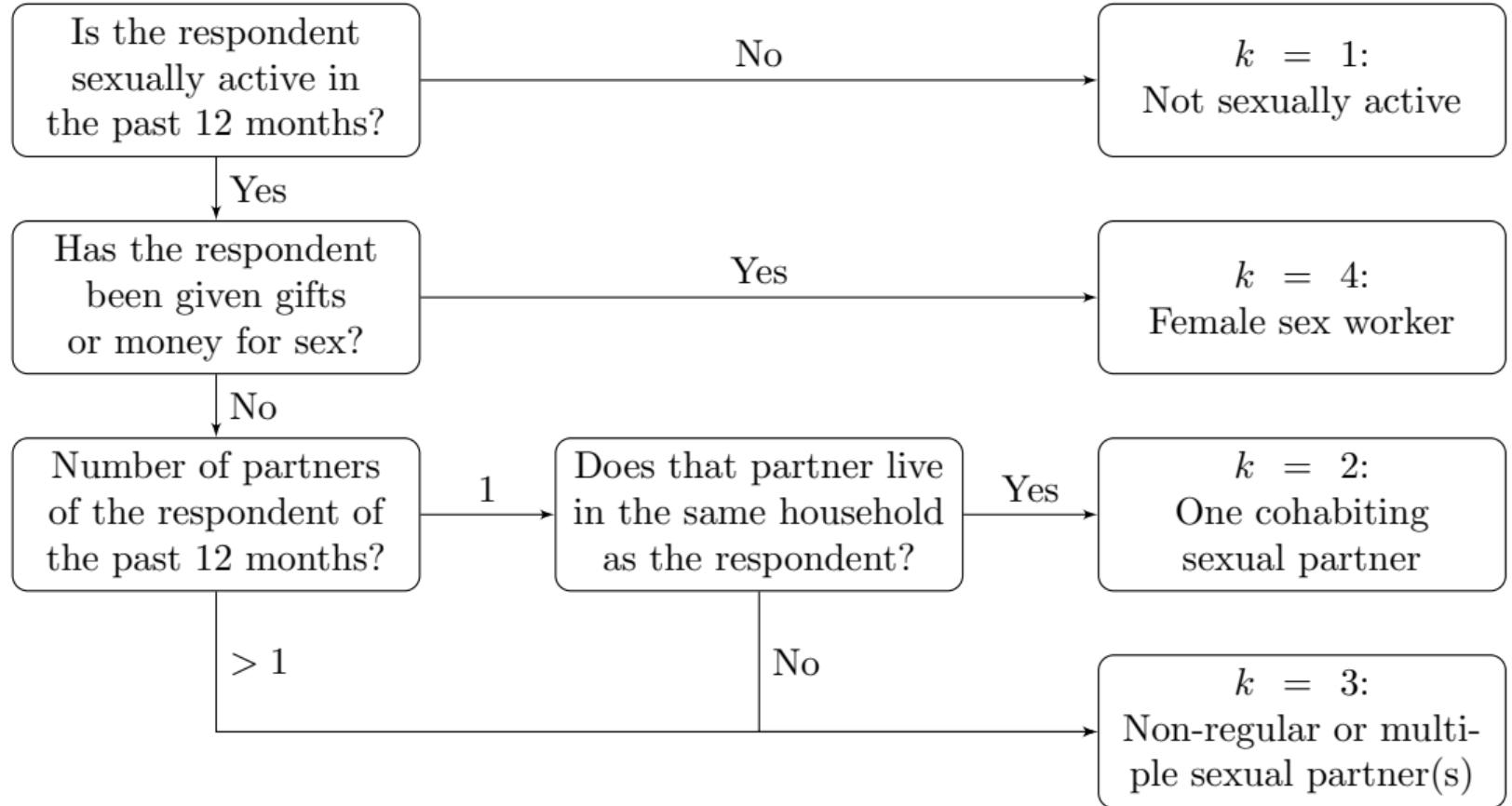
1. Enable implementation of prevention stratified by incidence and behaviour
2. Assess the benefits of such approaches: is it worth it?

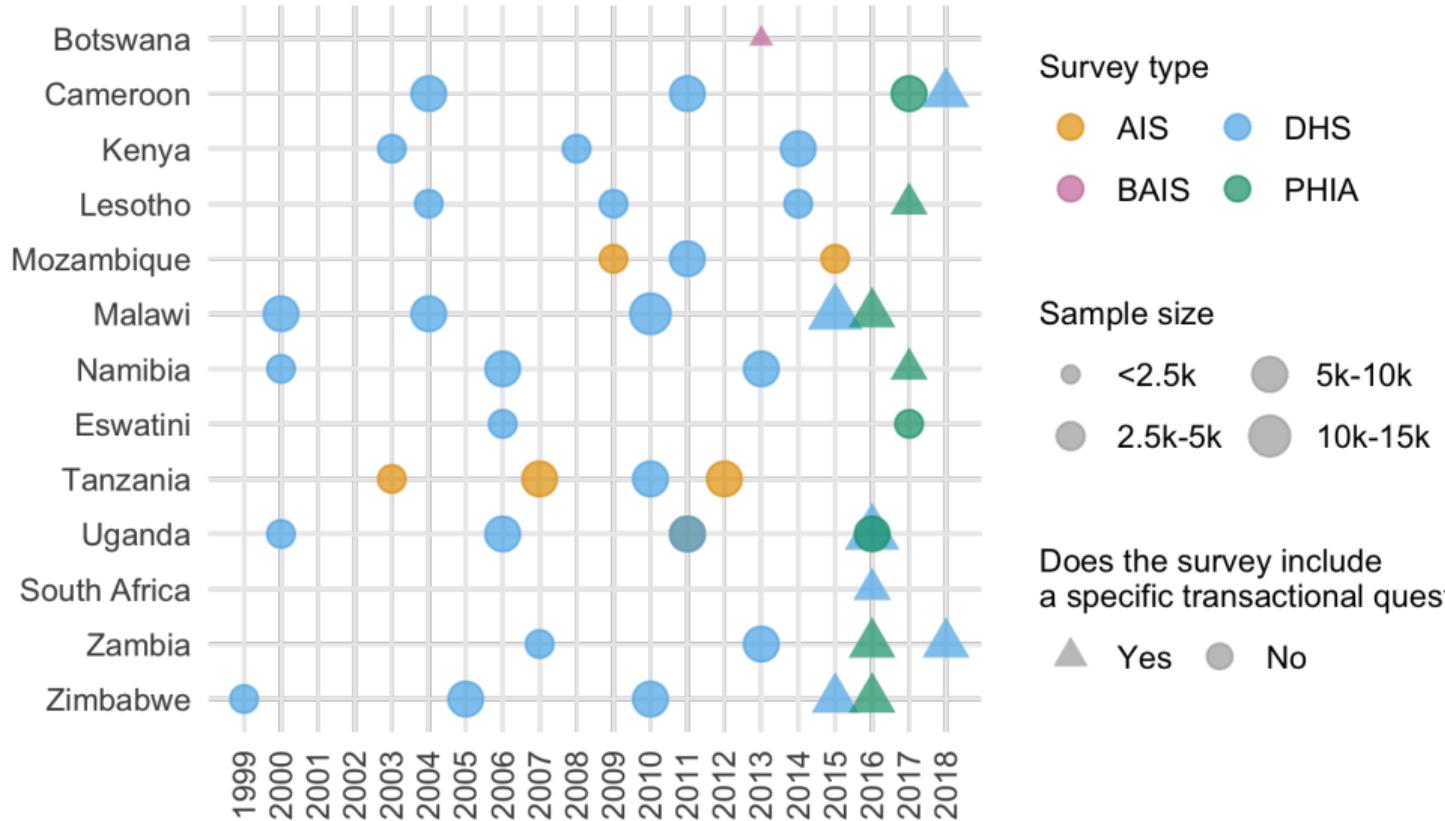
## Approach

1. Estimate the proportion of AGYW in four behavioural risk groups at a district level (in 13 countries identified as priority by The Global Fund)
2. Analyze the new infections which could be reached by different stratified prevention strategies

# Data

- We used sexual behaviour data from AIS, BAIS, DHS and PHIA household surveys to place respondents into  $K = 4$  risk groups:
  1.  $k = 1$  Not sexually active
  2.  $k = 2$  One cohabiting sexual partner
  3.  $k = 3$  Non-regular sexual partner(s)
  4.  $k = 4$  Female sex workers
- District-level HIV incidence, prevalence, population size estimates from the Naomi model (Eaton et al. 2021)
  - Combines survey and programmatic data to estimate indicators in the general population
- Risk ratios from ALPHA network analysis (Slaymaker et al. 2020) and UNAIDS analysis led by Keith Sabin
  - 10 longitudinal studies: <https://alpha.lshtm.ac.uk/>





## Two-stage model for risk group proportions

- Only some of the surveys included a transactional sex question, required to differentiate between the  $k = 3$  and  $k = 4$  risk groups
- Our approach was to fit a two-stage model
  1. Spatio-temporal multinomial logistic regression model for the proportion of AGYW in the  $k = 1, 2, 3^+$  risk groups, using all 47 surveys
  2. Spatial logistic regression model for the proportion of those in the  $k = 3^+ = \{3, 4\}$  risk groups who are in the  $k = 4$  risk group, using only the 13 surveys with a specific transactional sex question

## Notation

- $k \in \{1, \dots, 4\}$ : risk groups
- $i \in \{1, \dots, n\}$ : districts
- $c[i] \in \{\text{Botswana}, \dots, \text{Zimbabwe}\}$ : country containing district  $i$
- $t \in \{1999, \dots, 2018\}$ : years
- $a \in \{15-19, 20-24, 25-29\}$ : age groups
- $y_{ita}^* = (y_{ita1}^*, y_{ita2}^*, y_{ita3}^*, y_{ita4}^*)$ : survey weighted multinomial observations
- $m_{ita}^*$ : survey weighted multinomial sample size

## Multinomial logistic regression model

- Would like to use integrated nested Laplace approximations for fast, accurate inference, but R-INLA is not compatible with multinomial likelihoods because they depend on multiple elements of the latent field
- Instead, use that multinomial logistic regression models can be recast as a Poisson log-linear models using the Poisson trick
- This works because conditional on their sum, Poisson counts are jointly multinomially distributed
- If you include observation-specific random effects  $\theta_{ita} \sim \mathcal{N}(0, 1000^2)$  in the linear predictor  $\eta_{itak} = \theta_{ita} + \dots$  then the sample sizes  $m_{ita}^*$  can be exactly recovered, ensuring the models are actually the same

# Multinomial logistic regression model

- Consider models of the form

$$y_{itak}^* \sim \text{Poisson}(\lambda_{itak})$$

$$\log(\lambda_{itak}) = \theta_{ita} + \beta_k + \zeta_{c[i]k} + \alpha_{ac[i]k} + \phi_{ik} + \gamma_{tk} + \delta_{itk}.$$

- The terms are
  - $\theta_{ita}$ : observation (IID)
  - $\beta_k$ : category (IID)
  - $\zeta_{ck}$ : country-category (IID x IID)
  - $\alpha_{ack}$ : age-country-category (IID x IID x IID)
  - $\phi_{ik}$ : space-category ( $\{\text{IID}, \text{Besag}\} \times \text{IID}$ )
  - $\gamma_{tk}$ : year-category ( $\{\text{IID}, \text{AR1}\} \times \text{IID}$ )
  - $\delta_{itk}$ : space-year-category (Implemented but crashing on cluster at the moment...)

# Multinomial logistic regression model

- Independent penalised complexity (Simpson et al. 2017) priors on all standard deviation parameters with  $\sigma = 0$  and  $\mathbb{P}(\sigma > 2.5 = 0.01)$ 
  - Sidenote, I'm interested as to if joint priors might be more suitable
- Possible (but tricky) to define all these interactions in R-INLA by combination of the group and replicate options
- Used sum-to-zero constraints to make posterior inferences interpretable
  - Because we're interested in the contribution of each random effect to total variance
- Model comparison via CPO statistic

# Logistic regression model

- Consider models of the form

$$y_{ia4}^* \sim \text{Binomial}(y_{ia3}^* + y_{ia4}^*, q_{ia}),$$

$$q_{ia} = \text{logit}^{-1}(\eta_{ia}),$$

$$\eta_{ia} = \beta_0 + \zeta_{c[i]} + \alpha_{ac[i]} + \phi_i + \beta_{\text{cfsw}} \text{cfsw}_{c[i]}.$$

- The terms are
  - $\beta_0$ : intercept
  - $\zeta_{c[i]}$ : country effects (IID)
  - $\alpha_{ac[i]}$  age-country effects (IID)
  - $\phi_i$ : spatial effects (IID, **Besag**)
  - Clients of FSW covariates (cfswever, cfswrecent) (Hodgins et al. 2022)

## Combination and FSW adjustment

- Take 1000 samples from each model, then manipulate suitably to generate estimates for all four risk groups
- We adjusted the samples from the  $k = 4$  risk group to match age-country FSW estimates, reallocating into non-regular partner(s)
  - Obtained these by disaggregating Stevens et al. (2022) by age using estimates of sexually active population from Nguyen and Eaton (2022)

⇒ Estimates of risk group proportions  $p_{itak}$  by district, year and age group

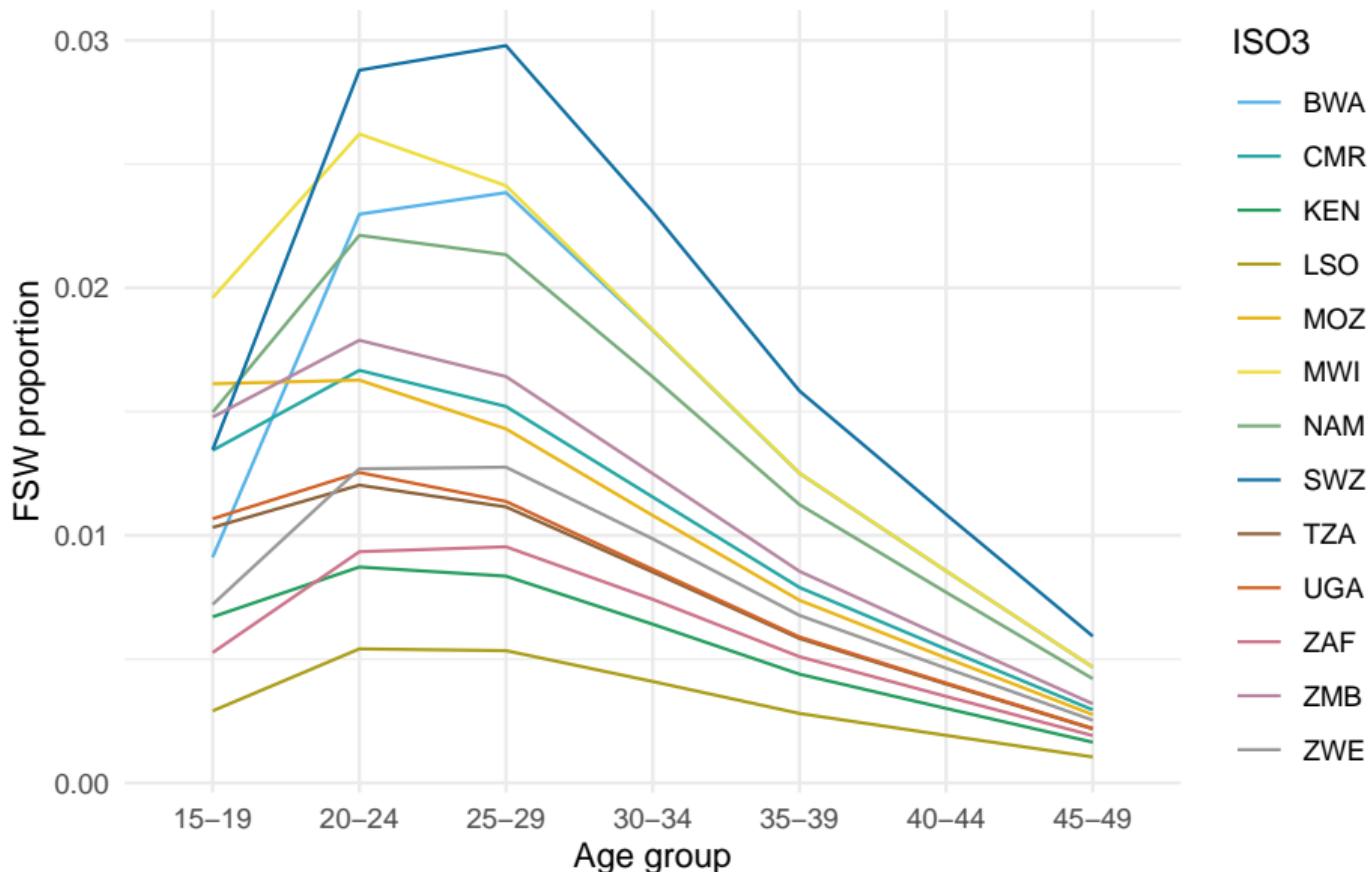


Figure 3: Results of FSW age disaggregation.

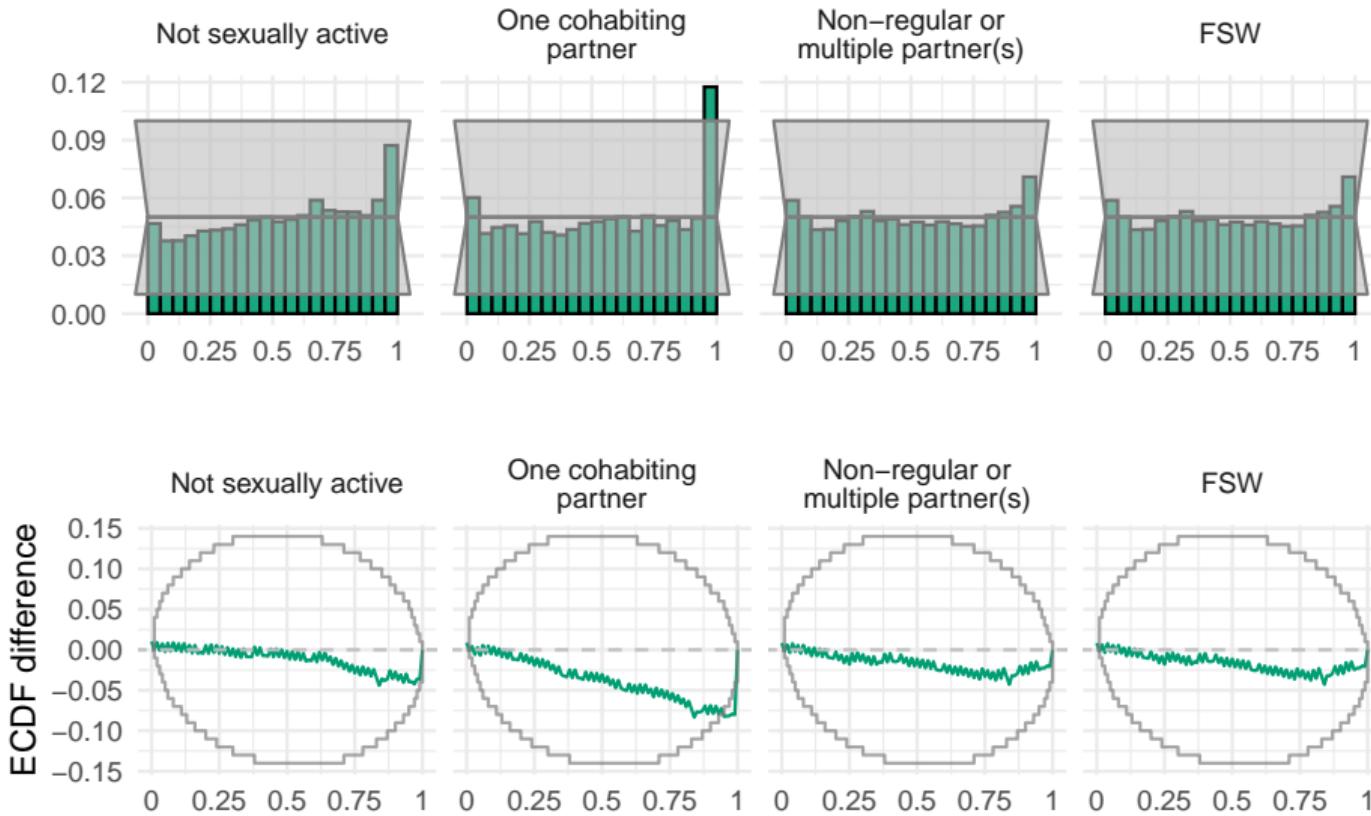


Figure 4: PIT histograms and ECDF difference plots.

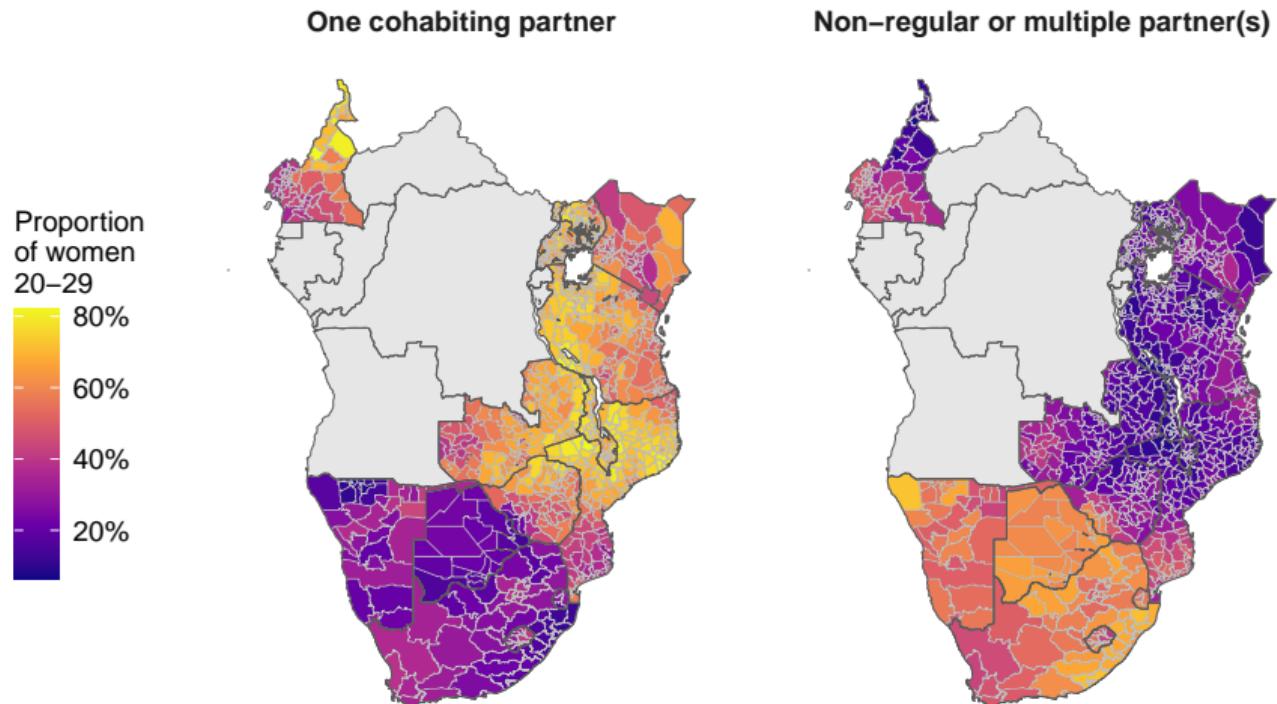
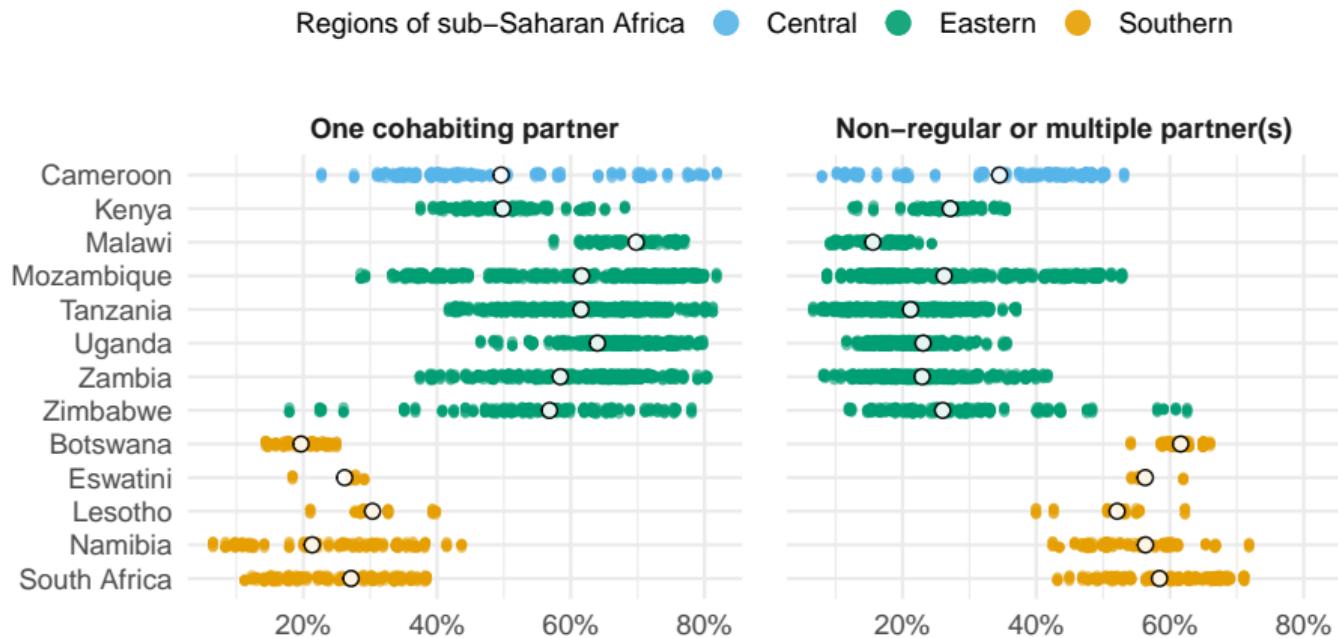


Figure 5: We found a geographic discontinuity in behaviour between Southern and Eastern Africa.



**Not sexually active (not shown) + Cohabiting partner + Nonregular partner(s) + FSW (not shown) = 100%**

Figure 6: Viewing the discontinuity another way.

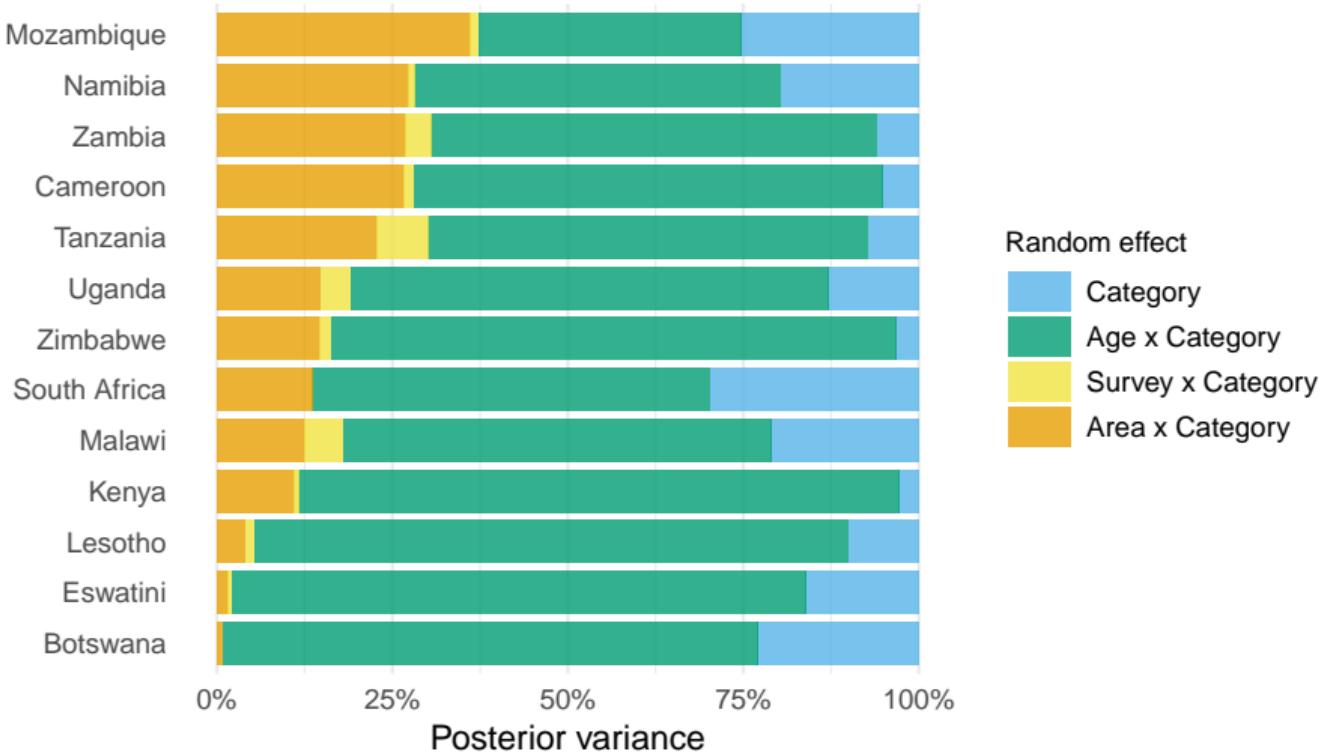


Figure 7: Proportions of variance explained.

# Benefits of our modelled risk group estimates

- Integration of all relevant surveys
  - Two-stage approach allowed estimating FSW proportion even for surveys without a specific transactional sex question
- Alleviating small-sample sizes by borrowing information
  - We borrowed information across space, between countries and over surveys so that our estimates more plausibly reflect spatial heterogeneity
- Estimates where there isn't direct data
  - Although some people think of this as "making up data", the data almost never "speak for themselves" (everything is a model)
  - Uncertainty should be higher in regions with infilling: important to transparently communicate this

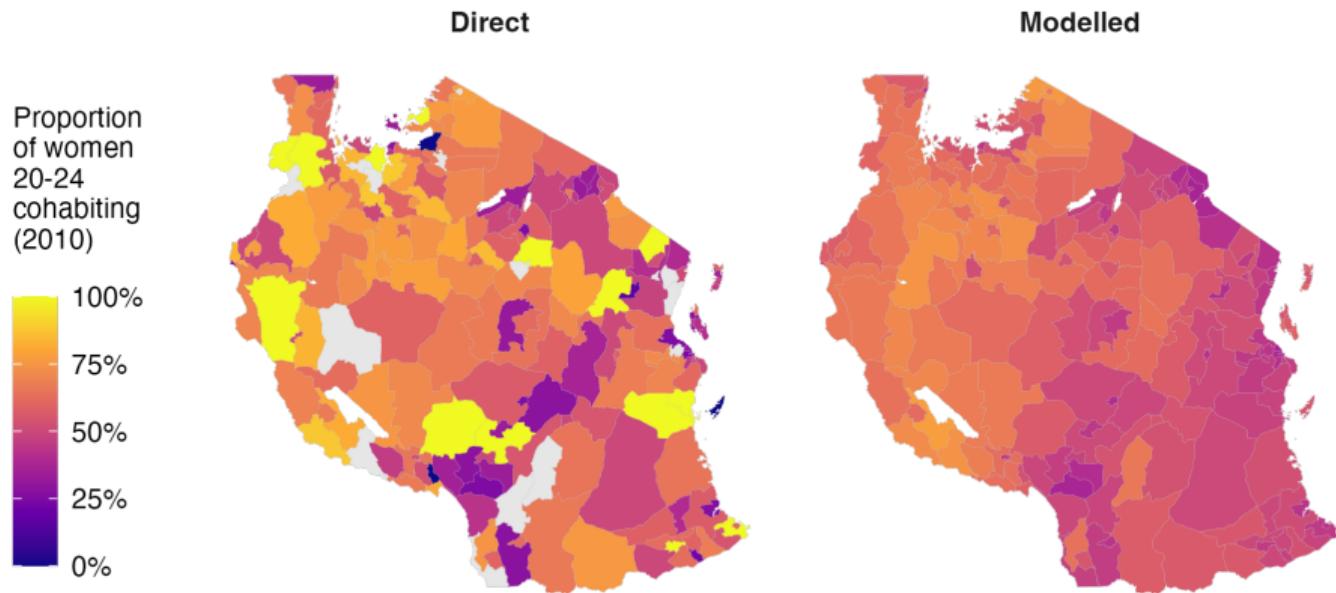


Figure 8: Illustration of the problem with direct survey estimates.

## HIV prevalence and incidence by risk group

- We used our risk group proportion estimates together with incidence relative risk ratios and prevalence ratios to disaggregate general population HIV estimates in the most recent year
- Disaggregated number of new infections on a linear scale, and people living with HIV (PLHIV) on a logit scale
  - Using a linear scale for PLHIV resulted in prevalences outside [0, 1]

⇒ Estimates of HIV incidence  $\lambda_{iak}$ , number of new HIV infections  $I_{iak}$ , HIV prevalence  $\rho_{iak}$  and PLHIV  $H_{iak}$  by district, age group and risk group

## Prioritisation with risk group information

- Suppose we have all of the information (district, age, and risk group)
- Which are the strata with highest incidence?

area_id	age_group	category	population	incidence
ZMB_2_16	Y015_019	sexpaid12m	119.03	0.19
ZAF_2_MAN	Y015_019	sexpaid12m	152.77	0.17
ZAF_2_DC29	Y015_019	sexpaid12m	150.13	0.17
ZAF_2_DC27	Y015_019	sexpaid12m	158.38	0.17
SWZ_1_3	Y015_019	sexpaid12m	262.68	0.16
TZA_4_161rz	Y015_019	sexpaid12m	44.27	0.16

## Prioritisation without risk group information

- What about if we lost the risk group information? Now what are the strata with the highest incidence?

area_id	age_group	population	incidence
SWZ_1_2	Y025_029	8395.92	0.03
MOZ_3_0820	Y020_024	6517.29	0.03
SWZ_1_2	Y020_024	9915.55	0.03
MOZ_3_0803	Y020_024	4278.59	0.03
MOZ_3_0816	Y020_024	11857.78	0.03
SWZ_1_3	Y025_029	17643.13	0.03

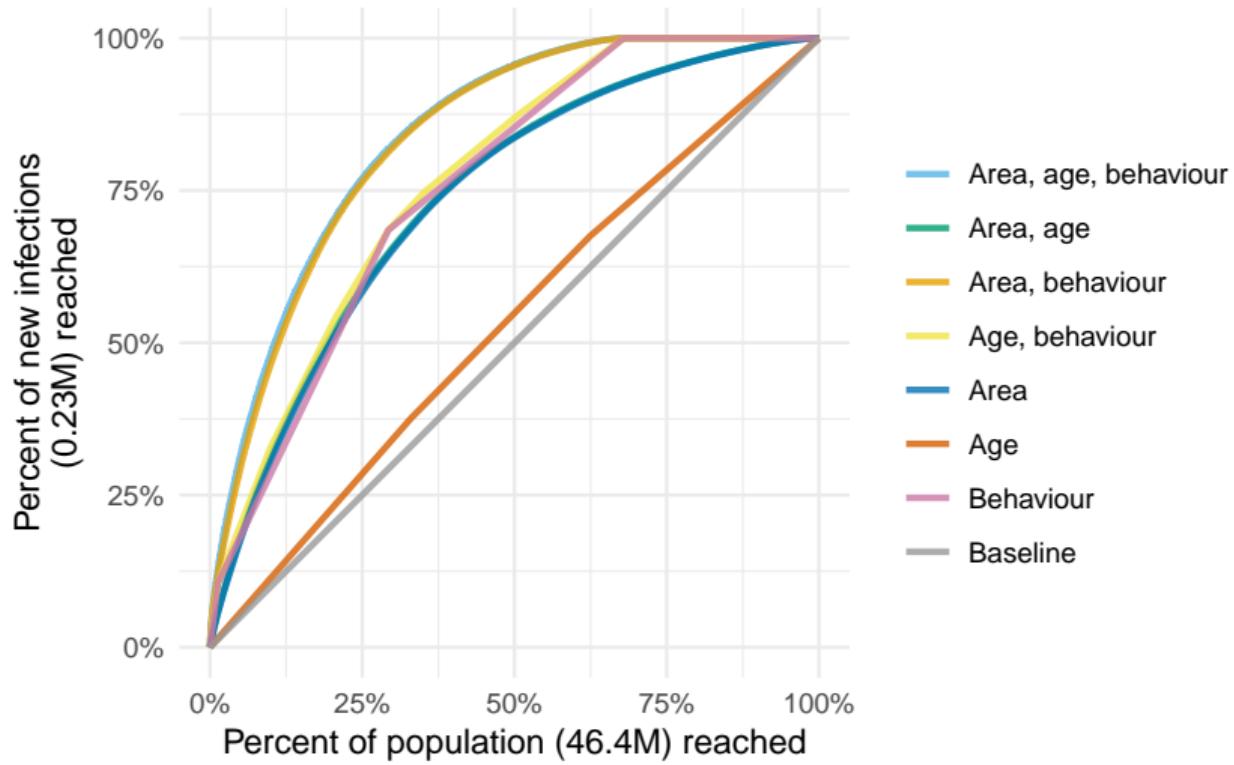


Figure 9: New infections reached prioritising according to different stratifications.

# Limitations

- Simplistic infections reached analysis
  - No accounting for difficulty in reaching each strata
  - Variable intervention effectiveness
  - Change in strata membership
- Under-reporting of high risk sexual behaviours
  - Variation in under-reporting (likely by age, foremost, and location, less so) particularly concerning
- Risk groups definition justification not clear
  - Didn't consider other important characteristics that may determine risk e.g. condom usage
- Only focused on AGYW 15-29
  - Could be extended to adults of both sexes aged 15-49

## Takeaways

- Risk group estimates can help implement the Global AIDS Strategy; tool and user guide currently being rolled out!
- Importance of reaching FSW
- Countries have different epidemic profiles

# Thanks for listening!

- Joint work with members of the HIV inference group ([hiv-inference.org](http://hiv-inference.org)) particularly Katie Risher and Jeff Eaton
- The code for this project is at [github.com/athowes/multi-agyw](https://github.com/athowes/multi-agyw)
- You can find me online at [athowes.github.io](https://github.io/athowes)

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