The Impact of Sexual Mixing By Age on Sexually Transmitted Infection Models

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Background

- Mathematical models of sexually transmitted infection (STI) dynamics are commonly used to evaluate interventions. For example, recently used to inform HPV vaccination policy recommendations.
- In STI models, a commonly used representation of sexual partner choice is the **assortative-proportionate (A-P) mixing structure**:
  - a single parameter defines the spectrum from assortative (only mixing with one's own subgroup) to proportionate (choosing a partner solely based on the proportion of the population in each subgroup and the number of partnerships they offer).
- Problems with A-P: not flexible enough to capture age mixing patterns
- We propose **empirical mixing**: use standard statistical methods to define probability distributions for mixing behavior.

Objectives

- Compare fit of A-P and empirical age mixing structures to survey data.
- Quantify effects of different mixing structures on model-predicted HPV vaccine benefits.

Methods

- We analyzed the British population probability survey National Survey on Sexual Attitudes and Lifestyles (Johnson, et al. 2015)
  - We used heterosexual age preference data, based on respondents' most recent sexual partners (up to 3).

Assortative-Proportionate Versus Empirical Mixing

Age Mixing Estimation: A-P

- Use maximum likelihood estimation to find optimal degree of assortativeness.

Age Mixing Estimation: Empirical

- Model the age preference data as a collection of probability distributions - one for each age group
- Partner age is heteroscedastic with respect to chooser age.
- Model variance:
  1. Linear regression of chooser's age versus age of partner, predict mean partner age for each age group.
  2. Model the squared residuals (and assorted transformations) as linear functions of chooser's age, and predict variance.

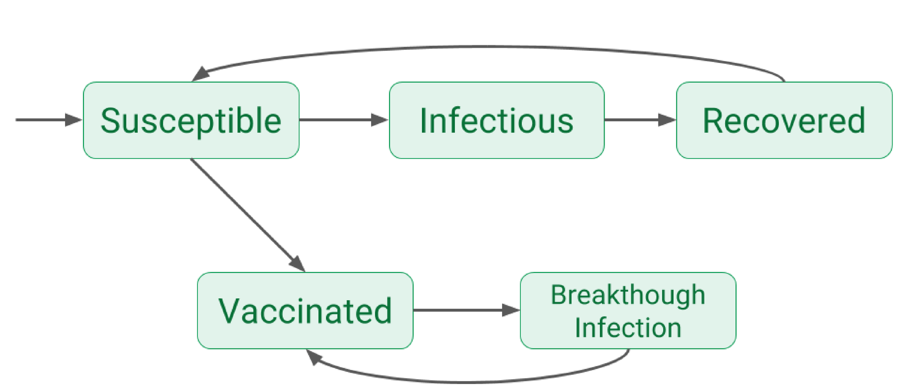
Likelihood Comparison

Calculate likelihood of Natsal-3 age mixing data under:

- A-P mixing
- Empirical mixing, with:
  - Linear: variance $\sim$ chooser age
  - Square Root: $\sqrt{\text{variance}} \sim$ chooser age
  - Log: $\log(\text{variance}) \sim$ chooser age
  - Constant: variance $= \hat{\sigma}^2$

Mathematical Model of HPV

- Age- and sexual-activity-structured compartmental model
- Assume life-long vaccine protection.
- Model diagram on right, with age and sexual activity omitted for clarity.



Results: Age Mixing Structures

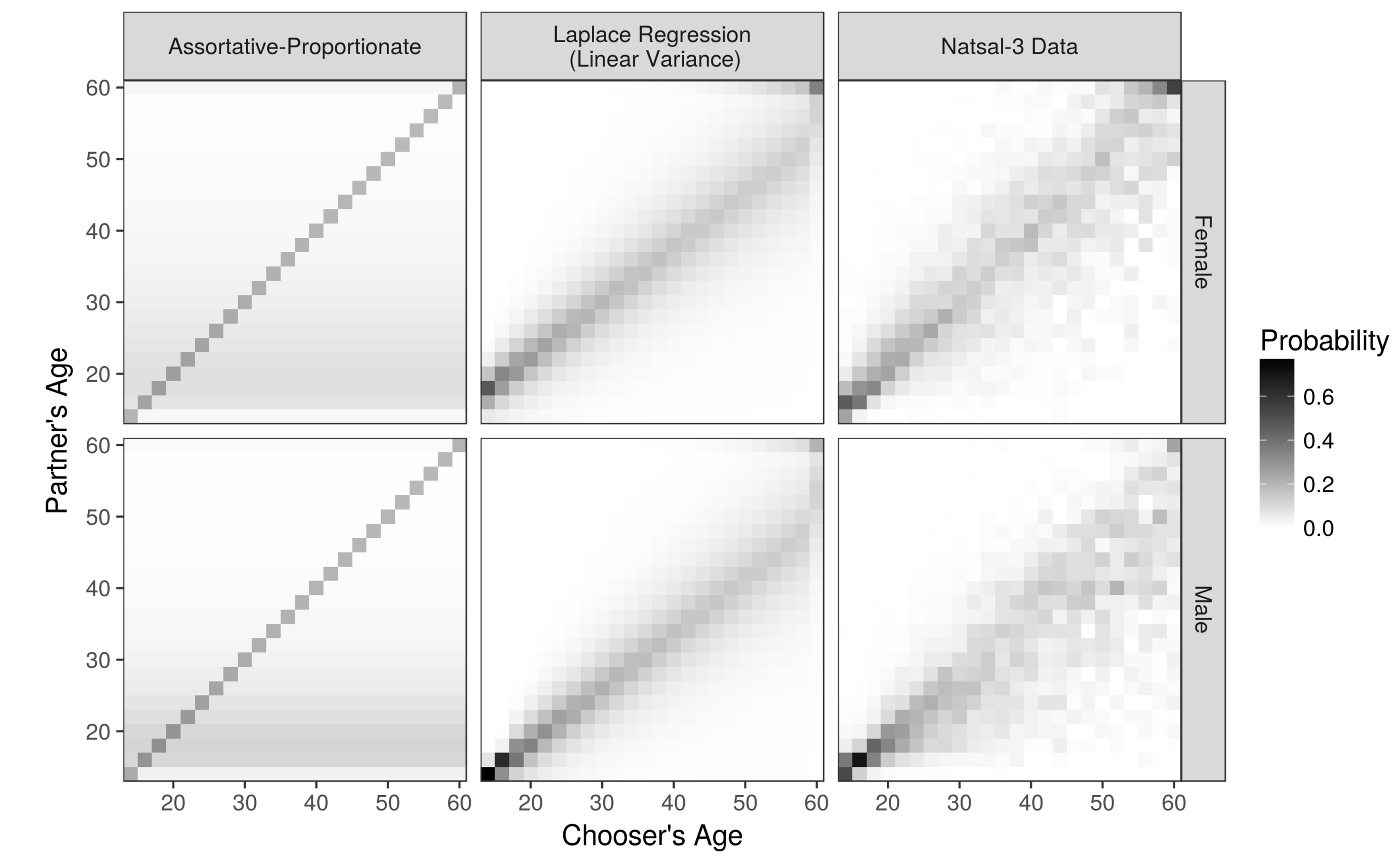


Figure 1: From left to right: the A-P structure, a regression model with Laplace distributed errors and variance as a linear function of age, and the Natsal data. Note the constant probabilities in rows of the A-P structure.

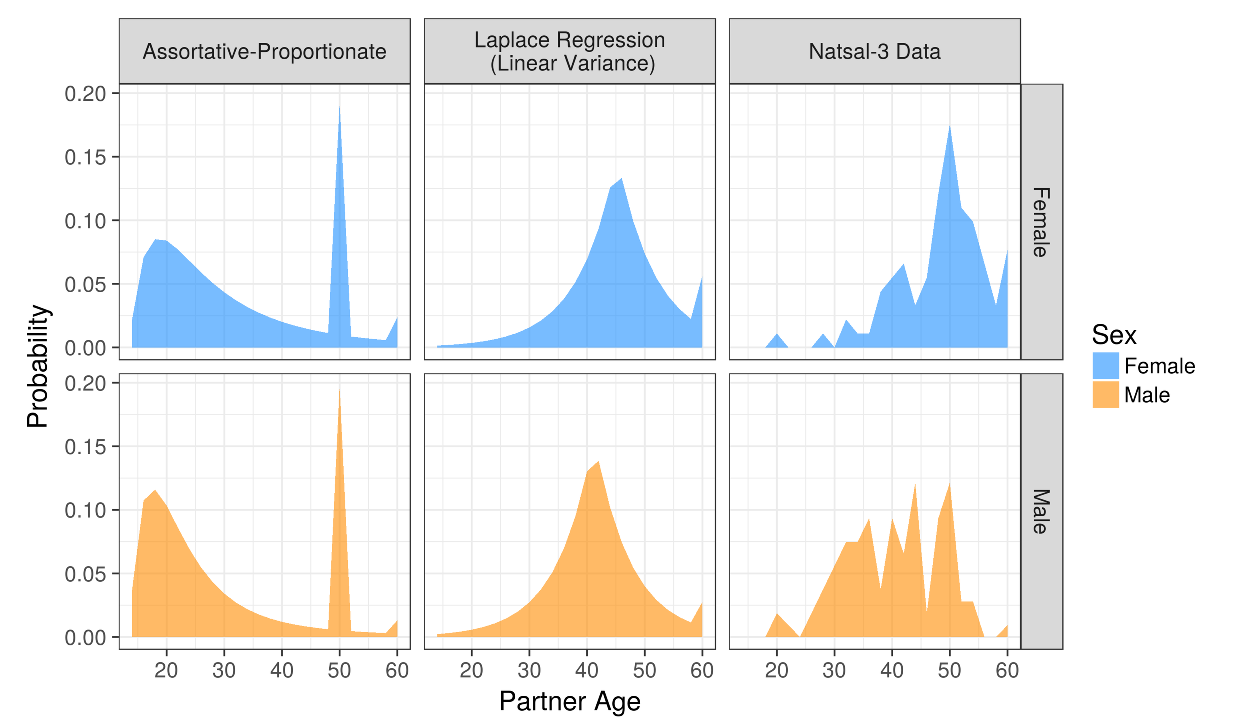


Figure 2: The partner age distributions for 50-year-old male and females.

Results: Likelihood Comparison

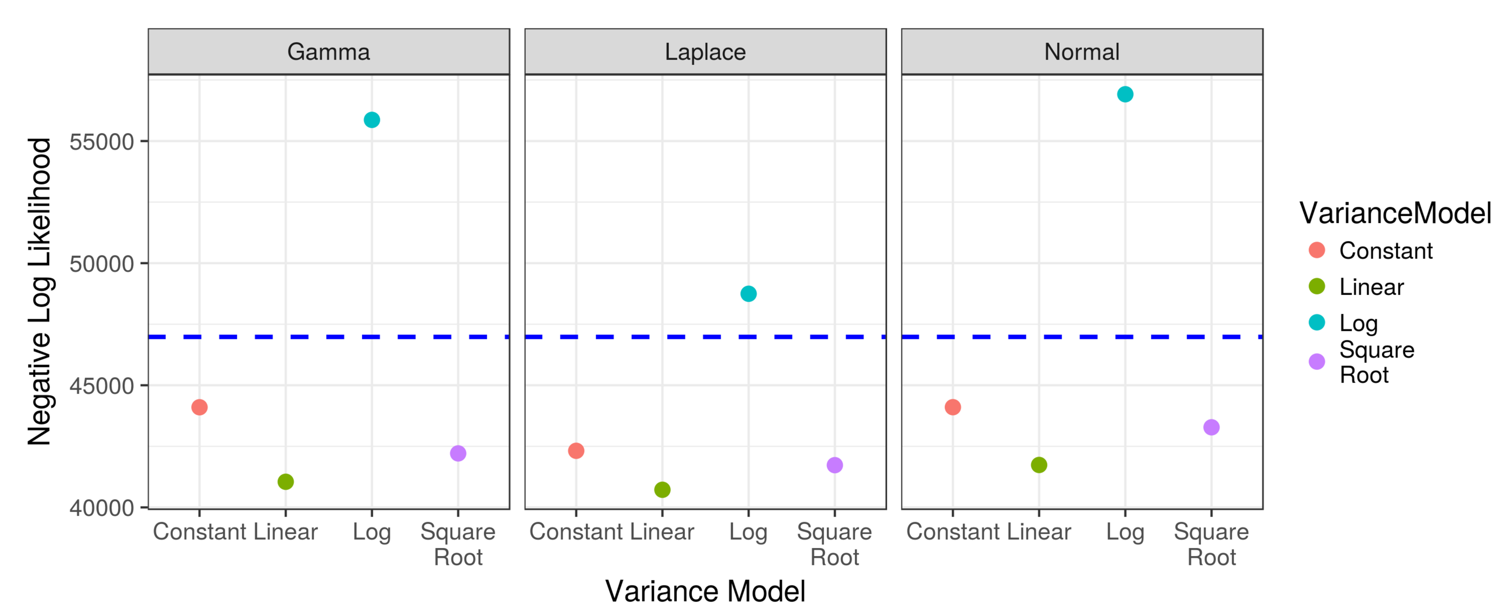


Figure 3: Likelihood of Natsal age mixing data under different mixing assumptions. The dotted blue line is the likelihood under A-P

Results: Extending Vaccination to 26-39-year-old Females

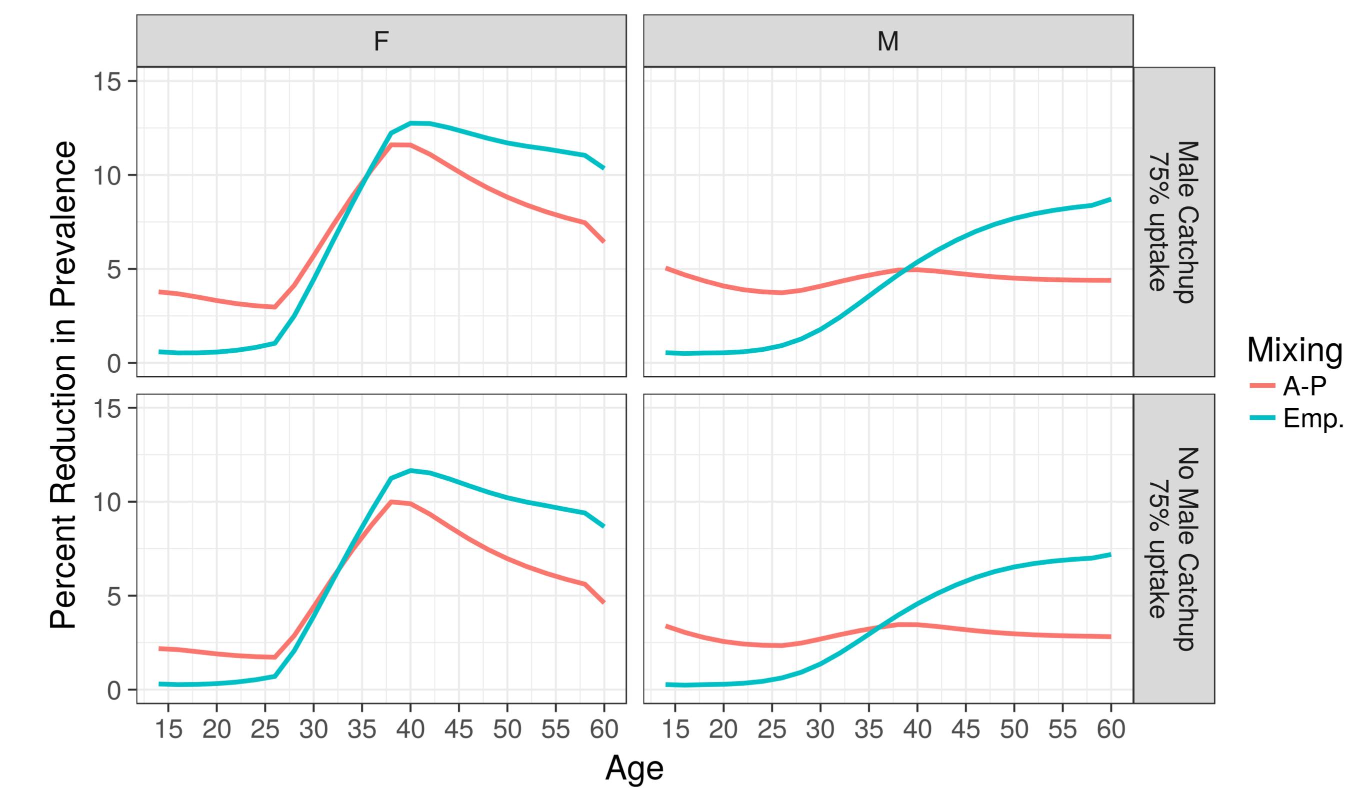


Figure 4: Relative reduction in prevalence due to extending vaccination, by sex, age, and male catch-up scenario.

Summary Measures

Table 1: Ratio of percentage reduction in prevalence predicted by A-P model to that predicted by empirical model.

Sex	<26 y/o	>41 y/o
M	760.8	58.1
F	551.5	72.6

- The A-P model predicts a reduction in prevalence **7 times greater** (young males) and **5 times greater** (young females) than empirical model prediction.
- A-P model predicts slightly more than one half of the reduction for older males, and slightly less than 3/4 of the benefit for older females.

Conclusions

- Standard regression models fit Natsal-3 age mixing data better than the A-P mixing structure.
- The A-P mixing structure overestimates the sexual connection between those above and below 30.
- The choice of mixing structure impacts model-estimated vaccine benefits.
- A model with an A-P mixing structure:
  - Overestimates reduction in HPV prevalence for younger individuals
  - Underestimates reduction in prevalence for older individuals

Future Directions

- Analyze other sexual behavior surveys (National Survey of Family Growth, etc.) and compare results.
- Extend HPV model to include cervical cancer and other outcomes, for cost-effectiveness analysis.
- Calibrate model to HPV prevalence and incidence and examine degree to which calibration corrects for mixing structure differences.
- Develop empirical mixing estimates for non-heterosexual sexual mixing.