Title: Beyond instantaneous partnerships: capturing partnership-level herd effects in compartmental models of sexually transmitted infections

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Abstract: PURPOSE. For decades, standard compartmental models of sexually transmitted infections have simulated sexual partnerships as "instantaneous". However, this instananeous approach can bias model-based epidemic projections and analyses of interventions. We developed a new approach to simulating sexual partnerships in compartmental models which moves beyond the instananeous paradigm.

METHODS. In the instananeous approach, a fraction of people change partners per unit time, reflecting average partnership duration, and possibly simultaneous partnerships per-person. Then, a fraction of people changing partners become infected, reflecting the cumulative probability of transmission per-partnership. In the proposed approach, we define a rate of transmission per-partnership, reflecting sex frequency; such rates can be summed across multiple simultaneous partnerships. Then, we track the number of people who recently transmitted or acquired infection; we decrease by one the effective numbers of partnerships among these people, until they form a new partnership, determined by partnership duration. We integrated the proposed approach, and the instananeous approach, into a calibrated model of heterosexual HIV transmission in Eswatini, and compared modelled HIV incidence under the proposed versus the instananeous approach.

RESULTS. Incidence under the proposed approach increased faster initially, but was later surpassed by incidence under the instantaneous approach (Figure). This difference can be explained mechanistically as follows. Initially, transmission is faster under the proposed approach because the *rate* of transmission per-partnership-year in the proposed approach is greater than the *probability* of transmission per-partnership-year in the instantaneous approach, due to survival effects in the latter (HIV transmission can only occur once per-partnership). As prevalence increases, both approaches capture population-level herd effects: reduced onward transmission from each infection due to *new* parnterships forming between two infected people (assumed to be at random). However, the proposed approach also captures partnership-level herd effects: reduced transmission due to *existing* partnerships continuing between two infected people following transmission. Thus, the proposed approach yields lower incidence versus the instananeous approach, after initial epidemic growth.

CONCLUSIONS. Modelling sexual partnerships as instananeous can cause compartmental models of HIV transmission to underestimate early epidemic growth, and overestimate HIV incidence in mature and declining epidemics. The proposed approach offers a generalizable solution to move beyond instantaneous partnerships in compartmental models of sexually transmitted infections, and captures key epidemic dynamics related to partnership-level herd effects.

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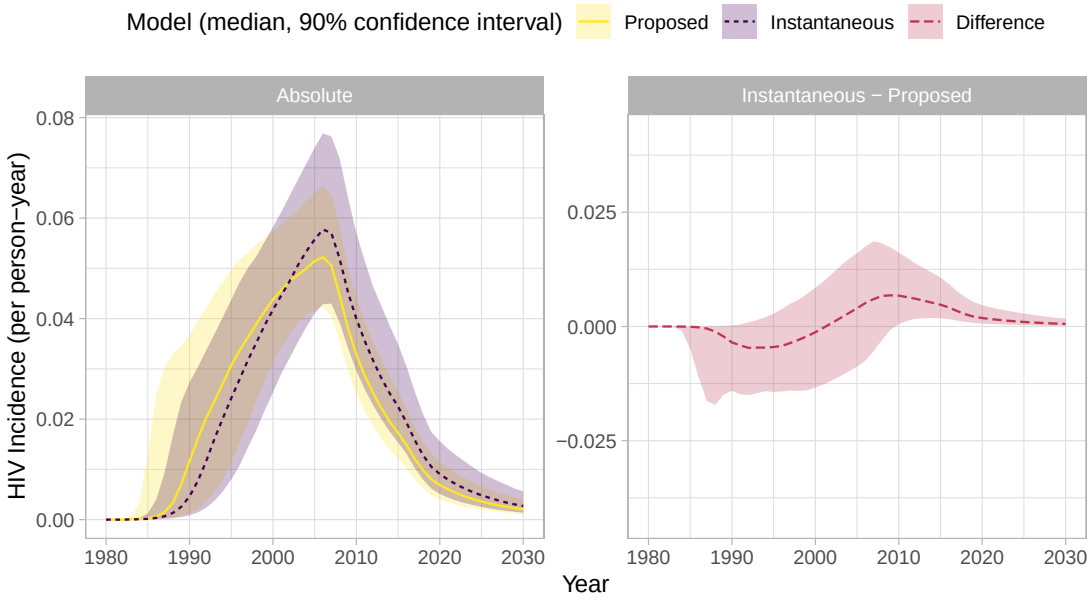
Figure:


Model (median, 90% confidence interval)
Proposed
Instantaneous
Difference
Absolute
Instantaneous − Proposed
HIV Incidence (per person−year)
0.08
0.06
0.04
0.02
0.00
0.025
0.000
−0.025
1980
1990
2000
2010
2020
2030
Year