

Echoes of neglect: modeling the consequences of delayed HIV/AIDS treatment in Brazil

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Research Article

Keywords: HIV/AIDS, cART, COVID-19, Brazil, Mortality

Posted Date: October 21st, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11444733/v1>

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Additional Declarations:

The authors declare no competing interests.

Table 1 is available in the Supplementary Files section.

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Abstract

Introduction: Brazil's Unified Health System (SUS) established the country as a global reference in HIV/AIDS control, largely due to the timely implementation of universal access to combination antiretroviral therapy (cART) in 1996. However, recent policy setbacks—including service disruptions, testing shortages, and governance failures during the COVID-19 pandemic—highlight how institutional delays and neglect can yield severe health outcomes.

Methods: In this retrospective ecological time-series study, we used counterfactual modeling to estimate the potential long-term consequences of delaying key public health interventions, simulating alternative cART implementation scenarios. Annual HIV/AIDS mortality data from 1980 to 2023 were obtained from Brazil's Mortality Information System (SIM/DATASUS), and we employed the Prophet time-series framework to simulate delays of one year (1997) or two years (1998). **Results:** The historical introduction of cART in 1996 coincided with a marked decline in HIV/AIDS mortality. Counterfactual simulations indicated that a one-year delay could have resulted in 73,493 additional deaths by 2023, whereas a two-year delay could have resulted in 106,035 additional deaths. The effects were non-linear and extended well beyond the delay period, with mortality remaining elevated for decades. **Conclusions:** These findings demonstrate that delays and disruptions in HIV care generate persistent excess mortality. Counterfactual modeling underscores the critical need to safeguard institutional capacity, ensure continuity in testing and prevention, and prevent political or administrative setbacks in public health programmes.

Key words: HIV/AIDS; cART; COVID-19; Brazil; Mortality

Resumo

Introdução: O Sistema Único de Saúde (SUS) estabeleceu o Brasil como referência global no controle do HIV/AIDS, em grande parte devido à implementação oportuna do acesso universal à terapia antirretroviral combinada (cART) em 1996. No entanto, retrocessos recentes nas

políticas — incluindo interrupções nos serviços, escassez de testes e falhas de governança durante a pandemia de COVID-19 — evidenciam como atrasos institucionais e negligência podem gerar graves consequências em saúde. **Métodos:** Neste estudo retrospectivo ecológico de séries temporais, utilizamos modelagem contrafactual para estimar as potenciais consequências de longo prazo de atrasos em intervenções-chave de saúde pública, simulando cenários alternativos de implementação da cART. Dados anuais de mortalidade por HIV/AIDS de 1980 a 2023 foram obtidos do Sistema de Informações sobre Mortalidade (SIM/DATASUS), e empregamos o framework de séries temporais *Prophet* para simular atrasos de um ano (1997) ou dois anos (1998). **Resultados:** A introdução histórica da cART em 1996 coincidiu com um declínio acentuado na mortalidade por HIV/AIDS. As simulações contrafactuais indicaram que um atraso de um ano poderia ter resultado em 73.493 mortes adicionais até 2023, enquanto um atraso de dois anos poderia ter resultado em 106.035 mortes adicionais. Os efeitos foram não lineares e se estenderam muito além do período de atraso, com a mortalidade permanecendo elevada por décadas. **Conclusões:** Esses achados demonstram que atrasos e interrupções no cuidado do HIV geram excesso persistente de mortalidade. A modelagem contrafactual ressalta a necessidade crítica de proteger a capacidade institucional, garantir a continuidade dos testes e da prevenção, e evitar retrocessos políticos ou administrativos em programas de saúde pública.

Palavras-chave: HIV/AIDS; cART; COVID-19; Brasil; Mortalidade

Introduction

Brazil's Unified Health System (Sistema Único de Saúde, SUS) provides universal and free access to essential health services and has contributed substantially to reducing health inequalities and improving population health indicators (1). Within this institutional framework, Brazil has become internationally recognised for its response to the HIV/AIDS epidemic. Following a limited initial response during the early years of the epidemic, the country progressively implemented a comprehensive strategy combining universal and free access to antiretroviral therapy (ART), expanded diagnostic testing, prevention initiatives, and harm reduction programmes (2). The early adoption of combination antiretroviral therapy (cART), previously known as highly active antiretroviral therapy (HAART), in 1996 was associated with a marked reduction in AIDS-related mortality (3,4) and established Brazil as a global reference in HIV/AIDS control (5).

The success of the Brazilian HIV/AIDS response has been attributed not only to biomedical advances, but also to the timely incorporation of scientific evidence, strong institutional coordination, and active engagement with civil society organisations (2,6). In contrast, countries that delayed the implementation or expansion of antiretroviral treatment experienced persistently higher rates of HIV-related morbidity and mortality (7,8). The South African experience during the early 2000s, in particular, demonstrated how delays in the adoption of effective treatment strategies may result in substantial and preventable losses of life, with estimates suggesting that more than 330,000 deaths could have been avoided through earlier access to antiretroviral therapy (7).

Despite Brazil's historical experience in managing public health emergencies, the COVID-19 pandemic revealed important challenges in national health governance. Difficulties in institutional coordination, delays in vaccine procurement, and inconsistent public health communication characterised part of the federal response to the pandemic (Hallal, 2021). By June 2022, Brazil had recorded approximately 655,000 COVID-19 deaths. Earlier implementation of evidence-based interventions could have substantially reduced this burden. An estimated 391,000 deaths (nearly 60% of the total) might have been preventable (Araújo et al., 2023). These findings raise broader questions regarding the potential consequences of delayed or poorly coordinated responses during other large-scale health crises.

Previous analyses have documented how political and institutional changes can affect HIV prevention and treatment policies in Brazil, including through disruptions in services, weakened institutional structures, and reduced engagement with civil society (9,10). However, less attention has been given to quantifying the potential long-term mortality consequences of delaying the implementation of an effective HIV treatment strategy.

Counterfactual approaches provide an opportunity to explore how alternative policy scenarios might have influenced historical epidemic trajectories. In this study, we apply epidemiological modelling to estimate how a delay in the implementation of cART could have affected HIV/AIDS mortality in Brazil. Drawing inspiration from governance challenges observed during the COVID-19 pandemic and using the historical introduction of cART in 1996 as the reference point, we simulate hypothetical scenarios in which this intervention was delayed by one or two years. The central research question is: how might the trajectory of the HIV/AIDS epidemic in Brazil have evolved if cART had not been implemented in a timely manner? By addressing this question, we aim to quantify the potential consequences of delayed access to an

effective intervention and highlight the importance of timely, evidence-based decision-making in shaping epidemic trajectories.

Methods

This retrospective ecological time-series study employed a counterfactual time-series modeling approach to estimate how delays in the implementation of combination antiretroviral therapy (cART) could have influenced HIV/AIDS mortality trends in Brazil. Annual HIV/AIDS mortality data covering the period from 1980 to 2023 were obtained from the Mortality Information System (Sistema de Informações sobre Mortalidade – SIM), available through the Brazilian Ministry of Health (DATASUS - <https://sim.saude.gov.br/>). For reproduction of the analyses, the collected data can be accessed through the document on the Zenodo platform - <https://doi.org/10.5281/zenodo.21809915>

Deaths registered between 1980 and 1995 were identified using the International Classification of Diseases, Ninth Revision (ICD-9) code 279.1 (deficiency of cell-mediated immunity). From 1996 onwards, following the implementation of the Tenth Revision (ICD-10), deaths coded as B20–B24 (HIV disease) were included. A total of 393,779 HIV/AIDS-related deaths were identified during the study period.

Population estimates were obtained from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE; <https://www.ibge.gov.br/>). Annual mortality rates were calculated and expressed as deaths per 100,000 inhabitants.

Counterfactual scenarios were estimated using the Prophet framework, an additive time-series forecasting model originally developed by Facebook (Meta) Research (11). Prophet was selected because of its flexibility in modelling nonlinear temporal trends and abrupt changes in long-term epidemiological series, while requiring relatively few assumptions regarding the underlying data-generating process. The Prophet models were configured with a linear growth trend and changepoint prior scales of 0.1 for the growth-phase model and 0.5 for the decline-phase model. No yearly seasonality component was included, given the annual resolution of the data. Two simulated scenarios were generated, representing 1-year and 2-year delays in cART rollout. 95% confidence intervals for the observed and simulated mortality rates were estimated based on the standard error of the respective rates. Analyses were conducted using Prophet version 1.4.0 in Python.

The analysis was structured around the historical introduction of cART in Brazil in 1996, considered the principal intervention responsible for altering the trajectory of HIV/AIDS mortality in the country (12).

Initially, the model was trained using mortality data from 1980 to 1995, representing the pre-cART period. Based on the temporal pattern observed before the introduction of combination therapy, counterfactual projections were generated to simulate hypothetical scenarios in which cART implementation had been delayed.

Two alternative scenarios were considered:

1. One-year delay scenario, assuming the introduction of cART in 1997 rather than 1996;
2. Two-year delay scenario, assuming the introduction of cART in 1998.

For each scenario, projected mortality trajectories were compared with the observed historical series to estimate the excess mortality potentially attributable to delayed treatment implementation.

As this is an aggregate, population-level ecological time-series analysis rather than an individual-level cohort or case-control study, no confounder adjustment, subgroup analyses, or matching procedures were applicable. No individual-level record linkage across databases was performed; population denominators from IBGE were combined with aggregate mortality counts from SIM at the national level only. No missing annual values were present in the 1980–2023 series.

The counterfactual scenarios were inspired by governance challenges observed during the COVID-19 pandemic in Brazil, particularly those related to delays in implementing evidence-based public health interventions (13,14). However, the present model specifically simulates delays in the introduction of cART and does not directly estimate the effects of other factors potentially affecting HIV/AIDS outcomes, such as changes in prevention campaigns, reductions in testing coverage, modifications in health governance, or shifts in policies directed toward vulnerable populations.

Therefore, the results should be interpreted as estimates of the potential impact of delayed treatment implementation rather than as direct measurements of the broader political or institutional determinants of the HIV/AIDS response.

Results

The introduction of cART in Brazil in 1996 coincided with a marked change in the trajectory of HIV/AIDS mortality. After reaching a peak in the mid-1990s, mortality rates declined substantially and remained at comparatively low levels throughout the 2000s and 2010s (Figure 1). This downward trend contrasts sharply with the increasing mortality observed during the pre-cART period, suggesting a major epidemiological transition following the implementation of combination antiretroviral therapy.

The counterfactual simulations estimated the potential impact of delayed cART implementation on HIV/AIDS mortality in Brazil. In the one-year delay scenario, in which cART implementation was hypothetically postponed until 1997, the model projected an additional mortality peak immediately following the critical phase of the epidemic (Figure 2A). Mortality rates remained consistently higher than those observed in the historical series throughout the subsequent decades. According to the estimates presented in Table 1, the cumulative excess of deaths reached 73,493 by 2023

In the two-year delay scenario, assuming cART implementation in 1998, the model produced an even greater impact (Figure 2B), culminating in an estimated cumulative excess of 106,035 deaths by 2023 (Table 1). The increase in excess mortality between the one- and two-year delay scenarios was non-linear, indicating high sensitivity of HIV/AIDS mortality to the timing of therapeutic intervention.

Table 1 further reveals that the effects of delayed cART implementation would have been particularly pronounced during the first years following the hypothetical postponement. In the two-year delay scenario, the projected mortality rate for 1998 (12.49 deaths per 100,000 inhabitants) was nearly twice the observed rate (6.66 deaths per 100,000 inhabitants), highlighting the critical importance of intervention timing during the epidemic expansion phase. Moreover, the persistence of higher mortality rates throughout the subsequent decades suggests that early delays would have generated long-lasting effects, preventing the epidemic from returning to the trajectory historically observed in Brazil.

Discussion

The present study used counterfactual modeling to estimate the potential consequences of delayed implementation of cART on HIV/AIDS mortality in Brazil. The findings suggest that

even relatively short delays in treatment implementation could have resulted in substantial excess mortality, with a two-year delay potentially leading to more than 100,000 additional deaths by 2023. These results reinforce the critical importance of timely, evidence-based public health interventions during epidemic crises.

The marked decline in HIV/AIDS mortality observed in Brazil following the introduction of cART is consistent with previous studies demonstrating the transformative impact of combination antiretroviral therapy on survival among people living with HIV (12,15). Brazil was among the first middle-income countries to guarantee universal and free access to antiretroviral treatment through a publicly funded health system, establishing an internationally recognized model for HIV/AIDS control (16). The country's experience demonstrated that large-scale treatment programmes could be successfully implemented in resource-constrained settings and subsequently influenced global HIV policies (17).

The relevance of these findings extends beyond the historical introduction of cART. Previous analyses of Brazil's HIV response have documented how political and institutional changes can affect prevention, treatment, and the protection of people living with HIV, including through disruptions in services, institutional restructuring, reduced engagement with civil society, and threats to evidence-based and rights-oriented policies (9,10). Our findings complement this literature by quantifying the potential mortality consequences of a specific failure to implement an effective treatment intervention in a timely manner.

The findings of the present study are further supported by historical experiences observed in other countries. South Africa, for example, experienced substantial delays in the widespread implementation of antiretroviral therapy during the early 2000s. These delays were associated with hundreds of thousands of preventable deaths, highlighting the profound population-level consequences of postponing evidence-based interventions during rapidly evolving epidemics (18). Similarly, several low- and middle-income countries only achieved large-scale treatment expansion following major international initiatives, such as the United States President's Emergency Plan for AIDS Relief (PEPFAR), illustrating how delayed access to effective therapies may substantially alter epidemic trajectories (19).

Although the present study specifically modelled delays in treatment implementation, the findings also underscore the broader importance of governance in shaping epidemic responses. Effective HIV/AIDS control depends not only on biomedical innovations, but also on sustained

political commitment, institutional capacity, intersectoral coordination, and the incorporation of scientific evidence into public policy (20). The COVID-19 pandemic provided a contemporary example of how delays in implementing evidence-based measures and limitations in institutional coordination may compromise population health outcomes, even in countries with historically strong public health systems (21).

Despite the profound governance and health system disruptions experienced during the COVID-19 pandemic, the baseline resilience established by universal access to cART provided a critical protective buffer for people living with HIV. Although this population was initially hypothesized to face higher vulnerability to severe COVID-19 outcomes, evidence from Brazilian cohorts demonstrated that individuals receiving regular cART through the Ministry of Health—who presented with sustained viral suppression and preserved CD4+ T-cell counts—experienced clinical outcomes comparable to the general population, with severe disease driven primarily by pre-existing non-communicable comorbidities rather than HIV status per se (22). This underscores how the historical institutionalization of free, universal cART in Brazil not only substantially reduced HIV-related mortality, but also mitigated additional mortality risks during subsequent national public health crises.

The Brazilian response to HIV/AIDS has historically been characterized by close collaboration between government institutions, scientific communities, and civil society organizations, as well as by the adoption of inclusive prevention strategies directed toward populations disproportionately affected by HIV (23). The long-term sustainability of these structural components remains essential for maintaining epidemic control. Policies that weaken prevention programmes, reduce engagement with vulnerable populations, or undermine evidence-informed decision-making may indirectly compromise the effectiveness of HIV prevention and treatment strategies.

When scientific evidence is subordinated to political or ideological considerations, delays in the adoption of effective interventions may occur even when their population-level benefits are well established. The consequences of such delays may extend far beyond the period in which the initial decision was made, as suggested by the persistent excess mortality observed in the counterfactual scenarios. In this context, the counterfactual analysis extends beyond a retrospective exercise in epidemic modeling and serves as a warning about the potential population-level consequences of weakening evidence-informed and inclusive public health policies.

Some limitations should be acknowledged. First, the counterfactual scenarios were generated using statistical forecasting methods and therefore depend on the assumptions inherent to the Prophet framework. Second, the model specifically simulated delays in the introduction of cART and did not explicitly incorporate transmission dynamics, behavioural changes, healthcare access, or modifications in prevention policies. Consequently, the estimates should be interpreted as approximations of the potential impact of delayed treatment implementation rather than precise predictions of historical outcomes. Finally, as with all counterfactual analyses, the simulated scenarios cannot fully capture the complexity of real-world political and institutional processes.

An additional limitation concerns the introduction of cART in 1996 coincided with Brazil's transition from ICD-9 (code 279.1) to ICD-10 (codes B20–B24) for recording HIV/AIDS mortality. Consequently, part of the observed trajectory change might reflect differences in diagnostic classification rather than treatment effects alone—an inherent constraint when analyzing long-term mortality data across ICD revisions.

Despite the limitations inherent to counterfactual time-series modeling, this study demonstrates the potential long-term consequences of delaying an effective public health intervention. The simulations suggest that even a one- or two-year delay in the implementation of during subsequent national public health crises cART could have resulted in substantial excess mortality in Brazil, with effects persisting for decades. These findings underscore that the timing of public health action is not merely an operational consideration but can fundamentally influence the long-term trajectory of an epidemic. Maintaining institutional capacity, ensuring timely incorporation of scientific evidence into public policy, and sustaining effective and inclusive health programmes are therefore essential to prevent avoidable losses of life during current and future public health crises.

In conclusion, although simulating a delay in the implementation of universal cART distribution in 1996 represents a counterfactual scenario, the recent trajectory of Brazilian public health demonstrates that governance delays and institutional dismantling yield real and long-lasting consequences. In practice, the management of care for people living with HIV/AIDS in Brazil was documentally marked by severe setbacks during the Bolsonaro administration. This was reflected in direct negligence toward clinical care, as evidenced by the failure to renew essential contracts for viral load monitoring and diagnostic testing for both HIV and hepatitis C, alongside the restructuring of Ministry of Health departments and the

marginalization of civil society movements. Furthermore, during the COVID-19 pandemic, federal mismanagement led to the cancellation of routine consultations, disruptions in prevention services, and impaired access to pre-exposure prophylaxis (PrEP) (10). Therefore, the findings of this study reinforce that safeguarding universality, ensuring timely evidence-based responses, and maintaining the political and financial sustainability of the SUS are non-negotiable pillars to prevent avoidable mortality and epidemiological setbacks.

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Figures

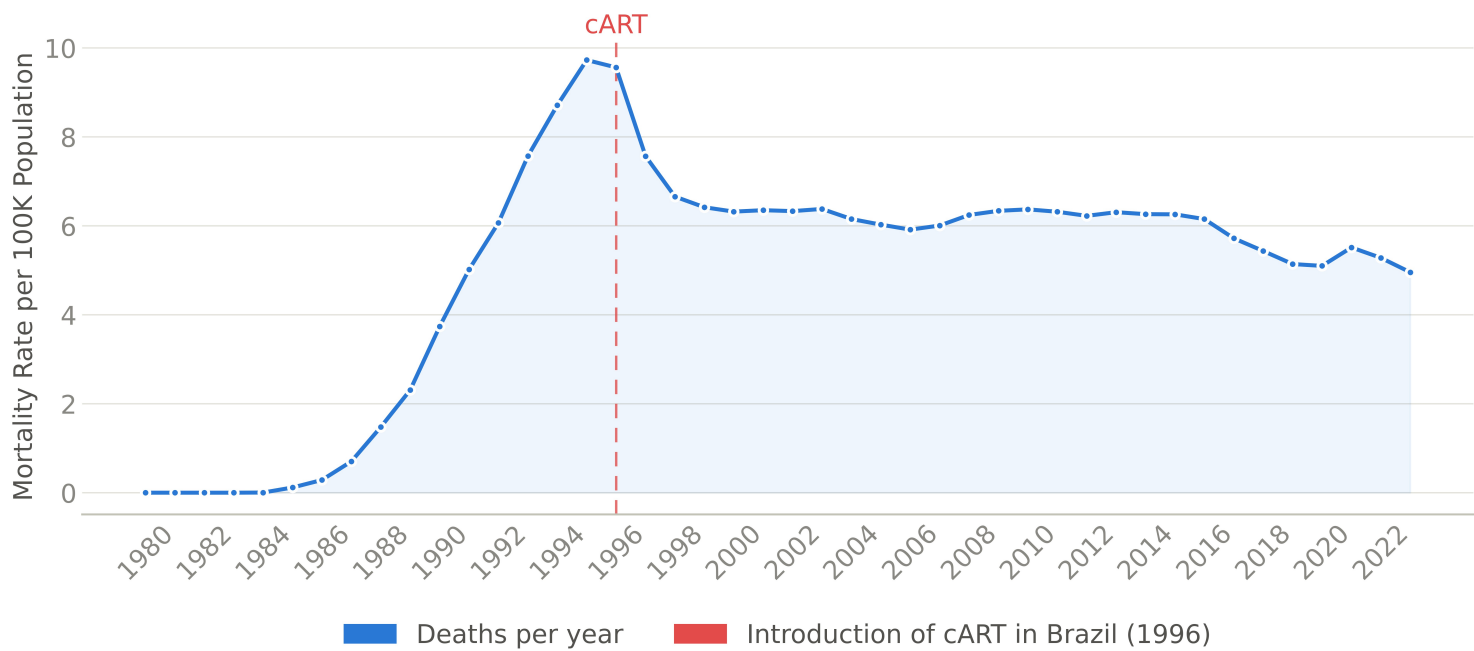


Figure 1

Historical HIV/AIDS mortality rates in Brazil, 1980–2023.

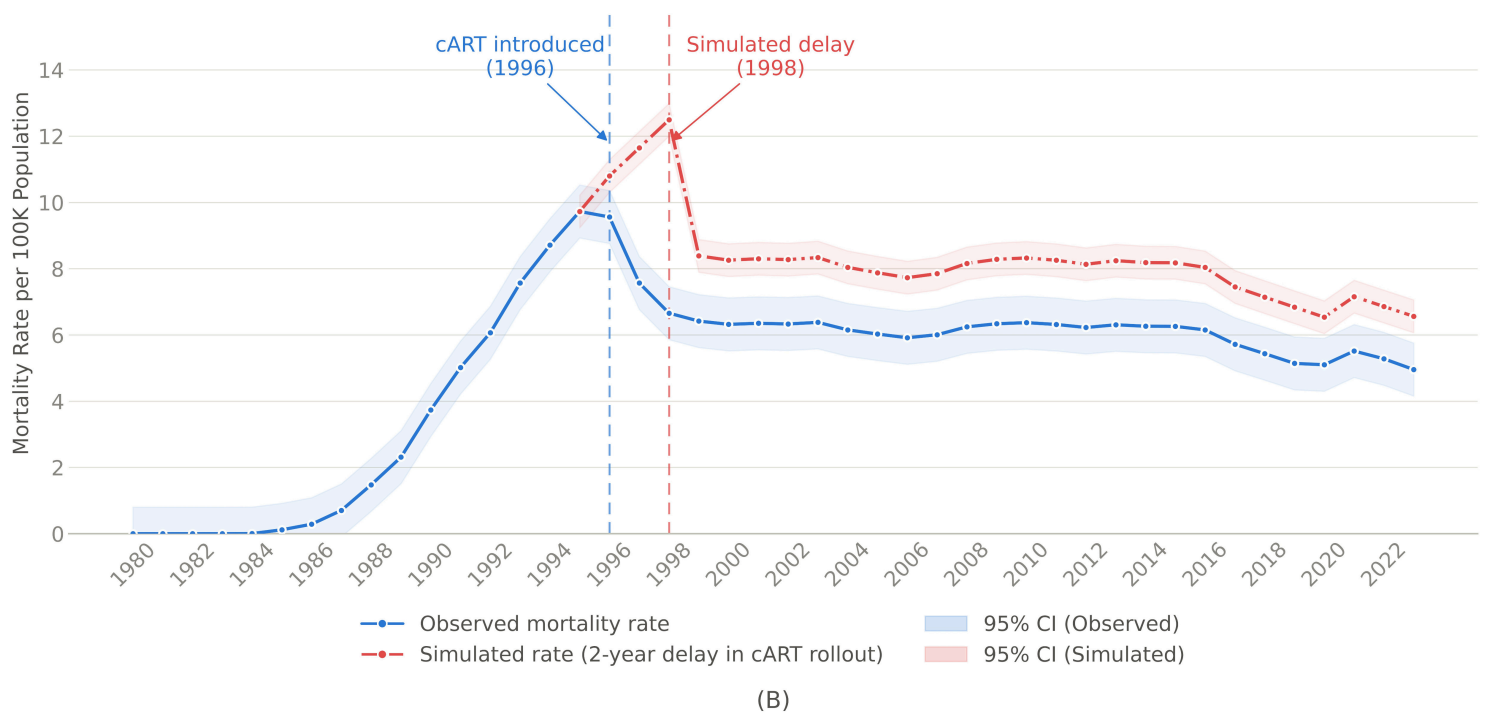
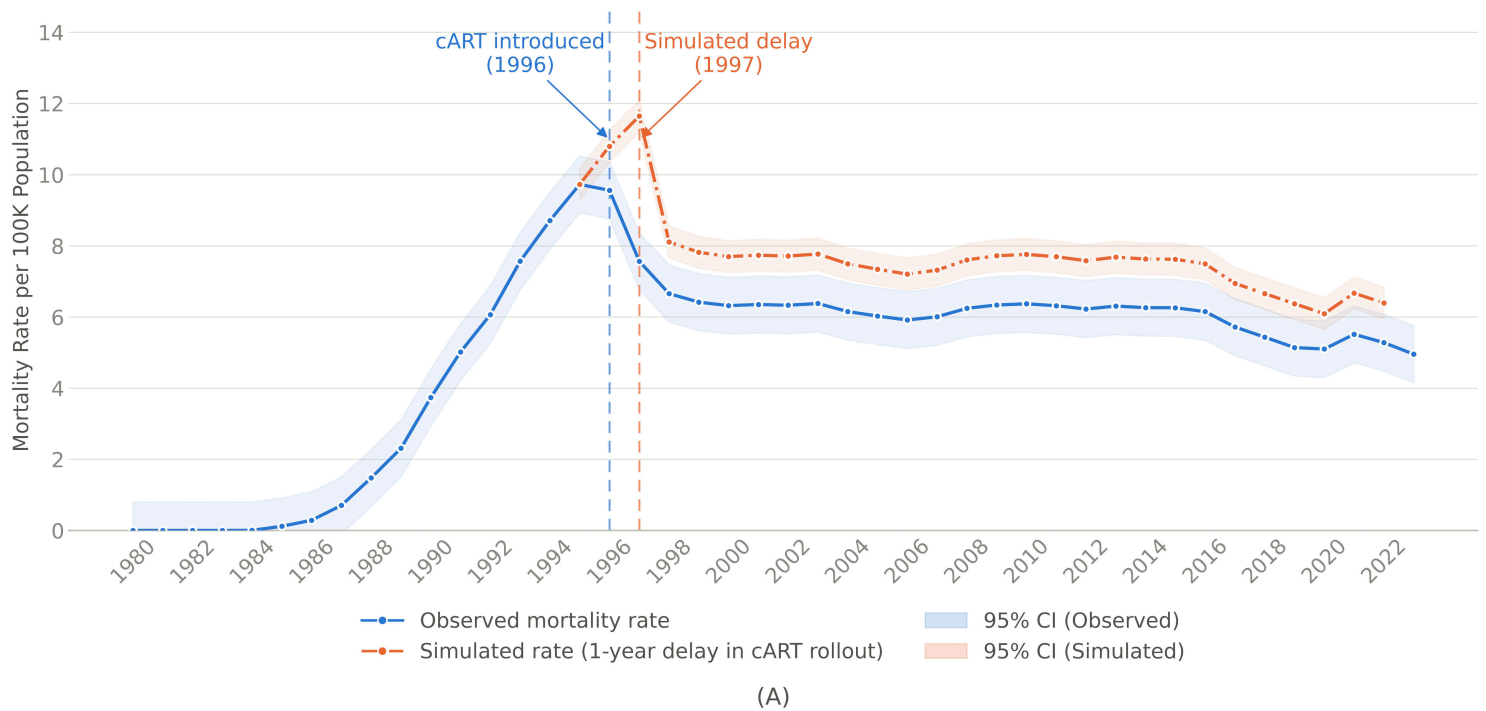


Figure 2

Observed and simulated HIV/AIDS mortality rates in Brazil under hypothetical scenarios of delayed HAART implementation: top panel shows a one-year delay; bottom panel shows a two-year delay.

Supplementary Files

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- [Table1.png](#)