A Review of the Impact of Social Determinants of Health on HIV/AIDS Transmission Dynamics in Urban U.S. Communities

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Abstract:
HIV/AIDS continues to disproportionately affect vulnerable populations in urban U.S. communities despite major biomedical advances. This review summarizes current research on how socioeconomic determinants of health (SDOH), such as poverty, education, housing instability, stigma, and healthcare access, influence HIV transmission dynamics and treatment outcomes. These structural factors influence risk behaviors, network configurations, and engagement across the HIV care continuum, sustaining localized micro-epidemics. We synthesize evidence linking SDOH to proximal behaviors and care outcomes and explore modeling approaches that integrate these determinants. Traditional compartmental models often overlook heterogeneity introduced by SDOH, while agent-based, network, and hybrid models provide richer representations of social and structural influences. Incorporating SDOH into mechanistic models improves accuracy and policy relevance by explicitly parameterizing pathways through which social conditions alter exposure and care retention. This enables evaluation of structural interventions, such as housing programs, stigma reduction campaigns, and expanded healthcare access, alongside biomedical strategies. Evidence suggests that addressing upstream determinants yields greater population-level impact than behavioral interventions alone. We argue for a paradigm shift that frames HIV not only as a biomedical challenge but as a social epidemic rooted in inequity. Advancing SDOH-informed modeling requires localized data, interdisciplinary collaboration, and computational innovations to guide equitable and effective public health responses.

Keywords: HIV Transmission Dynamics, Social Determinants of Health, Healthcare Access, Network Models, Policy Interventions.

1. INTRODUCTION

Despite decades of advancements in prevention and treatment, HIV remains a major health problem in the US. Significant geographic and social disparities remain in HIV incidence, prevalence, and clinical outcomes. Urban neighborhoods frequently carry a disproportionate burden of new HIV infections and negative health outcomes. Within these cities, the HIV burden is concentrated in specific neighborhoods and groups that are poor or homeless. Limited access to culturally competent health services exacerbates the problem, as do various types of stigma and prejudice. These trends demonstrate that HIV is not only a biological problem, but also a social and structural problem. People's exposure risk and access to preventative strategies are heavily influenced by their living environment. They also affect an individual's ability to establish and sustain viral suppression (Menza et al., 2021). The social determinants of health (SDOH) encompass daily life situations, including socioeconomic status, education, housing, neighborhood environment, systemic racism, criminal-legal policies, and access to healthcare. These factors influence HIV transmission via a variety of mechanisms. They influence individual behaviors, such as the start of injection drug usage or survival sex. SDOH has an impact on network topologies, including patterns of partner selection and concurrency. Furthermore, they have an impact on the healthcare cascade, which encompasses testing, linkage, retention, adherence to antiretroviral medication, and viral suppression. Research and systematic reviews demonstrate a clear link between SDOH, namely housing instability and material hardship, and poor HIV care results.

These effects include reduced viral suppression and an increased risk of contracting and spreading HIV (Aidala et al., 2016).

Mathematical and computational modeling provide a structured approach for converting empirical connections into quantitative estimates of population-level transmission. They also help to assess the possible impact of structural interventions. Traditional homogeneous compartmental models are effective for establishing wide forecasts. However, they may overlook how differences in SDOH contribute to epidemic persistence within specific subpopulations or areas. These models may also fail to account for how structural interventions, such as housing programs, culturally competent treatment, or anti-stigma measures, are disseminated through networked systems. As a result, they may not fully capture the role these interventions play in reducing incidence. Recent methodological work has emphasized the importance of explicitly including SDOH in epidemic models. This can be accomplished by categorizing compartments based on SDOH indications, including SDOH-informed behavior rules into agent-based or network models, or combining mechanical transmission models with causal or statistical models of social causes. Such methods can yield more accurate and policy-relevant results (Hogan et al., 2021). This study creates a modeling framework to connect empirical findings on SDOH with mechanistic HIV transmission modeling in urban U.S. settings.

Our goals are to synthesize evidence linking targeted SDOH domains (poverty/material deprivation, education, housing instability, stigma/criminalization, and access to health care) to proximal risk behaviors and care-continuum outcomes. Also, to develop a transparent conceptual model that maps each SDOH to parameters and causal pathways, and finally, demonstrate modeling strategies, including compartmental stratification and a hybrid agent-based approach. By explicitly parameterizing the pathways through which SDOH alter exposure and care outcomes, we aim to produce policy-relevant projections and identify high-leverage interventions for ending urban HIV epidemics. This review uniquely synthesizes social determinants of health into a unified modeling framework for HIV transmission.

2. OVERVIEW OF HIV/AIDS TRANSMISSION DYNAMICS

2.1 Basic epidemiology of HIV/AIDS

Since the 1980s, antiretroviral therapy (ART) and combined prevention efforts like condoms, harm reduction, and pre-exposure prophylaxis (PrEP) have drastically lowered HIV morbidity and mortality rates. Despite this success, the US continues to record tens of thousands of new HIV cases per year. These instances demonstrate persisting differences by region, race and ethnicity, gender, age, and risk group. In 2022, CDC surveillance data revealed roughly 38,000 new HIV cases in the US. The burden is still largest among males who have sex with men (MSM), racial and ethnic minorities, notably Black or African American people, and younger age groups. Regional differences also persist, with the Southern United States continuing to account for the majority of new infections nationwide (Anderle et al., 2024).

2.2 Transmission pathways and risk factors in urban communities

HIV transmission occurs through well-defined biological routes. These include receptive or inserted sexual contact (anal and vaginal), sharing of injection equipment, perinatal transmission, and, in rare cases, transfusion or medical exposure. However, the actual risk within a population depends heavily on network structure and social context.

In urban U.S. communities, transmission is influenced by dense sexual and drug-use networks, high rates of partner turnover in certain subpopulations, and limited access to prevention and care in some areas. Key behavioral risk factors in these settings include condomless anal intercourse among men who have sex with men, multiple concurrent partnerships, low PrEP uptake among eligible groups, and sharing of injection equipment among people who inject drugs (PWID). Each of these behaviors interacts with local network connections to shape the overall epidemic potential. Beyond individual behaviors, population-level factors have a significant impact on HIV transmission. These include network mixing patterns, such as assortative mixing based on race, ethnicity, or risk level. The geographical clustering of high-prevalence communities adds to uneven transmission. Another key issue is the availability of bridging populations, individuals who connect otherwise disparate networks. Agent-based and network studies have demonstrated that even small changes in average partner number or concurrency among high-risk groups can have a significant impact on overall HIV incidence. This happens because closely coupled networks can enhance transmission chains between populations (Jenkins et al., 2023).

2.3 The role of behavioral and structural factors

It is essential to differentiate between proximate behavioral and upstream structural determinants. Condom use, PrEP adherence, and needle sharing are all examples of proximate behavioral determinants. Poverty, housing instability, criminality, neighborhood segregation, and access to culturally competent healthcare are all examples of upstream structural determinants.

Behavioral factors affect immediate transmission risk, whereas structural determinants determine how behavioral hazards and access to prevention and care are dispersed throughout communities. For example, housing insecurity is highly associated with increased risk behaviors such as transactional sex and higher relationship turnover. It has also been linked to decreased rates of care retention and reduced viral suppression. These channels work together to increase community viral load and the risk of HIV transmission (Brawner et al., 2022).

Causal frameworks and new research indicate that structural determinants frequently have an indirect impact on HIV outcomes. They accomplish this by modifying the economic and social variables that influence behavior and access to healthcare. Interventions that address these systemic factors can lower HIV prevalence across groups. Examples include housing assistance, decriminalization, Medicaid expansion, and culturally appropriate clinics. These tactics can be beneficial even if they do not directly alter individual behaviors. Modeling studies that involve structural determinants also yield useful results. They may, for example, account for reduced care retention or poorer PrEP uptake because of housing instability or stigma. Such research demonstrates that the extent and long-term impact of intervention benefits varied significantly from models that assume all populations are behaviorally similar (Menza et al., 2021).

2.4 Surveillance patterns and urban heterogeneity, where transmission is concentrated

HIV monitoring statistics frequently demonstrate disparities amongst U.S. urban areas. Several large metropolitan statistical regions (MSAs) account for a sizable proportion of all HIV diagnoses. Recent estimates from 2014 to 2022 show that cities in the South, such as Miami, Memphis, and Atlanta, as well as a few other major areas, have a relatively high HIV incidence. In addition, infection rates in these cities are declining at a slower rate than in other MSAs. Within cities, some subpopulations suffer much greater dangers. HIV prevalence is notably high among transgender women, those facing homelessness, and Black males who have sex with men (MSM). They also face several overlapping socioeconomic obstacles, which raise the likelihood of transmission. These disparities between and within cities underline the importance of localized, SDOH-informed modeling rather than depending exclusively on national estimates (Fernandez et al., 2022). These epidemiological trends highlight the need to model how social factors shape transmission dynamics within cities.

3. SOCIAL DETERMINANTS OF HEALTH IN URBAN HIV/AIDS TRANSMISSION

The socioeconomic, structural, and interpersonal conditions in which people live shape both HIV exposure and the HIV care cascade (testing, linkage, retention, ART initiation and adherence → viral suppression). In metropolitan areas in the United States, SDOH commonly cluster, for example, poverty, housing instability, and limited clinic access in the same neighborhoods and interact synergistically to form localized "micro-epidemics" with high prevalence and low viral suppression (Dailey, A. F., 2022).

3.1 Poverty and income inequality

Poverty reduces the material resources available for prevention and care (transportation, phone access for appointments, stable housing), increases stress and survival strategies (transactional sex, higher partner turnover), and increases the likelihood of people becoming involved in higher-prevalence networks. Income inequality at the area level (measured by Gini or area deprivation indices) can also be influenced by relative social status, less social cohesion, and inferior local services, resulting in increased community viral loads and persistent transmission even when individual incomes differ (Kalichman et al., 2019). In U.S. studies, area-level social vulnerability and socioeconomic inequality are consistently linked to higher rates of new HIV diagnoses. For example, greater diagnosis rates in census tracts with high Social Vulnerability Index scores after accounting for individual risk variables, multilevel and ecological research, and reviews.

Modeling implications suggest that poverty and inequality can be represented in mechanistic models in several ways. First, they can act as modifiers of probabilities for engaging in risk behaviors, such as increasing partner change rates or the likelihood of transactional sex. Again, they can influence care-cascade probabilities by reducing testing and lowering retention in care. Lastly, they can appear as contextual parameters, such as a higher baseline prevalence in low-resource neighborhoods. To ensure accuracy, these modifiers should be quantified using area-level analyses and local surveillance data.

3.2 Education and health literacy

Individuals' educational attainment and HIV health literacy influence their understanding of risk, knowledge of and ability to navigate preventive alternatives (condoms, PrEP), interpretation of test results, and adherence to complex treatment regimens. Low literacy or health literacy increases the likelihood of missed appointments, misunderstanding of ART regimens, and decreased use/adherence to PrEP or PEP. According to systematic reviews and research conducted in the United States, lower health literacy and formal education are associated with poorer ART adherence and retention in care. Health literacy influences outcomes via mediators such as patient self-efficacy, trust in healthcare professionals, and stigma. Health education initiatives can enhance knowledge and adherence rates. Their effects are amplified when supplemented with structural aids such as patient navigation, medication reminders, and free medicine programs.

There are two basic strategies to incorporate education and health literacy into models. They may manifest individual-level characteristics, such as the likelihood of engaging in preventative actions, attending testing, or complying with ART. Alternatively, they can function as modifiers, influencing the effect sizes of interventions. Higher education levels, for example, can boost a PrEP campaign's adoption rate. To ensure correct parameterization, employ surveys that assess health literacy and adherence among local target populations.

3.3 Housing instability and homelessness

Housing instability, which might include repeated relocation, overcrowding, or homelessness, jeopardizes continuity of care. It also makes drug storage and adherence more challenging. Unstable housing promotes exposure to high-risk networks, including survival sex and injection sharing. It exacerbates comorbidities such as mental illness and substance use, which reduces engagement in care. Homelessness also limits access to continuous primary care, increasing reliance on emergency-only providers (Aidala et al., 2016). Systematic studies and large programmatic evaluations demonstrate that unstable housing is highly connected with delayed access to HIV care. It is also associated with a decreased chance of ART use, poorer adherence, and lower rates of viral suppression. In U.S. programmatic data, such as among Ryan White clients, viral suppression is significantly lower for those with precarious housing than for those who are permanently housed. According to CDC and other federal agency findings, including epidemic investigations, homelessness has been a major component of previous urban HIV outbreaks. These findings emphasize housing as an important area for reform. Represent housing status as a dynamic state, with people transitioning into and out of homelessness. Let housing status influence partner formation rates and care cascade probability. Consider interventions like housing-first programs and rental help to be transitions that improve care retention and virus suppression. These structural levers frequently result in greater population-level reductions in transmission than targeted behavioral treatments alone.

3.4 Access to healthcare (insurance, clinic availability, ART distribution)

Insurance coverage, clinic location and availability, and the presence of culturally competent care are all factors that contribute to access. It also includes navigation assistance and the availability and affordability of

ART and PrEP. Access barriers can cause delays in diagnosis, limit linkage to care, diminish ART initiation, and impede PrEP scale-up.

In contrast, legislative reforms that boost coverage, such as Medicaid expansion or Ryan White programs, as well as clinic capacity, improve early diagnosis, care linkage, and viral suppression. Studies on Medicaid expansion and insurance coverage reveal increased patient engagement. Several studies have found improvements in viral suppression among newly insured patients, albeit the results vary depending on the setting and how services are structured.

National monitoring and program assessments, such as the Medical Monitoring Project and the NHSS, show that a lack of insurance and inadequate clinic capacity lead to later diagnosis and lower viral suppression. Modeling implications suggest that access should be represented as probabilities for three key outcomes. These include receiving regular testing, being linked to and retained in care, and being prescribed ART or PrEP. Policy options such as Medicaid expansion, mobile clinics, telehealth, and pharmacy-based PrEP can then be evaluated within these models. Simulations based on these parameters can help estimate reductions in HIV incidence and changes in the time required to achieve viral suppression.

3.5 Stigma, discrimination, and social networks

Stigma, whether based on HIV status, sexual orientation, or race and ethnicity, lowers testing while discouraging disclosure and partner notification. It also reduces engagement and trust in health care while increasing social isolation. Social network structures have a significant influence on transmission dynamics. High-prevalence group clustering, assortative mixing based on race or risk, and the presence of bridge individuals all have an impact on transmission speed and reach. Stigma also influences whether people obtain PrEP or go for early testing (Harawa et al., 2022). According to quantitative and qualitative research, stigma is associated with decreased testing intent, delayed access to therapy, and poorer adherence. According to social network studies, network composition and connectedness have a significant impact on exposure risk and the efficacy of treatments targeting important players. Recent data from worldwide stigma indices and U.S. research show that persistent stigma remains a significant obstacle to egalitarian prevention and care. Modeling implications suggest that stigma should be included in models in three main ways. First, it can act as a modifier of care-seeking probabilities. Then, it can be represented as a parameter that reduces uptake of PrEP and testing. Lastly, stigma can function as a driver of hidden network structures by reducing disclosure and creating more concealed partnerships. Interventions such as community anti-stigma campaigns or peer navigation can be modeled as gradual increases in care-seeking and disclosure probabilities.

4. MODELING APPROACHES TO HIV TRANSMISSION

HIV epidemics in urban areas in the United States are defined by concentrated transmission among specific subpopulations, such as males who have sex with men, drug users, and racially or ethnically marginalized groups. They are also influenced by local patterns of housing insecurity, incarceration, poverty, healthcare access, and stigma. Models intended to inform urban policy should therefore incorporate local surveillance and care-cascade data, such as city or county prevalence, diagnostic rates, and viral suppression levels. These models should also consider how social determinants of health influence risk and engagement in care. Recent studies emphasize the complementary nature of mechanistic models, including compartmental, agent-based, network, and hybrid approaches. Having outlined key SDOH domains, this section examines modeling approaches that can incorporate them. (Hogan et al., 2021; Stannah et al., 2024).

4.1 Compartmental Models (e.g., SIR, SEIR variants for HIV)

Compartmental models classify the population into epidemiological states. HIV typically progresses through the following stages: susceptibility, infection (acute or chronic), diagnosis, ART, and viral suppression. Flows between states are represented by rates in ordinary differential equations or their stochastic counterparts. Urban U.S. models are often stratified to account for observed differences. The stratification may be based on risk category, such as men who have sex with men, people who inject drugs, or individuals at heterosexual risk, as well as age. In some cases, race, ethnicity, or geographic unit is also included. Compartmental models are useful for both projection and policy comparison. For instance, they can help determine how scaling up

ART or PrEP interacts with changes in testing. They are also valuable for identifying threshold quantities, such as effective reproduction rates under various intervention combinations (Stannah et al., 2024).
Modelers often use three main methods to incorporate social determinants of health (SDOH) into a compartmental framework. First, they may divide compartments by SDOH status, such as housed versus unhoused persons. Then, they may define transition rates based on SDOH variables, for example, lowering ART initiation or adherence rates during housing instability. Finally, they may include mediating characteristics that link structural exposures with proximate behaviors, such as condom use or partner acquisition rates The fundamental tradeoff is that while compartmental models are compact, they can mask individual heterogeneity and network clustering, both of which are important in many urban epidemics. As a result, their depictions of SDOH are frequently simplified until calibrated with extensive local data (Stannah et al., 2024).

4.2 Agent-Based Models

Agent-based models (ABMs) mimic humans or agents with characteristics that correspond to social determinants of health (SDOH). These characteristics could include housing status, employment, insurance, incarceration history, and stigma exposure. ABMs also utilize rules to govern how people interact and make healthcare decisions. In metropolitan contexts in the United States, ABMs can demonstrate how housing instability increases partner turnover or decreases care retention. They can also show how changes in employment or local service availability affect testing or PrEP adoption over time.

ABMs are particularly suitable for testing scenarios that integrate structural changes with clinical interventions, such as quick rehousing followed by expanded PrEP administration.
They are also useful for capturing heterogeneity and the temporal dynamics of exposures. However, ABMs require a significant amount of data. Credible models rely on local estimates of SDOH distributions, empirically informed behavioral norms, and calibration to observed incidence and prevalence to reduce uncertainty. For urban policy concerns, such as estimating how many illnesses a city may save over five years by increasing housing vouchers by a given percentage, ABMs can provide richer counterfactuals than basic compartmental techniques.
This is only true if the causal assumptions between SDOH and behavior are properly supported and sensitivity analyses are clearly documented (Hotton, 2025; Stannah et al., 2024)

4.3 Network Models

HIV spreads through social and sexual relationships, which are clearly represented by network models. In these models, nodes represent individuals and edges reflect collaborations. Concurrency, assortative mixing by race, age, or behavior, and short network path lengths can all contribute to significant local transmission potential in dense metropolitan networks, even when average risk behavior is low. Empirical research in US cities shows that social and sexual network structure influences risk behaviors and can increase inequities. Integrating social determinants of health (SDOH) into network models is critical when structural factors alter network position or tie dynamics. For example, housing instability or incarceration can disrupt and distort partnership links, a process known as network churn. This can result in repeated high-risk exposures, which accelerate transmission. Stigma can also affect clustering based on HIV status or use of health-care services. Network models are very useful for evaluating interventions based on relationships, such as partner services or targeted PrEP/ART in high-connectivity clusters. They are also beneficial for policy questions that require identifying and intervening in network hotspots (Schneider et al., 2013).

4.4 Hybrid Models

Hybrid techniques include compartmental, agent-based, and network components to capture both population dynamics and fine-scale variation. A compartmental backbone is commonly used in hybrid designs to reflect the general population. This framework incorporates agent-based or network sub models to replicate major high-risk groups, such as MSM networks or PWID clusters, as well as to represent specific geographic locations. Hybrid models are particularly effective when interventions take place at various levels. For example, they can model a city-wide expansion of ART as a population-level (compartmental) effect, as well as focused housing interventions and network-based partner services as agent- or network-level effects. The scoping literature suggests that hybrid models should be based on longitudinal data of how social determinants of health (SDOH) influence mediators, including testing, condom usage, and treatment adherence. These models should be calibrated using both epidemiological and SDOH prevalence data. Overall, hybrid models provide a practical solution for urban policymakers who require both the broad comparability of compartmental forecasts and the mechanistic insights afforded by individual and network models (Stannah et al., 2024).

5. INTEGRATION OF SOCIAL DETERMINANTS OF HEALTH (SDOH) INTO HIV TRANSMISSION MODELING

Early HIV transmission models focused mainly on biological processes and individual risk behaviors. These approaches were useful for understanding viral dynamics but performed poorly in explaining persistent disparities across urban U.S. communities. More recent work integrates social determinants of health into modeling frameworks, treating them as structural drivers of exposure, diagnosis, treatment, and retention. This section reviews three representative studies that explicitly incorporate SDOH into HIV models and outline how these approaches improve predictive accuracy and policy relevance compared to traditional models.

5.1 Poverty, Education, and Economic Structure in Compartmental Models

de Oliveira et al. (2022) developed an extended compartmental HIV/AIDS model that explicitly parameterized social and economic determinants. The population was stratified into susceptible, infected, AIDS, and treatment compartments, with transition probabilities modified by poverty, education level, substance use, and preventive behaviors. These determinants were identified through a structured review and incorporated directly into rates of testing, treatment initiation, adherence, and disease progression. The model was calibrated using national surveillance data through multi-objective optimization and then used to simulate long-term epidemic trajectories under varying poverty scenarios.

The model reproduced historical trends in incidence and mortality and showed that reductions in poverty led to substantial declines in new infections and AIDS related deaths.

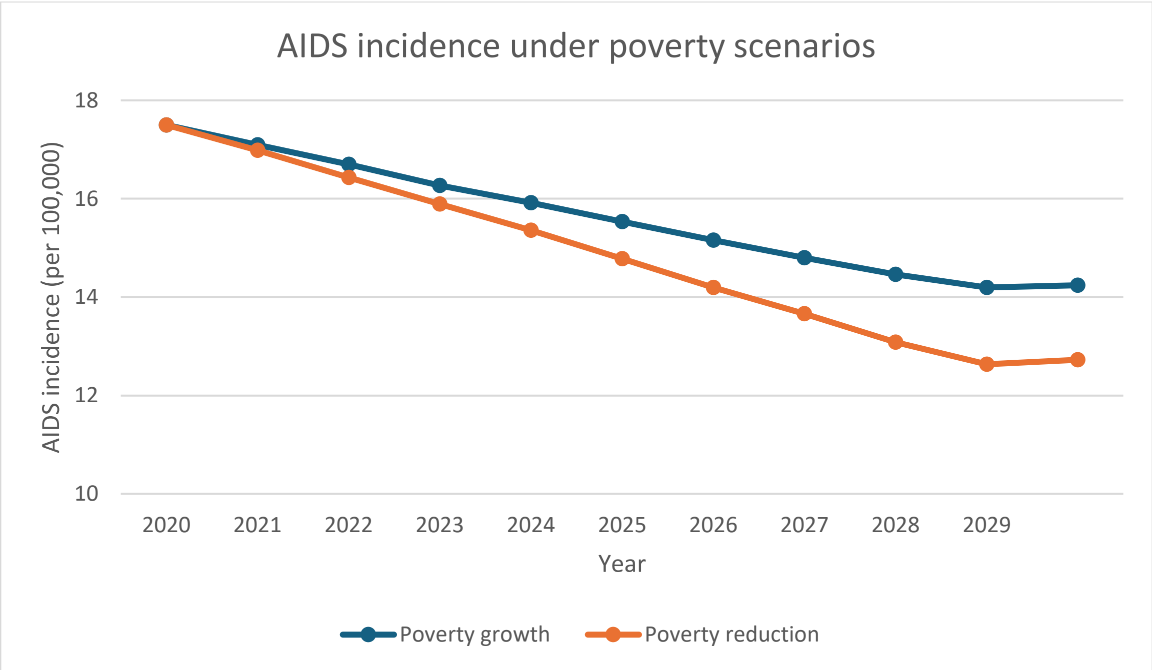

Figure 1 shows the projected HIV/AIDS incidence rate (per 100,000) from 2020 to 2030 under two poverty scenarios

These effects were mediated through improved engagement across the HIV care cascade rather than changes in biological transmissibility alone. In contrast, traditional homogeneous models without socioeconomic stratification underestimated incidence in disadvantaged subpopulations and failed to capture the downstream effects of economic instability. By embedding poverty and education within the transmission system rather than treating them as external correlates, this approach enables direct evaluation of structural interventions such as income support or employment programs. This substantially improves policy relevance by allowing decision makers to assess social policies as epidemic control tools, supporting the hypothesis that SDOH-informed models better reflect real-world transmission dynamics.

5.2 Stigma as a Behavioral and Network Modifier in Agent-Based Models

Bisanzio et al. (2024) used an agent-based modeling framework to examine the effects of HIV related stigma in a large simulated U.S. population. Anticipated, internalized, and experienced stigma were modeled as behavioral constraints that altered individual probabilities of testing, disclosure, treatment initiation, and long-term adherence. These stigma dimensions also influenced sexual network visibility and partner notification, linking social experience directly to transmission pathways.

Simulation results showed that even modest reductions in community-level stigma produced large increases in testing uptake and retention in care. These improvements led to lower community viral load and sustained reductions in HIV incidence. Sensitivity analyses confirmed that stigma affected multiple decision points simultaneously, amplifying its population-level impact.

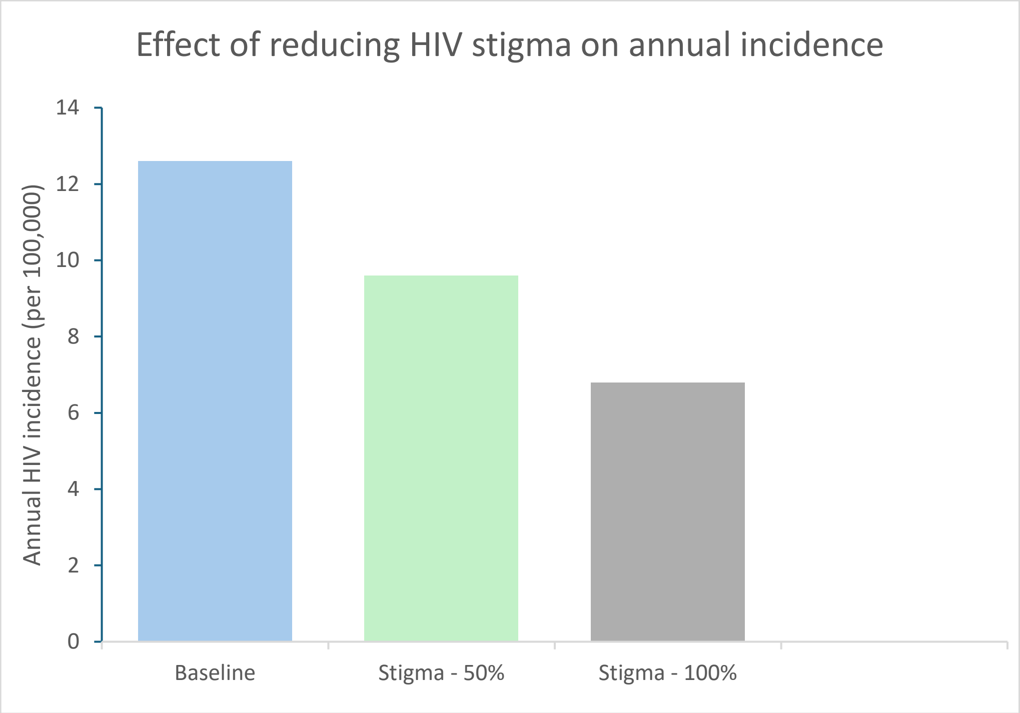

Figure 2. Estimated annual HIV incidence per 100,000 population under three stigma scenarios in a simulated U.S. urban setting. Incidence declines from the baseline scenario (12.6 per 100,000; 95% credible interval [CrI]: 11.4–13.5) to a 50% reduction in anticipated, internalized, and experienced stigma (9.6; 95% CrI: 8.6–10.3), and further to complete stigma elimination (6.8; 95% CrI: 6.1–7.3). Estimates are derived from agent-based model simulations.

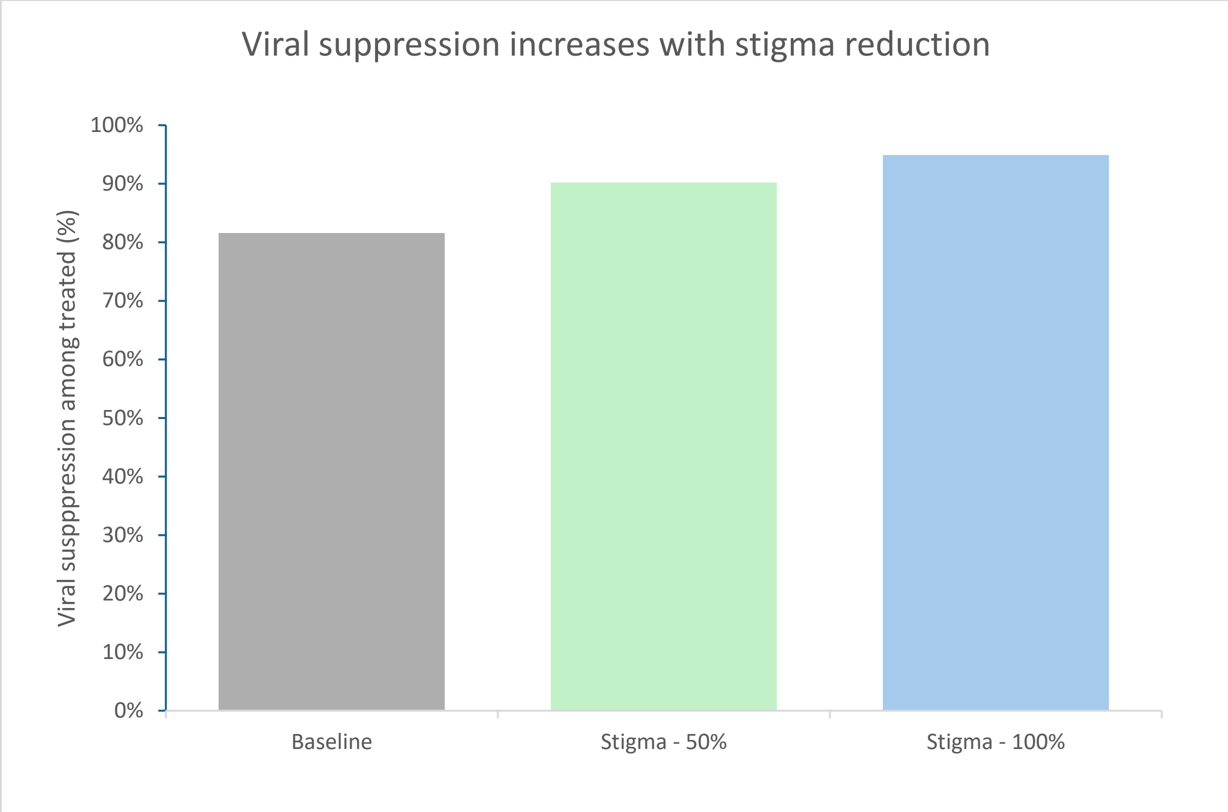

Figure 3. Viral suppression among people receiving antiretroviral treatment under three stigma scenarios in a simulated U.S. urban setting. At baseline, 81.6% of individuals on treatment are virally suppressed. Viral suppression increases to 90.2% with a 50% reduction in stigma and to 94.9% with complete stigma elimination.

Traditional models often represent disengagement from care as a fixed dropout rate with no social explanation. The agent-based approach outperformed these models by revealing how stigma driven behaviors shape network structure and cascade outcomes. This allows policymakers to compare biomedical interventions with stigma reduction strategies such as community education, provider training, and peer navigation. The model therefore expands the range of actionable interventions and improves the realism of epidemic projections in urban settings.

5.3 Housing Instability as a Dynamic State in Care Continuum Modeling

Rajabiun et al. (2018) examined housing instability as a structural determinant affecting HIV outcomes using a multi-site prospective cohort of individuals with unstable housing and co-occurring vulnerabilities. Housing status was treated as a dynamic state rather than a static background variable. Path analysis was used to evaluate how housing stability mediated retention in care and viral suppression over time while accounting for substance use, food insecurity, and mental health factors. The study found that achieving housing stability significantly increased retention and viral suppression, with indirect effects through improved food security and reduced substance related risk. These findings demonstrate clear causal pathways through which housing interventions affect epidemic relevant outcomes.

Housing stability is associated with higher retention, ART use, and viral suppression. The adjusted models show that these differences remain after accounting for other factors, supporting housing as a modifiable upstream driver of downstream cascade outcomes. AOR denotes adjusted odds ratio, comparing participants who achieved housing stability with those who remained or became unstably housed, after controlling for socio-demographic, behavioral, and clinical covariates.

Table 1. Housing stability and HIV care outcomes

HIV care outcome	Stabilized housing	Became/remained unstably housed	Effect size (AOR)
Retained in care	86%	79%	AOR 2.12 (95% CI 1.11–4.05)
Prescribed ART	84%	72%	AOR 2.06 (95% CI 1.62–2.63)
Virally suppressed	77%	66%	AOR 1.62 (95% CI 1.03–2.55)
Linked to care	86%	85%	AOR 1.81 (95% CI 0.87–3.04), not significant

In Table 1, adjusted odds ratios (AORs) are used to illustrate how social determinants of health (SDOH) operate as independent structural drivers of HIV care and transmission outcomes after accounting for individual-level clinical and behavioral factors. An AOR greater than 1 indicates that favorable social conditions are associated with higher odds of achieving key HIV care outcomes, whereas an AOR less than 1 indicates reduced odds under adverse social conditions. When the 95% confidence interval does not include 1, the association is statistically significant, providing quantitative evidence that SDOH exert measurable effects beyond biological processes alone. Within the context of this study, these adjusted estimates demonstrate why models that explicitly incorporate SDOH outperform traditional approaches. By isolating the independent contribution of structural factors, AORs provide empirical justification for embedding SDOH into HIV transmission and care models, thereby improving explanatory accuracy and strengthening the evaluation of policy-relevant interventions.

Models that overlook housing dynamics fail to capture the compounding risks associated with missed appointments, poor adherence, and unstable social networks. By treating housing as a modifiable state linked to policy driven transitions, this approach improves explanatory power and supports evaluation of interventions such as Housing First, navigation services, and low barrier care delivery. This strengthens the alignment between modeling outputs and real world policy decisions at the municipal and state levels.

5.4 Implications for Model Accuracy and Policy Design

Across these studies, integrating SDOH into HIV models consistently improved alignment with observed disparities and revealed intervention pathways that traditional models miss. Poverty, stigma, and housing instability functioned as upstream drivers that influenced multiple points in the transmission and care cascades. Models that incorporated these determinants produced more realistic forecasts and supported broader policy portfolios beyond biomedical scale up alone.

This evidence supports the hypothesis advanced in this review that SDOH informed modeling frameworks provide superior predictive accuracy and policy relevance for understanding HIV transmission dynamics in urban U.S. communities. Treating social determinants as endogenous components of transmission systems is therefore essential for designing equitable and effective HIV prevention strategies.

6. POLICY AND INTERVENTION IMPLICATIONS

The studies reviewed in Section 5 demonstrate that integrating social determinants of health (SDOH) into HIV transmission models not only improves predictive accuracy but also transforms public health strategy. For example, Anderle et al. (2024) showed that incorporating poverty into national-level models revealed that reducing economic hardship significantly decreases new infections and AIDS-related deaths, guiding policymakers toward structural interventions such as income support programs. Bisanzio et al. (2024) used agent-based models to test stigma reduction. They found that even small drops in stigma raised testing uptake and improved care retention. This supports anti-stigma campaigns and provider training as key parts of HIV prevention. Mgbako et al. (2022) identified housing instability as a major determinant of outcomes. Their network-based models showed that housing-first programs improve ART adherence and increase viral suppression. This supports housing assistance as a high-impact intervention. These findings validate this study's hypothesis that SDOH-informed models outperform traditional approaches by capturing the upstream drivers of transmission and care disparities. By parameterizing structural factors, these models help policymakers test full strategies. This includes housing programs, stigma reduction, and expanded healthcare access. They can compare these with biomedical interventions. This supports responses that are effective and equitable.

The incorporation of SDOH in HIV modeling does more than just improve forecast accuracy; it also reshapes public health strategy. SDOH-informed models provide policymakers with detailed insights into the underlying mechanisms that perpetuate inequities, allowing them to test policy solutions prior to implementation. When models show that poverty, housing instability, or stigma drive ongoing transmission despite high ART availability, policymakers are urged to pursue more comprehensive initiatives that go beyond biological remedies (Mgbako et al., 2022).

SDOH-informed modeling in urban U.S. neighborhoods demonstrates that treatments focusing primarily on medical considerations, such as increasing ART or PrEP, are insufficient. Instead, comprehensive programs that address housing instability, economic fragility, and social stigma have a longer-term impact. For example, models with home stability as a variable show that providing stable housing can greatly improve ART adherence and viral suppression rates. Individual-based models have also shown stigma-reduction activities, such as community education campaigns and healthcare provider training, boost testing uptake and retention in care (Bisanzio et al., 2024).

Healthcare access is another crucial area where model-based evidence can inform policy. Expanding Medicaid coverage, establishing mobile health units, and offering free or low-cost PrEP distribution stations can all help to eliminate barriers for vulnerable populations. Interventions with an educational focus are also significant. Peer-led awareness programs, for example, improve community-level health literacy and result in higher prevention and treatment adherence. Equity-focused modeling has emerged as a critical tool for guiding resource allocation in the system. These models can suggest solutions for reducing HIV incidence and inequality by modeling how different interventions influence different subpopulations (Khosheghbal et al., 2025).

This combined emphasis on efficacy and fairness helps to ensure that limited resources are directed to populations at greatest risk. Such modeling approaches are consistent with the public health goals of the US Ending the HIV Epidemic project, which prioritizes data-driven and socially conscious treatments. The relationship between SDOH, modeling discoveries, and policy actions can be conceptualized as a causal pathway. Social determinants enter into model frameworks, providing information on the causes of infection and inequities. These findings then guide targeted actions such as housing programs, stigma reduction initiatives, and increased healthcare access. The cumulative effect of these therapies results in lower HIV transmission.

This approach emphasizes the need to tackle structural injustices in reducing the HIV epidemic in urban America (Papageorgiou et al., 2022).

7. CHALLENGES AND FUTURE DIRECTIONS

Despite significant progress, major obstacles persist in including socioeconomic determinants of health (SDOH) into HIV modeling. One of the most critical constraints is the availability and quality of data. Many databases lack thorough or consistent measures of important factors, including housing, stigma, and neighborhood deprivation. When such data is available, it is frequently aggregated at broad regional levels, obscuring significant local variances within cities. In addition, stigma and discrimination, two of the most powerful social variables, are rarely quantified. As a result, their inclusion in models frequently relies on indirect measures or assumptions (Katz et al., 2019).

Another significant impediment is the complexity of the methodology. Social determinants of health (SDOH) frequently have an indirect impact on HIV transmission via behavioral mediators such as substance use or healthcare involvement. Advanced causal frameworks capable of representing feedback loops and nonlinear connections are required to accurately understand these pathways. Uncertainty in parameters is also a significant challenge. Effect sizes obtained from observational studies may be confounded or very context-specific, lowering the dependability of model estimates. Structural assumptions influence model outcomes. For example, network models capture clustering and connectedness more realistically than compartmental models, but they require larger datasets and more computer resources (Stannah et al., 2024).

Moving forward, multidisciplinary collaboration between epidemiologists, social scientists, and computational modelers is critical. Social scientists can offer detailed insights into the lived experiences that underpin quantitative variables, such as how stigma and housing instability emerge in specific communities. These perspectives help to keep models anchored in social reality. Advances in data science, particularly machine learning (ML) and artificial intelligence (AI), provide new possibilities for incorporating complicated, high-dimensional SDOH data into predictive and mechanistic models. ML can detect nonlinear relationships between SDOH variables, whereas AI-powered hybrid models can dynamically learn parameters from real-time surveillance data. The integration of copula models with probabilistic graphical models is a potential method for merging disparate data sources and enhancing how social heterogeneity is represented in simulation. To summarize, the future of SDOH-informed HIV modeling depends on connecting disciplines and leveraging modern computational techniques to create models that are both socially aware and scientifically rigorous (Khosheghbal et al., 2025).

8. CONCLUSION

To address HIV/AIDS in metropolitan areas of the United States, it is necessary to recognize that biological therapies alone will not be sufficient to halt the pandemic. The persistence of transmission and inequality is linked to broader societal circumstances such as poverty, education, housing, stigma, and healthcare access. These factors influence all stages of the HIV care continuum. Integrating such factors into epidemiological models elevates them from just technical tools to tools for social comprehension and policy significance. They help policymakers develop solutions that are both successful and equitable. Evidence suggests that adding structural variables improves forecast accuracy and indicates leverage points where social programs like housing assistance, stigma reduction, and healthcare expansion can have the greatest impact. Moving forward, we need data systems that record SDOH in more depth, modeling frameworks that incorporate complicated social variables, and research environments that encourage interdisciplinary collaboration. Finally, tackling HIV/AIDS in urban America requires a paradigm shift. The disease must be viewed not only as a biological issue, but also as a social epidemic rooted in inequity. Integrating SDOH into HIV modeling is not only a methodological advance but an ethical imperative for equitable public health

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