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

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**Abstract:** PURPOSE. Classic compartmental models of sexually transmitted infections simulate sexual partnerships as "instantaneous" by applying the cumulative risk of transmission per-partnership to the fraction of people forming new partnerships per unit time. This "instananeous" approach can bias model outputs, like overestimating the contribution of long-term partnerships to overall transmission. We developed a new approach to modelling sexual partnerships in compartmental models, and explored differences in epidemic dynamics under the new (proposed) versus old (instananeous) approach.

METHODS. In the proposed approach, we parameterize sexual partnerships using: the number of concurrent partnerships per-person, frequency of sex per-partnership, and partnership duration; whereas the instantaneous approach uses: rate of partnership change, and total sex acts per-partnership. We track the numbers of people who recently transmitted or acquired infection via each partnership type, and who have not yet formed a new partnership of that type. Then, in the incidence equation, we reduce by one the effective numbers of partnerships of that type among those people. 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 (proposed approach) is greater than the *probability* of transmission per-partnership-year (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: 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.

**Limits:** 134 / 150 title characters

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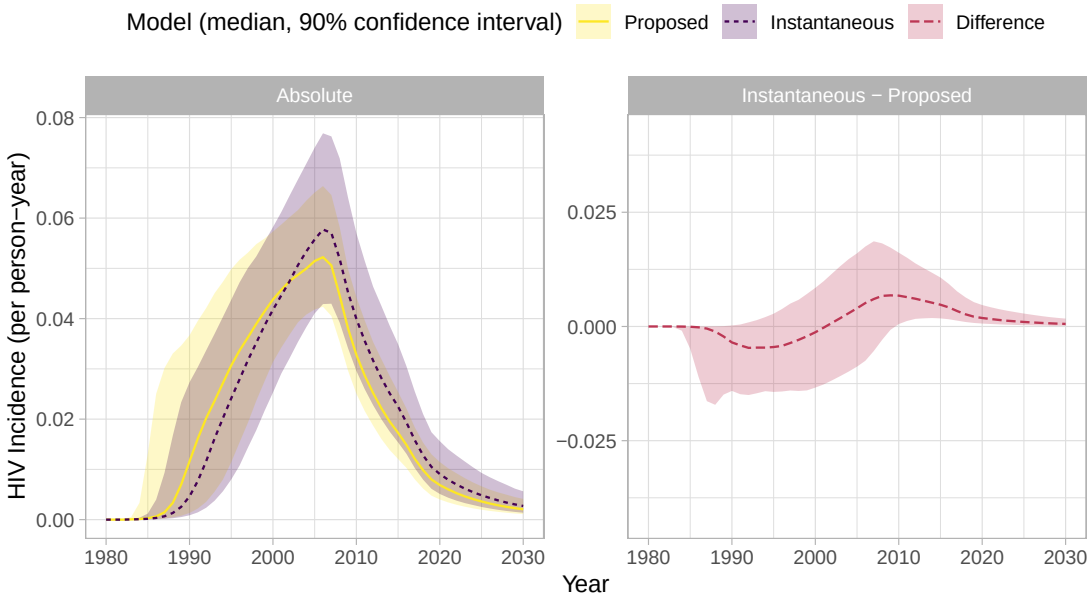
**Keywords:** compartmental models, incidence, sexual behavior, sexually transmitted disease, HIV, herd effects

**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