Population-Level Dynamics of COVID-19 Vaccine Uptake in the US

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Extended abstract

Vaccination is a cornerstone of infectious disease control and has substantially reduced severe illness, hospitalization, and mortality from diseases such as COVID-19 and influenza (Ghaffarzadegan, 2022; Gupta et al., 2021; Osterholm et al., 2012). Despite these benefits, vaccination uptake has stagnated or declined in many countries, including the United States, raising concerns about population-level immunity and long-term health outcomes (Parums, 2024). Understanding the factors that drive differences in vaccination uptake across communities is therefore critical for effective epidemic control and resilient health systems. In this study, we use COVID-19 vaccination as a recent case of large-scale vaccine deployment.

COVID-19 vaccination uptake varied substantially across U.S. states, raising questions about the behavioral and structural mechanisms shaping these patterns. While many epidemiological models treat vaccination behavior as exogenous, real-world uptake emerges from feedback between risk perception, social influence, eligibility, and capacity constraints (Funk et al., 2010). Understanding these endogenous processes is essential for explaining observed vaccination trajectories. However, the majority of behavioral epidemic models focus on formulating non-pharmaceutical interventions as a response to risk (LeJeune et al., 2024; Rahmandad et al., 2022), leaving vaccination underexplored as an alternative behavioral response to changing risk.

To address this gap, in this paper we develop a dynamic simulation framework that captures the feedback mechanisms through which population behavior shapes vaccination uptake over time (Figure 1). The model integrates responses to perceived infection risk with changes in vaccine availability, eligibility, and delivery capacity. By explicitly representing these interacting processes, rather than treating vaccination coverage as a static endpoint, the framework offers insight into why vaccination trajectories differ across regions.

As described in the final report (Xu et al. 2026), the behavioral parameters are estimated using an ODE-informed Tobit regression framework applied to weekly vaccination data from all 50 U.S. states and the District of Columbia during 2021–2022, providing an empirical basis for model calibration. The calibrated model reproduces observed regional vaccination trajectories and reveals three distinct phases of uptake. Early dynamics are governed primarily by responses to vaccine eligibility and capacity constraints, while later dynamics are driven by behavioral responses to changing COVID-19 incidence, followed by saturation dynamics. We note that rising case numbers stimulate additional vaccination, whereas cumulative vaccination generally reduces subsequent uptake due to depletion of more willing individuals.

Together, these findings highlight the importance of endogenizing vaccination behavior in epidemic models. Regional heterogeneity in responsiveness to infection risk and baseline vaccination propensity suggests the potential value of moving beyond uniform policy assumptions to better explain observed heterogeneities in vaccine uptake.

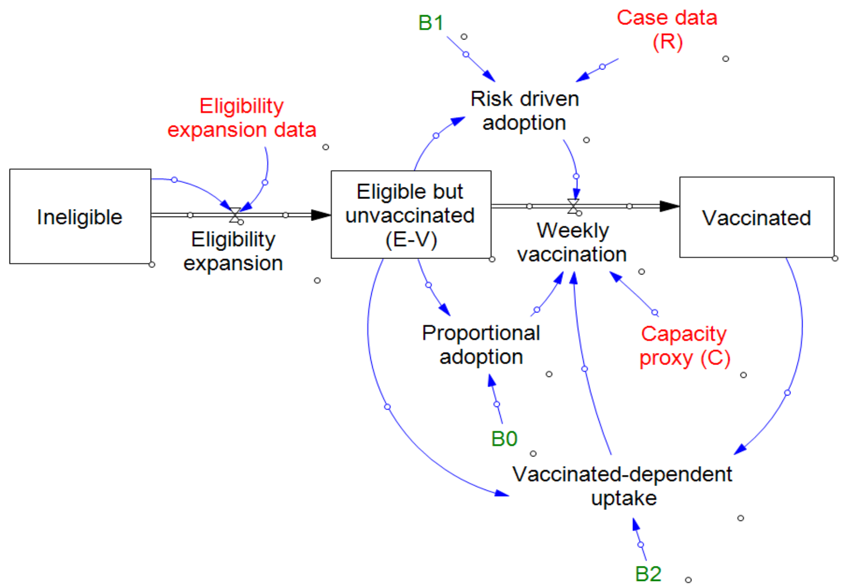

Figure 1: Stock flow representation of vaccination dynamic model

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