

OPINION OPEN ACCESS

Democratising Artificial Intelligence for Pandemic Preparedness and Global Governance in Latin American and Caribbean Countries

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Received: 31 October 2024 | **Revised:** 16 September 2025 | **Accepted:** 12 October 2025

Funding: This work was supported by Canada's International Development Research Centre (109981) and Deutsche Forschungsgemeinschaft (460129525).

Keywords: AI governance | AI in pandemic response | democratisation of AI | equitable public health systems | global south initiatives | responsible AI use

ABSTRACT

Infectious diseases continue to pose a significant global health challenge, necessitating innovative approaches for predicting outbreaks, detecting variants, conducting contact tracing, discovering new drugs and managing misinformation. Artificial intelligence (AI) has significantly supported work in these areas, particularly during the COVID-19 pandemic. However, the benefits of AI must be equitably distributed, and its use must be responsible and inclusive. As various nations implement AI regulations, the global nature of AI necessitates international collaboration to establish ethical guidelines and governance frameworks. In response to these needs, the Global South AI for Pandemic & Epidemic Preparedness & Response Network (AI4PEP) is leading a multinational effort across 16 countries to strengthen public health systems through responsible, Southern-led AI solutions. This opinion piece highlights AI4PEP's initiatives in Latin America and the Caribbean (LAC), examining the region's AI governance models and the challenges they present. By lowering barriers to AI adoption and fostering equitable access to AI-driven public health innovations, our network empowers researchers, healthcare professionals and policymakers in LAC to harness AI for infectious disease preparedness and response, ultimately improving health outcomes in low- and middle-income countries.

Ulisses Rocha, Robson Bonidia, Jude Dzevela Kong, Mariana Dauhajre and André de Carvalho contributed equally.

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1 | Introduction

Lessons learned from the COVID-19 pandemic outbreak highlight the need to improve our preparedness for similar events (Alakija 2023). This pandemic has shown us that no single person, community or country is isolated, and that suffering and a lack of support affecting individuals, regardless of their location, affect us all. Moreover, we must recognise talent, wherever and whoever they are, to join and collaborate in the search for solutions to the world's challenges.

In this effort, Artificial Intelligence (AI) emerges as a valuable tool for reducing the impacts of pandemics (Syrowatka et al. 2021). In an era where AI is present in various processes that impact society, it is essential to ensure that its contributions are distributed equitably (Seger et al. 2023). Moreover, the democratisation of AI must empower each individual, community or society to contribute proportionally to their aptitude, availability and commitment, thereby increasing the implementation of AI in practical applications (Ahmed and Wahed 2020).

With AI advances, concerns and contributions, the world has received both positive and negative signals (i.e., ethically, technologically and societally) regarding the future of a world where AI is firmly present (Colavizza et al. 2021). Advances in all knowledge domains demonstrate how AI can not only accelerate scientific discoveries and the design of innovative solutions, many of which improve people's health, but also be one of the most valuable tools for enhancing the quality of life on earth (Gupta and Degbello 2023). On the other hand, recent articles, talks and interviews address the dangers of developing and using AI (Colavizza et al. 2021; Rajpurkar et al. 2022; Gerke 2024).

Furthermore, the development of AI has been concentrated in countries with a long focus on technological advancements, overlooking the unique needs and challenges faced by less developed regions, such as the Global South (The 'AI Divide' Between the Global North and Global South 2023). A study assessing 181 countries worldwide reveals that many nations in the Global South rank among those with the lowest AI readiness scores (2024 Government AI Readiness Index n.d.). The study emphasises that, without a supportive environment, these disparities could deepen global inequality in access to and development of AI (Okolo et al. 2022).

Consequently, law-making bodies in many countries and regions are passing new regulations regarding the development and use of AI to reduce or avoid risks associated with this technology (Anderljung et al. 2023; Hacker et al. 2023). These regulations may prevent biased AI systems, ensure fairness and improve privacy protection. Nevertheless, AI has no borders. Potential risks that may not be adequately addressed in countries with permissive or absent AI regulation include practices such as training biased algorithms or exploiting personal data without consent. Even when some nations adopt stricter frameworks, the global circulation of AI systems through the internet means that weak regulation elsewhere can still expose users in well-regulated environments to these risks. Recent articles have defended the idea that AI

regulation should not be the responsibility or work of a single country or region.

Therefore, a global board should indicate the best actions to create legislation regulating AI, similar to the Intergovernmental Panel on Climate Change (IPCC), an intergovernmental body of the United Nations (Ho et al. 2023; Meskó and Topol 2023). The democratisation of AI aims at its ethical and responsible expansion, encompassing its development, use and governance (Ahmed and Wahed 2020; Himmelreich 2023). These aims require equal opportunities worldwide. Furthermore, we should plan to share knowledge and training involving AI to benefit all regions of the globe (Himmelreich 2023).

Considering these issues, York University (Toronto, Canada) was selected in a Canadian national bid for a grant from the International Development Research Centre (IDRC) (AI for Global Health Investment) (Artificial Intelligence for Global Health | IDRC—International Development Research Centre 2024) to support countries in the global south to fight infectious diseases using AI, the Global South AI for Pandemic & Epidemic Preparedness & Response Network (AI4PEP) (Artificial Intelligence for Global Health | IDRC—International Development Research Centre 2024). This network comprises 16 projects from 16 countries in the global south. This opinion introduces our branches in Latin American and Caribbean (LAC) countries and discusses AI governance in the LAC region.

The Brazilian branch of the network, AutoAI-Pandemics, investigates and designs automated machine learning (ML) tools to democratise healthcare professionals' use of AI. These tools support (1) automated epidemiological analysis for designing interventions, (2) automated bioinformatics analysis and (3) fighting misinformation/disinformation. AutoAI-Pandemics hopes to democratise access to data science and ML techniques by allowing non-experts (e.g., biologists, physicians and epidemiologists) to use AI in their research and development.

The Dominican branch, AI4EWARS, uses AI to model the spread of Aedes-borne diseases in the country. It comprises multidisciplinary and experienced health researchers, including entomologists, mathematicians and medical doctors. They plan to design a predictive model of Aedes-borne viruses in the Dominican Republic that provides early warnings of outbreaks and streamlines Public Health responses.

The AI4PEP hub in Peru enhances an existing database of forced cough sounds to further train pilot AI algorithms for classifying various respiratory infectious diseases in patients with respiratory symptoms. The project aims to evaluate the utility of longitudinal cough monitoring in indexing patients and their household contacts, and to integrate AI-based tools to improve respiratory infection surveillance, access and equity within the Peruvian healthcare system.

Our network in LAC has the potential to reduce the expertise barrier required to engage with ML pipelines, making AI tools and applications more accessible to researchers fighting infectious diseases, particularly in low- and middle-income countries. This initiative enables biologists, physicians,

epidemiologists and other stakeholders to apply these techniques widely, thereby improving the health and well-being of their communities. Ultimately, by providing a simplified approach to conducting complex AI analyses, we encourage the broader inclusion of researchers from diverse backgrounds and resources, thereby strengthening the global commitment to science and health.

2 | Challenges and Inequalities in LAC

AI solutions have been proposed in several domains (e.g., health-care, finance, education and agriculture). In October 2022, the Food and Drug Administration (FDA) reported 521 AI and ML-enabled medical devices (Joshi et al. 2024). Furthermore, the COVID-19 pandemic demonstrated the potential of ML techniques to minimise the effects of a pandemic, such as predicting deaths, contact tracing, diagnosis, treatments and others (Luengo-Oroz et al. 2020; Comito and Pizzuti 2022).

Nevertheless, many ML algorithms and AI models have a black-box nature (i.e., AI decisions are not comprehensible on a human level) (Rudin 2019; Babic et al. 2021), which may reduce trust, accountability and acceptance of AI (Hutter et al. 2019). Another concern is that ML models can inadvertently reflect and amplify hidden social biases present in the training data, leading to unfair, harmful or prejudiced decisions. These biases often arise from systemic issues or human oversight in data collection and curation, rather than being inherent flaws of the technology itself. Some examples of these problems have been reported in various fields.

In 2009, genome-wide association studies revealed that more than 96% of participants were of European descent (Popejoy and Fullerton 2016), thereby failing to encompass the full range of racial and geographic diversity, which can limit the applicability of the findings to diverse populations. A study regarding bias in AI highlighted sex and gender biases in AI applications for biomedicine and healthcare, emphasising the need for more inclusive data representation (Cirillo et al. 2020). Similarly, in

dermatology, medical imaging and diabetes management, studies have identified a lack of racial diversity in training datasets, raising concerns about potential health disparities (Adamson and Smith 2018; Pham et al. 2021; Ricci Lara et al. 2022).

Consequently, initiatives have discussed concerns regarding the ethical, fair, reliable, sustainable, transparent and reproducible AI (Shang et al. 2019). Thus, in our pursuit of responsible solutions, our network adheres to guidelines proposed in the literature, such as those on developing and using AI responsibly (Dignum 2019), AI for all (Ramos 2021) and the Guidelines for Trustworthy AI (Zhang and Zhang 2023). We also adopt and recommend the principles of Data-Centric AI (Whang et al. 2023), which puts data at the heart of an AI system development process, and the guidelines to improve the Findability, Accessibility, Interoperability and Reuse of data known as FAIR data principles (Wilkinson et al. 2016).

3 | Comparative AI Governance Models in LAC

According to a report by the OECD (2022), AI capacities in LAC countries vary widely. Countries like Trinidad and Tobago, Venezuela and Bolivia have yet to achieve significant public sector development. Uruguay and Colombia are regional leaders in AI strategy research and development. These countries are followed by Peru, Chile, Brazil, Costa Rica and Argentina, which have drafted or enacted legislation about AI. In addition, Mexico was the first LAC nation to create a national strategy for AI, as shown in Table 1. Lastly, Paraguay, Panama, Jamaica, Ecuador, the Dominican Republic and Barbados are beginning to integrate public sector strategies for AI.

According to the same OECD Report, Annex A (OECD 2022), we describe the main features and points regarding LAC nations' AI strategies, including:

- *Uruguay (AI Strategy for the Digital Government)* focuses on applying AI to public administration, emphasising capacity building, responsible use and promoting digital citizenship.

TABLE 1 | Overview of AI laws, strategies and definitions in different Latin American countries.

Year	Country	AI definition	Comparison and contrast
2012–2013	Colombia	No explicit definition	Colombia has a personal data protection law and an International AI Council for Colombia
2018	Mexico	No explicit definition	Mexico presented the first national AI strategy in the Latin American and Caribbean region in March 2018. The strategy focuses on ethics, governance, investment and innovation
2019	Brazil	The Brazilian AI Strategy defines AI as 'a set of techniques that enable machines to perform tasks that, if performed by humans, would require intelligence'	The strategy focuses on AI research and development, as well as ethics and governance
2021	Chile	No explicit definition	Chile has a national AI policy focusing on ethics, governance and innovation
2021	Peru	No explicit definition	Peru has a national AI policy focusing on ethics, governance and innovation

- *Peru (National Strategy for Artificial Intelligence)* addresses infrastructure, ethics, training and new economic models, with a commitment to renew and update the strategy every 2 years after 2026.
- *Mexico (IA-MX 2018)* has an AI subcommittee to coordinate government, academia and industry, promoting cross-sectoral collaboration and participation in international technology working groups.
- *Colombia (Digital Transformation and AI National Policy)* integrates AI into the modernisation of government services and public sector innovation, highlighting efficiency and citizen engagement.
- *Chile (AI Action Plan and AI National Policy)* emphasises the integration of AI into sustainable development, human well-being and regulatory frameworks, linking AI to broader societal goals.
- *Brazil (Brazilian Artificial Intelligence Strategy)* provides one of the most comprehensive frameworks, combining regulation, public-service applications, legislation, ethics and international positioning.
- *Argentina (AI National Plan)* aims to enhance state efficiency and citizen services through the use of AI, with a particular focus on aligning technology adoption with social needs.
- *Uruguay (Agenda Uruguay Digital 2020)* converges its national AI strategy by combining responsible and equitable use of AI, with explicit protections for user privacy (Veronese and Lemos 2021a, 2021b).
- *Costa Rica* gained attention in 2022 when lawmakers drafted an AI regulation bill using ChatGPT. The proposal highlighted the need for legislation governing the use and development of AI (Editorial Team at World Litigation Forum 2023).
- *The Dominican Republic* has articulated a national stance on AI but has not yet defined a concrete mechanism or roadmap for enforcement.

The OECD report provides valuable guidance for LAC governments on maximising AI's positive impacts and minimising the negative ones. By following these recommendations, governments can help to ensure that AI is used for the benefit of all. Overall, the strategies converge on several common priorities, including ethics, governance and the use of AI in public services. At the same time, they differ in emphasis: Chile and Peru highlight sustainability, while Brazil stresses regulatory comprehensiveness and international positioning. Mexico, Colombia, and Argentina place a stronger focus on citizen engagement and aligning AI adoption with social needs.

4 | Democratising AI Knowledge in LAC

The growing interest in AI has reached several areas and, in many cases, has directly impacted people's lives, particularly in healthcare. However, scaling the implementation of AI innovations requires adaptation and acceptance, which are often challenging. Moreover, in the Global South, specifically in the LAC

region, we face significant challenges, including limited accessibility to, as well as funding for, AI resources and a knowledge gap. The complexity of AI techniques and the skills required to apply them create a barrier, restricting the potential for innovative research. Another critical issue is the necessary infrastructure to implement these solutions, as many institutions still struggle with inadequate access to high-quality internet and computational resources.

Therefore, understanding which factors influence the adoption of new ideas is crucial. Thus, our network proposes to use Rogers' Diffusion of Innovation Theory, which aims to explain how new ideas or innovations can be adopted, such as (1) relative advantage, (2) compatibility, (3) complexity, (4) experimentability and (5) observability (Rogers 1995). This theory can be complemented by other measures for innovation adoption, such as cost-efficacy, feasibility, perceived evidence, innovation fit with users' norms, relevance and ease (Chor et al. 2015).

To democratise AI knowledge, we maximise the dissemination of results and products among the target communities where our motivating issues arise, as well as the training of human resources. Therefore, our network proposes several strategies (Figure 1), such as (1) engagement with underrepresented communities; (2) offer of short AI-related courses; (3) public awareness campaigns in AI; (4) collaboration with industry; (5) international collaboration; (6) open-source initiatives and (7) community-based development (Table 2).

Considering this, our AI4PEP-LAC initiative has already made a tangible impact through projects like InteliGente, which empowers students to apply AI for social good and has been recognised by the Regional Fund for Digital Innovation in Latin America and the Caribbean (FRIDA) as one of the most transformative initiatives in the LAC region. Additionally, AutoAI-Pandemics has played a crucial role in leveraging AI to enhance pandemic preparedness by distributing various open-source solutions that enable non-specialists to harness the power of AI, such as BioAutoML (Bonidia et al. 2022), BioPrediction (Florentino et al. 2024) and Dominique (Information Integrity Assistant).

Beyond these projects, our contributions extend to the policy sphere, with participation in the development of documents for public policies on AI governance and ethical implementation, such as (1) International AI Safety Report (International AI Safety Report 2025 2025), (2) Strengthening health systems through responsible AI: an emergent research landscape (Sinha 2025), (3) Fostering responsible innovation (Artificial Intelligence for Global Health | IDRC—International Development Research Centre 2024) and (4) Brazilian Artificial Intelligence Plan 2024–2028 (PBIA n.d.). These results illustrate how our multifaceted approach is driving meaningful change across education, research and policymaking in the LAC region.

Furthermore, our network organises and supports academic meetings to strengthen the collaboration of our multinational team and bridge it to local groups in LAC. In these events, we provide novel training sessions to environmental and healthcare professionals and students (e.g., tools developed for intervention design and combating misinformation) (AI4PEP at the

DEMOCRATISING AI KNOWLEDGE IN LAC



FIGURE 1 | Democratising AI knowledge in Latin America and Caribbean countries.

TABLE 2 | Our key strategies for inclusive AI development in LAC.

Strategy	Implementation examples
Engagement with underrepresented communities and community-based development	Our educational project, called InteliGente, is dedicated to promoting equity in AI development by educating and empowering individuals to create socially impactful solutions for underserved communities
Special short courses	Several courses and competitions have been organised by the network, such as: (1) I Advanced Summer School on Responsible AutoML; (2) AI4GHI Challenge 2024—Student Summit; AI4PEP Colloquia; (3) Podcast Series and (4) AI4PEP Lecture Series
Public awareness campaigns in AI	Numerous materials have been made available, such as: (1) Data Science—Fundamentals and Applications; (2) InteliGenteCards—Deciphering AI; (3) AI4PEP Newsletter; (4) Policy Perspectives; (5) Our researchers participated in the commission responsible for creating an international report on AI safety; (6) Participants in the Artificial Intelligence Plan of the Brazilian Computer Society
International collaboration	We are an international network spanning 16 countries in the Global South, holding biweekly and monthly meetings to exchange knowledge and share ongoing work. Among the countries are Brazil, Peru, Dominican Republic, Cameroon, Ethiopia, Ghana, Senegal, South Africa, Indonesia, Malaysia, Philippines, Lebanon, Morocco, Tunisia, West Bank
Open-source initiatives	Our network has developed several open-source initiatives, including BioAutoML, Dominique, BioPrediction, MuDoGeR, BioDeepFuse, MathFeature, InteliGenteCards, among others

UNGA79 Science Summit—AI4PEP [n.d.](#)). We also encourage new partnerships addressing key challenges explicitly faced by AI initiatives in the Global South and make special efforts to finance the participation of promising students from other developing countries, providing them with novel training opportunities and possibilities for continued education. For example, we organised a student summit (AI4GHI Challenge 2024—Student Summit—AI4PEP [n.d.](#)). In this summit, we proposed challenges that engaged 140 students from 21 countries, bringing together expertise from health sciences, computer science, environmental science and related fields. The participants were tasked with addressing five pressing themes: from predictive analytics for disease outbreaks to the intersection of climate change

and mental health. Despite their varied disciplines, a common thread bound them: the drive to make a tangible impact on global health systems.

In our efforts to promote the democratisation of AI across LAC countries, our consortium has made remarkable strides in visibility and engagement. Our direct interactions have provided over 100,000 people with access to various resources, including articles, educational programs and engaging events, demonstrating a significant level of interest and participation in our initiatives. Beyond these direct impacts, the ripple effect of our work has reached an astounding 182,000 individuals through indirect channels. This broad influence can largely be attributed to our

robust media coverage and social media outreach. We estimate that approximately 32,000 people have been touched through awards and recognitions, amplifying our message and reaching thousands in their respective communities. Meanwhile, our presence in the media has been equally impactful, with major news outlets alone giving us a voice that resonates with around 150,000 individuals.

When we combine these figures, the total estimated impact of our consortium exceeds 282,000 individuals. This estimate is a testament to our advocacy and reflects a careful and conservative approach to measuring our reach. We ensure that our claims are based on solid data from website analytics, social media metrics, award announcements and media reporting. This extensive outreach illustrates the numbers and the growing awareness and engagement with the democratisation of AI in our region. It is a call to action, showing that we can continue to inspire and empower communities throughout LAC with collective effort. As we approach the conclusion of our work, these figures remind us of the potential we have to change the narrative around AI and its accessibility.

5 | Conclusions

Harnessing AI's potential in LAC requires not only technological advancements but also ethical and responsible issues, inclusive policies and international collaboration. Our network's efforts to democratise AI knowledge and tools aim to bridge existing knowledge gaps, empowering healthcare professionals, researchers and policymakers to leverage AI for public health and beyond. By fostering accessibility, responsible innovation and global cooperation, we can ensure AI contributes to a more equitable and prepared world where the LAC region actively shapes the future of AI governance and its ethical application.

Author Contributions

Ulisses Rocha: conceptualization, funding acquisition, writing – original draft, writing – review and editing, supervision, resources. **Robson Bonidia:** conceptualization, writing – original draft, writing – review and editing, supervision. **Jude Dzevela Kong:** conceptualization, writing – original draft, writing – review and editing, funding acquisition, supervision, resources, project administration. **Mariana Dauhaje:** writing – original draft, writing – review and editing. **Claudio Struchiner:** writing – original draft, writing – review and editing. **Guilherme Goedert:** writing – original draft, writing – review and editing. **Peter F. Stadler:** writing – original draft, writing – review and editing. **Danilo Sanches:** writing – original draft, writing – review and editing. **Troy Day:** writing – original draft, writing – review and editing. **Marcia C. Castro:** writing – original draft, writing – review and editing. **John Edmunds:** writing – original draft, writing – review and editing. **Manuel Colomé-Hidalgo:** writing – original draft, writing – review and editing. **Demian Arturo Herrera Morban:** writing – original draft, writing – review and editing. **Edian F. Franco:** writing – original draft, writing – review and editing. **Cesar Ugarte-Gil:** writing – original draft, writing – review and editing. **Patricia Espinoza-Lopez:** funding acquisition, visualization. **Gabriel Carrasco-Escobar:** writing – original draft, writing – review and editing. **André de Carvalho:** writing – original draft, writing – review and editing, conceptualization, funding acquisition, supervision, resources, project administration.

Acknowledgements

We acknowledge that this work is based on a report we originally submitted to the United Nations Call for Papers on Global AI Governance (<https://www.un.org/techenvoy/ai-advisory-body>). The insights and research contained herein were drawn from that report, and we are grateful for the opportunity to contribute to the ongoing discourse on global AI governance through this extended work. This research was funded by Canada's International Development Research Centre (IDRC) (Grant No. 109981) in collaboration with the UK International Development. Ulisses Rocha was supported by the Deutsche Forschungsgemeinschaft under the NFDI4Microbiota consortium, Grant No. 460129525. Open Access funding enabled and organized by Projekt DEAL.

Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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ARTIGO ESPECIAL



Epidemiologia e vigilância em saúde: sinergias e desafios em um mundo em transformação

Epidemiology and health surveillance: synergies and challenges in a changing world

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RESUMO

Este ensaio discute os desafios concernentes à interação da epidemiologia com políticas, programas e serviços de saúde, com destaque para a vigilância em saúde. Ainda que o escopo dela compreenda saberes para além da epidemiologia, a utilização do conhecimento epidemiológico é elemento fundamental para a qualificação das suas ações. Apresenta-se a trajetória do processo de institucionalização da vigilância em saúde no Brasil, que culmina com a instituição da Política Nacional de Vigilância em Saúde (PNVS) em 2018. A PNVS destaca uma série de necessidades que podem e devem ser contempladas pela epidemiologia e que oferecem oportunidades para a maior interação entre epidemiologia e políticas, programas e serviços de saúde, mas exige uma atualização dos modelos de formação em epidemiologia, seja na graduação ou na pós-graduação, uma maior valorização das atividades de tradução do conhecimento e uma maior atualização do ambiente acadêmico em relação aos avanços nas políticas de vigilância em saúde do Brasil. Com base na análise de artigos brasileiros sobre vigilância em saúde listados no PubMed e em dados de linhas, projetos de pesquisa e trabalhos de conclusão de curso de programas de pós-graduação, avalia-se a inserção do tema da vigilância em saúde na pesquisa e pós-graduação em saúde coletiva no Brasil. Conclui-se discutindo a contribuição do V Plano Diretor para o Desenvolvimento de Epidemiologia no Brasil (2025-2029) para o fortalecimento da vigilância em saúde.

Palavras-chave: Vigilância em saúde pública. Epidemiologia. Aplicações da epidemiologia. Capacitação profissional. Pesquisas sobre serviços de saúde.

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CONFLITO DE INTERESSES: nada a declarar

COMO CITAR ESTE ARTIGO: Werneck GL. Epidemiologia e vigilância em saúde: sinergias e desafios em um mundo em transformação. Rev Bras Epidemiol. 2025; 28(Suppl. 1): e250006supl1. <https://doi.org/10.1590/1980-549720250006.supl.1.2>

EDITORA CIENTÍFICA: Cassia Maria Buchalla 

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Recebido: 19/10/2025.

Aceito em: 30/10/2025



INTRODUÇÃO

O arcabouço teórico da epidemiologia toma a distribuição populacional do processo saúde-doença e de seus determinantes e limitantes como domínio particular de interesse^{1,2}. Nesse contexto, a epidemiologia trabalha com teorias sobre os mecanismos específicos causadores desses eventos e sobre os motivos que levam às heterogeneidades espaço-temporais de sua distribuição nas populações², sutil diferença que se expressa em múltiplas práticas e perspectivas de epidemiologia, que, por sua vez, refletem visões de mundo vigentes em distintos tempos e lugares³.

Reconhecer tal diversidade implica demarcar a concepção de epidemiologia aqui empregada: a que parte do princípio de que a epidemiologia é um empreendimento científico que busca a geração de conhecimento inovador e se compromete com sua tradução e aplicação para subsidiar ações e políticas efetivas que levem à redução das iniquidades sociais em saúde e que promovam uma sociedade mais justa². Uma epidemiologia que reconhece suas raízes nas lutas pela democratização do país e pela Reforma Sanitária, que não se conforma em ser somente epidemiologia-ciência, que necessita ser também epidemiologia-ação, enfim, uma epidemiologia da Saúde Coletiva⁴.

Encontra-se justamente nessa interface entre ciência e prática um dos maiores desafios para o desenvolvimento de uma epidemiologia implicada com a transformação social. Um primeiro entrave é a própria natureza e dinâmica das decisões em saúde pública. Mesmo que os diferentes níveis de gestão do Sistema Único de Saúde (SUS) possam reconhecer que tais decisões devem ser pautadas na melhor evidência científica disponível, é notório que elas ultrapassam o escopo da ciência, exigindo ponderações de cunho social, econômico, legal e ético, bem como de valores e princípios, como os de equidade, transparência e participação social⁵. Ainda assim, a epidemiologia tem sido cada vez mais frequentemente instada a contribuir nesse processo decisório, como se pôde observar durante a pandemia de Covid-19⁶. Essa recente experiência de ter sido alçada a um alto grau de protagonismo e prestígio revelou a maturidade técnica e científica da epidemiologia, assim como sua capilarização nas práticas das instituições de saúde. Entretanto, desvelou também uma série de desafios no que concerne à sua interação com políticas, programas e serviços de saúde^{7,8}.

Considerando as identidades entre suas definições e objetivos, um campo de práticas inequívoco para a epidemiologia é a vigilância em saúde. A definição de epidemiologia abarca tanto o estudo do processo saúde-doença e dos seus determinantes em populações, como a aplicação desse conhecimento para controlar problemas de saúde⁹. Já a vigilância em saúde enfatiza o processo de transformação dos dados em informações para subsidiar o planejamento e a implementação de ações de proteção e promo-

ção da saúde e de prevenção e controle de riscos, agravos e doenças em populações¹⁰. Ainda que o escopo da vigilância em saúde compreenda saberes para além da epidemiologia, o conhecimento epidemiológico é fundamental para a qualificação das suas ações¹¹.

Declaração da disponibilidade de dados

Todo o conjunto de dados que dá suporte aos resultados deste estudo está disponível mediante solicitação ao autor.

Institucionalização da vigilância em saúde no Brasil

No início do século XX, mesmo no âmbito internacional, as práticas de vigilância não apresentavam significativa organização institucional. A expressão “vigilância epidemiológica” passou a ser adotada no controle das doenças transmissíveis por volta da metade do século XX, enfatizando inicialmente a vigilância de pessoas com base em medidas de isolamento ou de quarentena, mas logo ampliando seu escopo para eventos de saúde em populações. A estruturação e institucionalização de serviços especificamente orientados para a execução das ações de vigilância epidemiológica ganham força no cenário internacional com a criação da unidade de vigilância epidemiológica na Divisão de Doenças Transmissíveis da Organização Mundial da Saúde (1965) e com as discussões técnicas da 21ª Assembleia Mundial de Saúde (1968), que reforçam a concepção de vigilância como uma função essencial das práticas de saúde pública^{12,13}. Em paralelo, o Regulamento Sanitário Internacional (RSI), criado em 1951, e suas subseqüentes alterações, estabeleceram novos processos de monitoramento, vigilância e resposta às emergências de saúde pública de importância internacional¹⁴.

A constituição e institucionalização da vigilância em saúde no Brasil têm como um possível marco a criação do Departamento Nacional de Endemias Rurais (DNERu), em 1956, que ofereceu uma oportunidade de integração, em uma única instituição, das campanhas contra as chamadas grandes endemias, que abarcavam ações de epidemiologia e vigilância¹⁵. Porém, somente com a criação do Sistema Nacional de Vigilância Epidemiológica (SNVE), em 1975, é que se estabelece uma consolidação normativa sobre a organização das ações de vigilância epidemiológica no país. Fundamentadas em ações verticalizadas e centralizadas nas esferas de gestão federal e estadual da saúde, o SNVE se reorganizou a partir da década de 1990, com a criação e implementação do SUS e o estabelecimento do Centro Nacional de Epidemiologia (CENEPI).

Esse processo avançou nos anos subseqüentes, a partir de marcos normativos como:

a Portaria 1.399/1999 (GM/MS), que estabelece as atribuições de cada esfera de governo na área de epidemiologia e controle de doenças e define a sistemática de financiamento¹⁶;

a criação, em 2003, da Secretaria de Vigilância em Saúde (SVS/MS) com o intuito de fortalecer e ampliar as ações de Vigilância em Saúde no Ministério da Saúde;

o Pacto pela Saúde (2006), em que o SNVE passou a ser denominado Sistema Nacional de Vigilância em Saúde (SNVS);

a Portaria 3.252/2009 (GM/MS), que estabeleceu as diretrizes para execução e financiamento das ações de Vigilância em Saúde no Brasil, ampliando seu escopo para abranger as vigilâncias epidemiológica, sanitária, em saúde do trabalhador e em saúde ambiental, além da promoção da saúde e vigilância da situação de saúde¹⁷.

O movimento pela estruturação de uma política do Estado brasileiro para a vigilância em saúde se fortalece com a publicação da Portaria 1.378/2013 (GM/MS), que prevê a criação do Grupo de Trabalho Tripartite para discussão e elaboração de uma Política Nacional de Vigilância em Saúde, o que é efetivado no mês seguinte^{18,19}. Afinal, a PNVS foi instituída em 2018 por meio da Resolução 588/2018 do Conselho Nacional de Saúde, considerando as resoluções da 1ª Conferência Nacional de Vigilância em Saúde, realizada em Brasília/DF no início de 2018^{10,20}.

A Epidemiologia e a PNVS

A PNVS é uma política pública de Estado de caráter universal, transversal e orientadora do modelo de atenção à saúde nos territórios e que define os princípios, as diretrizes e as estratégias a serem observados pelas três esferas de gestão do SUS para o desenvolvimento da vigilância em saúde. A PNVS estabelece que a organização das ações da vigilância em saúde compreende a articulação dos saberes, dos processos e das práticas das vigilâncias epidemiológica, sanitária, em saúde ambiental, em saúde do trabalhador e trabalhadora. Ao mesmo tempo, a PNVS visa a integralidade na atenção à saúde e pressupõe a inserção da vigilância em saúde na rede de atenção à saúde. A PNVS contempla toda a população, mas prioriza territórios e populações em situação de maior risco e vulnerabilidade, de modo a superar desigualdades sociais e de saúde e buscar a equidade na atenção¹⁰.

A PNVS é fruto das lutas pela constituição e defesa do SUS, e o sucesso de sua implementação representa a consolidação de uma visão abrangente de vigilância em saúde como um alicerce fundamental da promoção e proteção à saúde da população e um eixo estruturante da atenção primária à saúde²¹⁻²³.

Apesar de ter sido instituída em 2018, ainda não se observa uma efetiva implementação da PNVS nos territórios. Esses sete anos de vigência da PNVS foram particularmente desafiadores. O ciclo de austeridade fiscal associado à maior participação das emendas parlamentares no orçamento da saúde implicou agravamento do já crônico subfinanciamento do SUS e limitação na execução de políticas sociais²⁴. Nesse contexto, o impacto da pandemia de Covid-19 foi dramático: aprofundou as já substanciais desigualdades sociais do

país e interagiu sindemicamente com diferentes fontes de vulnerabilidades, potencializando os efeitos deletérios de todos os fatores na saúde da população²⁵.

Que pesem essas intempéries, a implementação da PNVS é uma agenda que une os três níveis de gestão do SUS e o controle social, mas os desafios são grandes e de diversas matizes. Por exemplo, a compartimentalização de saberes, processos e práticas dificulta uma efetiva integração das diferentes vigilâncias¹¹. Entraves organizacionais e o distanciamento do território limitam a efetiva articulação entre rede de atenção e vigilância. Barreiras a uma efetiva participação da comunidade no controle social, financiamento insuficiente e ausência de indicadores para avaliação e monitoramento da implementação da PNVS, inseridos nos instrumentos de gestão do SUS, são elementos adicionais que contribuem para esse panorama.

Boa parte desses desafios depende de mudanças estruturais e de cultura organizacional que se dão fora do âmbito de atribuições diretas das instituições de ensino e pesquisa que desenvolvem atividades no campo da epidemiologia. No entanto, a PNVS destaca uma série de necessidades que podem e devem ser contempladas pela epidemiologia, entre as quais destacam-se¹⁰:

- produção de evidências a partir da análise da situação da saúde para subsidiar a gestão em saúde;
- investigação de surtos e eventos inusitados ou situação de saúde decorrentes de impactos ambientais de processos e atividades produtivas;
- identificação dos condicionantes e determinantes de saúde no território;
- avaliação do impacto de novas tecnologias e serviços relacionados à saúde, de forma a prevenir riscos e eventos adversos;
- adoção de critérios epidemiológicos para a identificação e definição das linhas prioritárias de pesquisas; e
- desenvolvimento de ações de qualificação e capacitação da força de trabalho em saúde na área de epidemiologia e vigilância em saúde.

Essas necessidades oferecem oportunidades para a maior interação entre a epidemiologia e as políticas, e os programas e os serviços de saúde, nos moldes preconizados pelo V Plano Diretor para o Desenvolvimento da Epidemiologia no Brasil (2025–2029)⁷. O sucesso dessa empreitada passa, por um lado, pela atualização dos modelos de formação em epidemiologia, seja na graduação ou na pós-graduação, pela maior valorização das atividades de tradução do conhecimento⁸ e por uma maior atualização do ambiente acadêmico em relação aos avanços nas políticas de vigilância em saúde do Brasil.

Vigilância em saúde na pesquisa e pós-graduação

A vigilância em saúde é uma atividade fundamentalmente interdisciplinar, mas que tem a epidemiologia como um de seus principais eixos de conhecimento e prática.

Até, principalmente, a década de 1980, quando a pós-graduação em saúde coletiva no Brasil aprofundou seu processo de institucionalização, a ênfase da epidemiologia era menos no seu aspecto científico e mais nas questões relacionadas ao campo da epidemiologia aplicada aos serviços de saúde, tendo em vista o processo de criação e consolidação do SUS.

A expansão do Sistema Nacional de Pós-Graduação brasileiro teve efeitos inquestionáveis na formação de docentes e pesquisadores e na expansão e qualificação da produção científica em diversas áreas do conhecimento²⁶. Em 2024, havia quase 100 programas de pós-graduação em Saúde Coletiva em funcionamento em 22 Unidades da Federação, quase todos com áreas de concentração e/ou linhas de pesquisa em Epidemiologia. Nesse ano, os programas de pós-graduação contavam com quase 10.000 alunos, entre matriculados ou titulados, além de mais de 2.000 docentes. De modo geral, o processo de expansão dos programas de pós-graduação em Saúde Coletiva refletiu na ampliação da base de pesquisadores e docentes em Epidemiologia, contribuindo para o crescimento e aprimoramento da produção científica brasileira nesse campo, o que deve ter se refletido também na presença de linhas e projetos de pesquisa, trabalhos de conclusão de curso e artigos em periódicos sobre o tema da vigilância em saúde.

Para avaliar a penetração do tema da vigilância em saúde no âmbito da pesquisa científica brasileira, procedeu-se a uma busca de artigos científicos listados no portal de busca PubMed, em que o termo “vigilância” aparecia no título ou nos descritores em ciência da saúde (DeCS/MeSH) e que pelo menos um dos autores registrou sua afiliação a uma instituição brasileira, sem restrição de data. Foram excluídos manuscritos em *preprints* e sem resumo. Assim, chegou-se a um total de 1.575 artigos nos quais o tema da

vigilância foi mencionado, produzidos com a participação de pelo menos um autor afiliado à instituição brasileira. Esse conjunto de artigos é, aqui, livremente denominado “artigos de vigilância com autores brasileiros”. Para a análise dos dados derivados dessa busca, usou-se o método de *cubic splines* com 8 bandas para suavizamento nas curvas de tendência temporal. Para apresentar os termos (etiquetas ou *tags*; $n=21.756$) registrados nos artigos, utilizou-se a técnica de nuvem de palavras. Para esse fim, procedeu-se à harmonização e agrupamento dos termos utilizados para melhor caracterizar temas. Foram eliminados termos referentes à faixa etária, sexo e espécie (humano ou animais). Esse processo foi realizado de forma livre pelo autor, de acordo com sua experiência e visão sobre o tema, resultando numa listagem de 16.309 termos (75% do total). A perspectiva propiciada por essa abordagem tem como unidade de análise não o artigo, mas os termos.

A Figura 1 mostra a tendência temporal dos artigos abordando o tema da vigilância, globalmente e com pelo menos um dos autores com afiliação a uma instituição brasileira. Observa-se que as tendências são similares, com maior aceleração na década de 2000.

A Figura 2 mostra a tendência temporal da razão entre artigos abordando o tema da vigilância e o total de artigos registrados no portal PubMed, globalmente e com pelo menos um dos autores com afiliação a uma instituição brasileira, além da razão entre artigos de vigilância do Brasil e total global. Para o Brasil, apesar das variações, observa-se que os estudos de vigilância representam uma parcela crescente do total de artigos publicados até 2005, caindo em sequência até novo incremento a partir do início da pandemia de Covid-19. Globalmente, observa-se um incremento na participação de artigos de vigilância dentre o total até 2010, quando a curva se estabiliza. A curva da razão entre artigos de vigilância do Brasil e global mostra

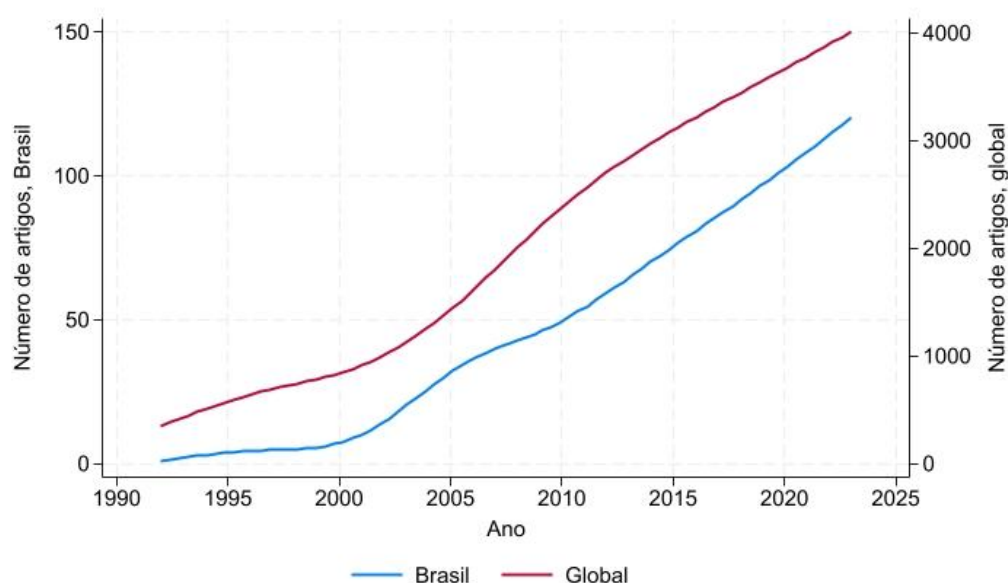


Figura 1. Tendência temporal de artigos científicos abordando o tema da vigilância disponíveis no portal PubMed, Brasil e global, 1990–2024.

que a parcela de artigos de vigilância publicados por autores brasileiros em relação ao total mundial vem crescendo de forma sustentada, apesar de representar um valor relativamente baixo (cerca de 30 artigos de vigilância de autores nacionais por mil artigos de vigilância publicados globalmente no final da série).

As Figuras 1 e 2 indicam que, apesar de o volume anual de artigos de vigilância com autores nacionais e de a razão em relação ao total mundial serem relativamente baixos, a tendência é de aumento sustentado para ambos os indicadores, sugerindo uma maior ênfase na produção científica nesse campo. Esse fenômeno pode ter sido fomentado por um maior interesse em pesquisas para o fortalecimento das ações de vigilância em saúde em função do crescente risco de emergência de novos patógenos²⁷.

Identificar o papel da epidemiologia na crescente produção científica de autores brasileiros sobre vigilância não é tarefa óbvia, devido à falta de marcadores objetivos e disponíveis nas bases de dados sobre que contribuição científica poderia ser efetivamente classificada como oriunda da área de epidemiologia. A Figura 3 explora essa questão, ainda que de forma indireta, mediante a apresentação da frequência relativa dos termos (etiquetas ou *tags*) registrados nos artigos sobre vigilância, após processo de harmonização, que apresentavam pelo menos 19 ocorrências.

O panorama apresentado na Figura 3 reforça o caráter interdisciplinar na vigilância em saúde, permitindo identificar classes abrangentes de temas. A classe definida pelo próprio uso do termo “vigilância” ou de práticas e elementos a ela relacionados (p. ex., vacinas, banco de dados e registros) representou 6% das menções. Classes definidas de acordo com áreas de conhecimento, como a epidemiologia (p. ex., medidas de frequência de doenças, desenhos de estudo e análise de dados) e a biologia (p. ex., genótipo,

filogenia, variação genética e entomologia), obtiveram cerca de 21% das citações cada uma. Outra classe de maior frequência refere-se às doenças e/ou agentes infecciosos específicos (p. ex., Covid-19, HIV, dengue, zoonoses e SARS-CoV-2; 20%). Outras classes identificadas foram as questões relacionadas ao tratamento e à atenção à saúde (p. ex., cuidados de saúde, agentes antibacterianos e resistência antimicrobiana; 8%), as técnicas comumente utilizadas em diagnóstico (p. ex., PCR e ELISA; 3%) e a localização geográfica (p. ex., Brasil e América Latina; 11%).

A interpretação desses resultados deve ser feita com cautela, dada a relativa informalidade da classificação empregada. Ainda assim, pode-se apreender que, em geral, os artigos analisados abordam temas e usam métodos e técnicas de interesse da vigilância, mas raramente estudam a própria vigilância, seus processos e práticas. Ainda, verifica-se a pouca representatividade de doenças e agravos não transmissíveis nesse contexto, possivelmente devido à ênfase nos estudos em contextos de surtos e pandemias. A epidemiologia, a clínica e a biologia se destacam como áreas de conhecimento que mais diretamente contribuíram para os estudos em vigilância.

A inserção da vigilância como objeto de estudo nos programas de pós-graduação em saúde coletiva no Brasil não é tão expressiva como se poderia imaginar, já que praticamente todos desenvolvem linhas de pesquisa em epidemiologia. Em 2023, dos 97 programas de pós-graduação com dados disponíveis na Plataforma Sucupira, 2 deles (1 acadêmico e 1 profissional) traziam o termo “vigilância” em sua denominação. Das 509 linhas de pesquisa cadastradas, 18 (3,5%) apresentavam o termo “vigilância” no título, enquanto a menção foi feita no título de 214 (3,2%) dos 6.680 projetos de pesquisa listados. A presença do termo “vigilância” no título dos projetos de pesquisa foi mais fre-

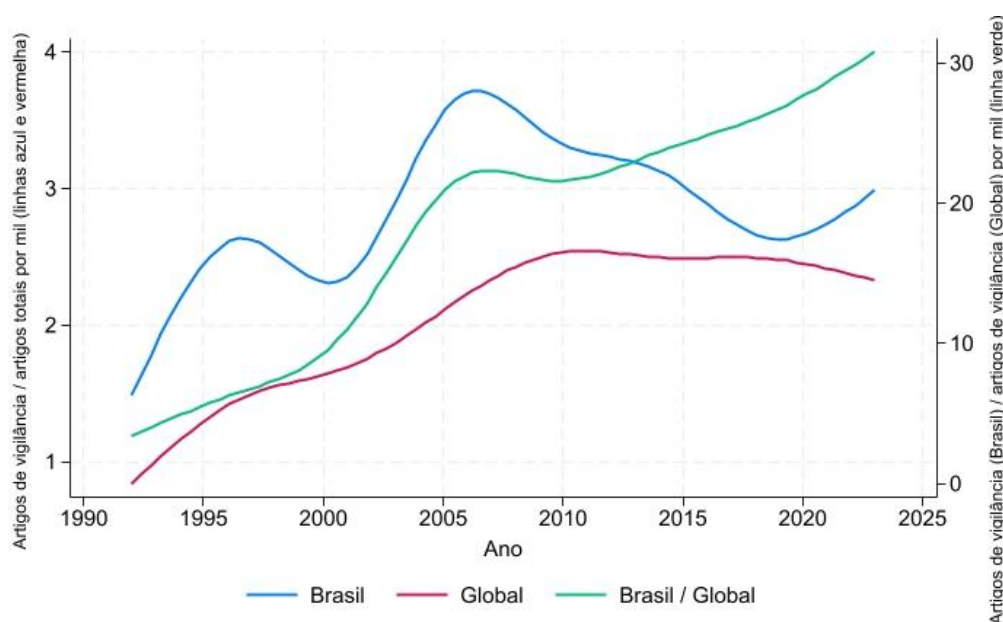
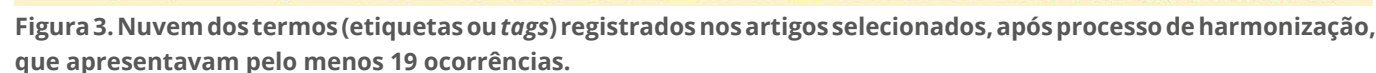


Figura 2. Tendência temporal da razão entre artigos abordando o tema da vigilância e o total de artigos registrados no portal PubMed, globalmente (linha vermelha) e com pelo menos um dos autores com afiliação a uma instituição brasileira (linha azul), e da razão entre artigos de vigilância do Brasil e global (linha verde), 1990–2024.



lância epidemiológica (n=8), vigilância alimentar e nutricional (n=6) e vigilância em saúde do trabalhador (n=5).

Evidentemente, a ausência do termo “vigilância” em títulos, palavras-chave e resumos não significa, necessariamente, que os temas ou objetos dos trabalhos de conclusão de curso não tenham implicações ou não sejam relevantes para a vigilância em saúde. Talvez sejam apenas estudos que não “se reconheçam” como relacionados à vigilância, um aspecto inusitado, já que a abrangência da vigilância em saúde, nos termos explicitados na PNVS, é suficientemente ampla para acomodar múltiplas abordagens. Por exemplo, a vigilância de doenças crônicas e agravos não transmissíveis se apoia em métodos distintos daqueles

usualmente empregados para as doenças transmissíveis de caráter agudo. Nesse caso, a realização de inquéritos populacionais sequenciais e a análise de estatísticas vitais desempenham papel fundamental. Da mesma forma, a vigilância das infecções crônicas transmissíveis, como tuberculose e HIV/aids, utiliza abordagens que requerem íntimas conexões com a rede de atenção e o monitoramento e a avaliação da cascata de cuidados das pessoas vivendo com essas condições. A articulação entre vigilância em saúde, rede de atenção e ações de promoção e proteção à saúde está explicitamente prevista na PNVS e é fundamental para alcançar a integralidade na atenção das doenças crônicas. Considerando o que preconiza a PNVS e a Política Nacional de Atenção Básica (PNAB), a vigilância em saúde é um eixo estruturante da atenção primária à saúde, implicando que a integração entre vigilância, atenção e ações de promoção e proteção à saúde é indispensável no contexto do SUS²².

Mesmo no campo das doenças transmissíveis, mais tipicamente associados à vigilância, os estudos sobre vacinação e cobertura vacinal nem sempre tomam os princípios e as práticas da vigilância em saúde como referencial de análise. Ainda que a avaliação da saúde mental seja tema caro à vigilância em saúde de trabalhadores e trabalhadoras, nem sempre o vínculo desses estudos com as ações de vigilância é bem explicitado. A análise de situação de saúde e vigilância laboratorial, embora sejam consideradas áreas transversais da vigilância em saúde, nem sempre são assim identificadas. Mesmo estudos sobre os condicionantes do processo saúde-doença são essenciais para a avaliação de risco, sobretudo em populações vulnerabilizadas. Tendo em vista todos esses aspectos, pode-se arriscar dizer que nem tudo é vigilância, mas muito do que se produz em epidemiologia poderia se encontrar na vigilância, restando que sejam desenvolvidas ações específicas no âmbito dos programas de pós-graduação em saúde coletiva para que essas interrelações sejam fortalecidas.

Desafios e oportunidades

O lançamento do V Plano Diretor para o Desenvolvimento de Epidemiologia no Brasil (2025–2029), após quase duas décadas desde a publicação do IV Plano, se dá em um contexto nacional e mundial de grandes transformações, que impõem novos desafios à garantia da saúde da população brasileira⁷.

O aprofundamento do capitalismo financeiro transnacional gera vetores estruturais de produção de adoecimento populacional, incluindo o aumento da desigualdade e da pobreza, o estímulo ao consumo de produtos nocivos à saúde, como álcool, tabaco e ultraprocessados, a precarização das condições de trabalho, a redução das políticas de proteção social, a ampliação da poluição e a agudização da crise climática^{28,29}. Nesse contexto, torna-se cada vez mais desafiador o fortalecimento das relações multilaterais solidárias para preparação e resposta a emergências sanitárias e à crise climática.

As dificuldades para encontrar soluções se tornam ainda maiores com a penetração do sentimento anticiência na sociedade, em particular da hesitação vacinal, inclusive entre profissionais de saúde^{30,31}, o que pode ter um impacto adicional na medida em que esses profissionais seriam aqueles dos quais se esperaria uma ação positiva para dirimir dúvidas e contribuir para o aumento da confiança em vacinas³².

Ainda que os desafios sejam imensos e a implementação de ações efetivas seja cada vez mais premente, é preciso reconhecer que diversas iniciativas e movimentos de resistência locais e globais têm produzido avanços substanciais em várias dimensões da saúde pública. Por exemplo, as alterações no Regulamento Sanitário Internacional e a aprovação do novo tratado de pandemias, embora muito aquém das necessidades globais, podem ser consideradas conquistas e constituem oportunidades para avançar na estruturação de melhores práticas de preparação e resposta às emergências sanitárias^{33,34}. Em 2024 e 2025, diversos países receberam a certificação de eliminação de doenças infecciosas como problema de saúde pública, como tracoma (7 países), malária (5 países), filariose linfática (2 países), hanseníase (1 país) e tripanossomíase africana (3 países). No Brasil, após um período de redução das coberturas vacinais, observou-se uma reversão desta para diversas vacinas do calendário infantil e o aumento do número de municípios, cumprindo as metas estabelecidas³⁵.

Que pese a grandeza dessas conquistas, sua sustentabilidade depende do sucesso das lutas em defesa da democracia, da vida e do direito universal à saúde. É com esse compromisso que o V Plano Diretor para o Desenvolvimento da Epidemiologia no Brasil (2025–2029) sistematiza um conjunto de problemas e propõe uma série de ações para seu enfrentamento nas áreas de formação e pesquisa em epidemiologia e na inserção da epidemiologia em políticas, programas e serviços de saúde.

A vigilância em saúde é um dos temas privilegiados no V Plano Diretor para o Desenvolvimento da Epidemiologia no Brasil (2025–2029). Destacam-se proposições como a criação de componentes curriculares de vigilância em saúde e de emergências de saúde pública nos cursos de graduação e pós-graduação, estímulo a espaços de práticas em vigilância em saúde, apoio à educação permanente das equipes de vigilância em saúde, estímulo à implementação de pesquisas orientadas para a qualificação das ações da vigilância em saúde, desenvolvimento de indicadores estratégicos da vigilância em saúde de base territorial e defesa da implementação efetiva da PNVS⁷.

O V Plano Diretor para o Desenvolvimento da Epidemiologia no Brasil (2025–2029) é um vetor essencial para o desenvolvimento teórico, metodológico e prático da epidemiologia. Ao reconhecer a vigilância em saúde como um tema central para o desenvolvimento da epidemiologia no país, o Plano é, também e sobretudo, um chamado para uma epidemiologia comprometida com o fortalecimento do SUS e com a construção de estratégias exitosas e participativas para a redução das desigualdades sociais em saúde.

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ABSTRACT

In this essay, we discuss the challenges related to the interaction between epidemiology and health policies, programs, and services, with a particular focus on health surveillance. Although the scope of health surveillance encompasses knowledge beyond epidemiology, the use of epidemiological knowledge is paramount for enhancing the quality of its actions. We present the trajectory of the institutionalization process of health surveillance in Brazil, which culminated in the establishment of the National Health Surveillance Policy (PNVS) in 2018. The PNVS highlights a series of needs that can and should be addressed by epidemiology. These needs offer opportunities for greater interaction between epidemiology and health policies, programs, and services, but they require an update in epidemiology training models, both at the undergraduate and graduate levels, a greater appreciation for knowledge translation activities, and an improved alignment of the academic environment with advances in health surveillance policies in Brazil. Based on the analysis of Brazilian articles on health surveillance listed in the PubMed database, as well as data from research lines, projects, and theses and dissertations from graduate programs, we evaluate how the topic of health surveillance is integrated into research and graduate education in Collective Health in Brazil. We conclude this essay by discussing the contribution of the Fifth Strategic Plan for the Development of Epidemiology in Brazil (2025–2029) for strengthening health surveillance.

Keywords: Public health surveillance. Epidemiology. Uses of epidemiology. Professional training. Health services research.

FONTE DE FINANCIAMENTO: nenhuma.

Effects of conditional cash transfers on tuberculosis incidence and mortality according to race, ethnicity and socioeconomic factors in the 100 Million Brazilian Cohort

Received: 15 April 2024

Accepted: 26 October 2024

Published online: 3 January 2025

 Check for updates

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Conditional cash transfer (CCT) programs have been implemented globally to alleviate poverty. Although tuberculosis (TB) is closely linked to poverty, the effects of CCT on TB outcomes among populations facing social and economic vulnerabilities remain uncertain. Here we estimated the associations between participation in the world's largest CCT program, the Brazilian Bolsa Família Program (BFP), and the reduction of TB incidence, mortality and case-fatality rates using the nationwide 100 Million Brazilian Cohort between 2004 and 2015. We also evaluated these relationships according to race, ethnicity, wealth levels, sex and age. Exposure to the BFP was associated with a large reduction in TB incidence (adjusted rate ratio (aRR): 0.59; 95% confidence interval (CI): 0.58–0.60) and mortality (aRR: 0.69; 95% CI: 0.65–0.73). The strongest BFP association was observed in individuals of Indigenous ethnicity both for TB incidence (aRR: 0.37; 95% CI: 0.32–0.42) and mortality (aRR: 0.35; 95% CI: 0.20–0.62), and in individuals of Black and Pardo ethnicity (incidence—aRR: 0.58; 95% CI: 0.57–0.59; mortality—aRR: 0.69; 95% CI: 0.64–0.73). BFP associations were considerably stronger among individuals living in extreme poverty both for TB incidence (aRR: 0.49; 95% CI: 0.49–0.50) and mortality (aRR: 0.60; 95% CI: 0.55–0.65). CCT can strongly reduce TB incidence and mortality in individuals living in extreme poverty, and of Indigenous, Black and Pardo ethnicity, and could significantly contribute to achieving the End TB Strategy targets and TB-related Sustainable Development Goals.

Conditional cash transfers (CCTs) are the world's most widely implemented interventions for poverty alleviation¹. Social protection, poverty alleviation and multisectoral actions on broad tuberculosis (TB) determinants are acknowledged as key pillars of the End TB Strategy by 2035, and they are essential to reduce the TB burden².

CCT programs have the potential to positively influence TB prevention, diagnosis and treatment^{3,4}. CCTs improve living conditions and incentivize behavioral changes by providing financial support to individuals or households who adhere to specific health-related

conditions, often associated with child and maternal health⁵. Previous studies in low- and middle-income countries showed that CCT programs were associated with improved TB outcomes, including increased treatment adherence and completion rates^{6–8}. Furthermore, CCTs could effectively alleviate the economic burdens faced by TB-affected households⁹. These costs, which often result from medical expenses, loss of income and other related factors, can push affected households into poverty and hinder their access to proper TB care¹⁰. Thus, these transfers help mitigate the catastrophic costs associated

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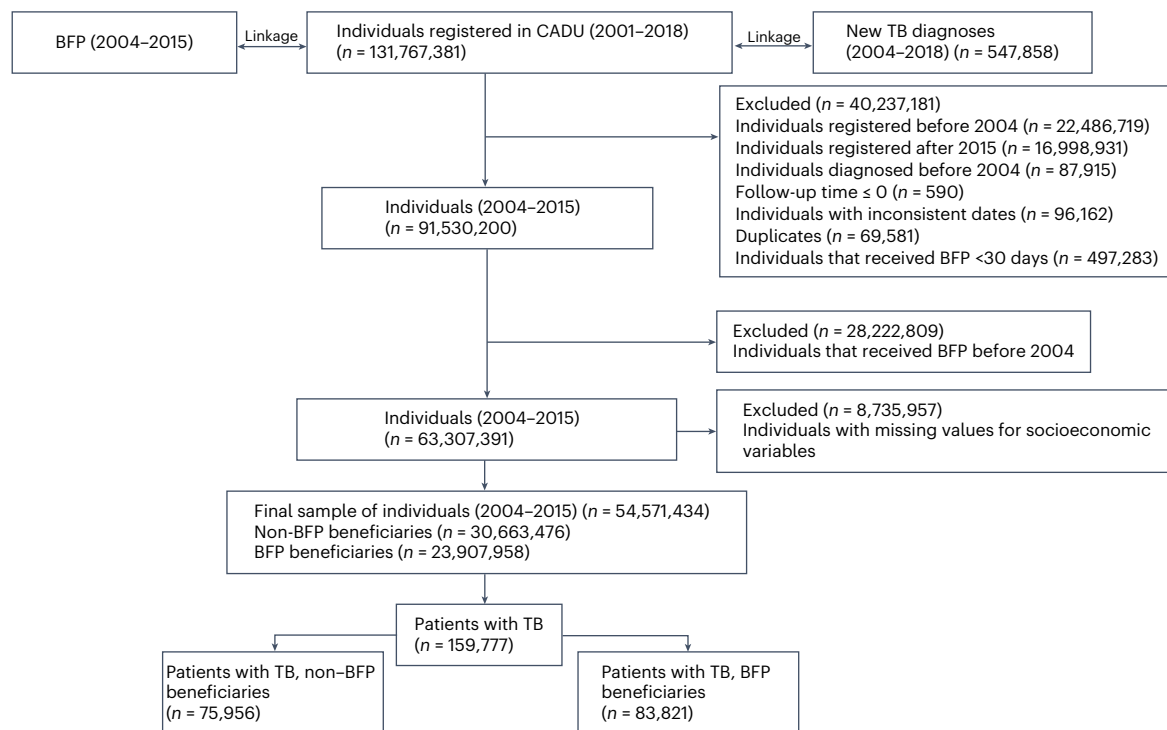


Fig. 1 | Flowchart of the selection of the study population from the 100 Million Brazilian Cohort, 2004–2015. Individuals from the 100 Million Brazilian Cohort were selected or excluded based on the study period (2004–2015) and availability of complete information of demographic and socioeconomic

variables. A total of 54,571,434 individuals were selected: BFP beneficiaries (43.8%, $n = 23,907,958$) and non-BFP beneficiaries (56.2%, $n = 30,663,476$). The selected population included 159,777 new TB diagnoses.

with TB, ensuring better access to treatment and reducing economic hardships for affected families.

Since 2004, Brazil has implemented one of the world's largest CCT programs, the Bolsa Família Program (BFP)^{11,12}. The governmental program provides direct cash transfers to households living in poverty with income below the poverty line defined by the Brazilian government as US\$43.6 per person per month (at an exchange rate of 5 Brazilian Reais to US\$1). The monthly cash benefits are at least US\$120; children in the family aged between 0 and 6 years old receive an additional US\$50, and pregnant women, children and adolescents up to 18 years old receive an additional of US\$10 (values corrected in 2023). To continue receiving the benefits, BFP beneficiaries have to fulfill specific conditionalities related to healthcare for pregnant women (carrying out prenatal care) and children (compliance with the national vaccination schedule, monitoring nutritional status) and education (school attendance) for children and adolescents¹³. The BFP has been able to improve the well-being of families in poverty, and to reduce social and income inequalities in society, improving access to education, food and health services¹¹. Several studies have shown the positive effects of the BFP on health outcomes such as child mortality¹², cardiovascular diseases¹⁴, suicide¹⁵, leprosy¹⁶ and some aspects of the TB burden^{3,17}, among others.

In addition to the income disparity, Brazil has a profound ethnic and racial inequality. Individuals with self-declaration of Black, Pardo and Indigenous ethnicity in Brazil face more barriers to accessing better job opportunities, salaries, decent housing, a balanced diet, and quality health and education services¹⁸. As a consequence, these populations are more subject to violence and worse health indicators¹⁸, including higher incidence of and mortality rates from TB¹⁹.

We are not aware of previous studies that have systematically evaluated the effects of CCT programs in large cohorts of vulnerable individuals at high risk for TB and with limited access to health

services, such as groups in situations of social marginalization and individuals living in extreme poverty, analyzing their effects according to subpopulation characteristics and evaluating the association between the participation in CCT and TB burden indicators. This study aimed to evaluate the comprehensive association between receipt of the BFP and the reduction of TB incidence, mortality and case-fatality rates using a nationwide cohort of 54.5 million low-income Brazilians over 12 years, estimating its heterogeneous effectiveness across the spectrum of ethnoracial factors and socioeconomic conditions.

Results

Study design and population

This study has a cohort study design, obtained after selecting individuals from the 100 Million Brazilian Cohort²⁰, a consolidated cohort created through the validated linkage²¹ between the Federal Government Unified Registry for Social Programs (Cadastro Único)—which gathers data from the poorest half of the Brazilian population—and health-related datasets from the Brazilian Ministry of Health. As described in the flowchart of the study population selection (Fig. 1), after individuals who were outside the study period 2004–2015 and who had missing information on demographic or socioeconomic variables were excluded, 54,571,434 individuals were selected, of which 23,907,958 were BFP beneficiaries (43.8%) and 30,663,476 were non-BFP beneficiaries (56.2%), with a total of 159,777 new TB diagnoses and 7,993 TB deaths.

TB incidence was lower among BFP beneficiaries than among non-beneficiaries (49.44/100,000 person-years at risk (pyr) (95% confidence interval (CI): 47.84–48.50) versus 81.37/100,000 pyr (95% CI: 80.97–82.13)), and the same was the case with TB mortality rate (2.08/100,000 pyr (95% CI: 2.01–2.15) versus 4.68/100,000 pyr (95% CI: 4.54–4.81)) and TB case-fatality rate (0.68/100 pyr (95% CI: 0.64–0.73) versus 1.37/100 pyr (95% CI: 1.25–1.49)) (Table 1). BFP beneficiaries and non-beneficiaries showed similar demographic and socioeconomic

Table 1 | Descriptive analyses of BFP beneficiaries and non-beneficiaries (n=54,571,434), Brazil, 2004–2015

	N-BF (n=30,663,476)		BF (n=23,907,958)		Total	
	Rates (95% CI)	Number (%)	Rates (95% CI)	Number (%)		
Incidence rate	81.37 (80.97–82.13)	75,956 (47.5)	49.44 (47.84–48.50)	83,821 (52.5)	159,777	
Mortality rate	4.68 (4.54–4.81)	4,359 (54.5)	2.08 (2.01–2.15)	3,634 (45.5)	7,993	
Case-fatality rate	1.37 (1.25–1.49)	495 (39.7)	0.68 (0.64–0.73)	751 (60.3)	1,246	
Social and demographic variables	Number or mean	% or s.d.	Number or mean	% or s.d.	P value^a	SMD
Sex					<0.001	0.0442
Male	14,595,815	47.6	10,854,212	45.4		
Female	16,067,661	52.4	13,053,746	54.6		
Age	25.32	2.14	24.17	1.60	<0.001	0.3829
Race or ethnicity					<0.001	0.1655
White	11,376,150	37.1	7,244,111	30.3		
Black or Pardo ^b	19,195,336	62.6	16,424,767	68.7		
Indigenous	91,990	0.3	239,080	1.0		
Education					<0.001	0.1986
Illiterate, never attended school	9,965,630	32.5	8,869,852	37.1		
Elementary school	9,536,341	31.1	7,459,283	31.2		
High school	6,040,705	19.7	5,140,211	21.5		
More than high school	5,120,800	16.7	2,438,612	10.2		
House construction materials					<0.001	0.0854
Bricks or cement	24,438,790	79.7	18,217,864	76.2		
Wood and other vegetal materials	6,224,686	20.3	5,690,094	23.8		
Number of people in the family					<0.001	0.3215
≤2	10,425,582	34.0	5,044,579	21.1		
3 or 4	14,810,459	48.3	12,432,138	52.0		
≥5	5,427,435	17.7	6,431,241	26.9		
Per salary expenses—% MW^c					<0.001	0.2856
Below median	13,461,266	43.9	13,866,616	58.0		
Above median	17,202,210	56.1	10,041,342	42.0		
Lighting					<0.001	0.2021
Electricity	27,321,157	89.1	19,604,526	82.0		
Non-electric ^d	3,342,319	10.9	4,303,432	18.0		
Adequate sanitation^e					<0.001	0.0795
Yes	19,961,923	65.1	14,655,578	61.3		
No	10,701,553	34.9	9,252,380	38.7		
Garbage disposal^f					<0.001	0.1044
Garbage collection	24,745,425	80.7	18,265,680	76.4		
Burned or buried	5,918,051	19.3	5,642,2788	23.6		
Water supply					<0.001	0.1255
Public network	23,334,905	76.1	16,879,018	70.6		
Other ^g	7,328,571	23.9	7,028,940	29.4		
Incidence cohort	123.2	90.4	146.0	103.3	<0.001	−0.2361
AIDS					0.060	0.0183
Yes	1,355	8.8	3,009	9.3		
No	14,080	91.2	29,331	90.7		
Diabetes					<0.001	0.1085
Yes	1,236	8.0	1,716	5.3		
No	14,199	92.0	30,624	94.7		

Table 1 (continued) | Descriptive analyses of BFP beneficiaries and non-beneficiaries (n=54,571,434), Brazil, 2004–2015

	N-BF (n=30,663,476)		BF (n=23,907,958)		Total	
	Rates (95% CI)	Number (%)	Rates (95% CI)	Number (%)		
DOT					<0.001	0.0601
Yes	8,445	54.7	16,724	51.7		
No	6,990	45.3	15,616	48.3		
Pulmonary TB					<0.001	0.3733
Yes	13,373	86.6	28,422	87.9		
No	2,062	13.4	3,918	12.1		
PHC^h	69.6	28.1	65.2	29.0	<0.001	0.1486
Specialized clinics per 1,000 inhabitants	0.12	0.14	0.10	0.12	<0.001	0.1535
Doctors per 1,000 inhabitants	1.17	1.01	1.21	0.99	<0.001	−0.0311
Nurses per 1,000 inhabitants	0.58	0.38	0.54	0.35	<0.001	0.3551
Unemployment rate (%)	7.3	5.0	8.98	5.2	<0.001	−0.3674
Gini index	52.3	7.1	54.2	6.9	<0.001	−0.2793
Year of entry into the cohort					<0.001	−0.5093
2004	2,177,107	7.1	2,438,612	10.2		
2005	1,318,529	4.3	1,936,545	8.1		
2006	5,396,772	17.6	6,072,621	25.4		
2007	3,403,646	11.1	2,103,900	8.8		
2008	2,269,097	7.4	1,267,122	5.3		
2009	1,379,856	4.5	2,175,624	9.1		
2010	1,993,126	6.5	1,864,821	7.8		
2011	1,655,828	5.4	1,673,557	7.0		
2012	3,526,300	11.5	1,601,833	6.7		
2013	2,054,453	6.7	1,147,582	4.8		
2014	3,035,684	9.9	884,594	3.7		
2015	2,422,415	7.9	741,147	3.1		
Obs	30,663,476		23,907,958			

BF beneficiaries; N-BF, non-beneficiaries; Obs, observations; SMD, standardized mean difference. ^aThe following were used for a comparison between the groups: (1) two-tailed t-test for continuous variables and (2) Pearson's chi-squared test (χ^2) for categorical variables. ^bRace or ethnicity: Black or Pardo, self-declared. ^cProportional to the baseline minimum wage (MW). ^dLighting: non-electric—no meter, lamps, candles and others. ^ePercentage of the municipal population with inadequate baseline sanitation. ^fPercentage of the municipal population with baseline garbage collection. ^gWater supply: other—well, spring and others. ^hPrimary healthcare (PHC) percentage coverage.

characteristics. Compared with non-beneficiaries, BFP beneficiaries are younger (mean age 25.3 versus 24.2 years) and had a slightly higher percentage of people self-identified as Black or Pardo race or ethnicity (62.6% versus 68.7%), people with no education (32.5% versus 37.1%), households with 3 or more individuals (66.0% versus 78.9%), people with lesser wealth (43.9% versus 58.0%), people without adequate sanitation (34.9% versus 38.7%) and people without a public network for water supply (23.9% versus 29.4%).

Main analyses

For the main statistical analysis, we used stabilized, truncated, inverse probability of treatment weighting (IPTW) multivariable Poisson regression models (see Methods for details). As shown in Table 2, the exposure to the BFP was associated with a significant reduction in TB incidence (adjusted rate ratio (aRR): 0.59; 95% CI: 0.58–0.60), decreased TB mortality (aRR: 0.69; 95% CI: 0.65–0.73) and lower TB case-fatality rate (aRR: 0.90; 95% CI 0.76–1.05), although not statistically significant.

Stratified analyses

In the stratified analyses according to wealth terciles (Table 3), the association between the BFP and the reduction of TB incidence showed

a marked gradient and was considerably stronger among the individuals living in extreme poverty (aRR: 0.49; 95% CI: 0.49–0.50), gradually decreasing until having only a small association on the wealthiest individuals (aRR: 0.95; 95% CI: 0.93–0.98). Also, for TB mortality, the BFP association was considerably stronger among the individuals living in extreme poverty (aRR: 0.60; 95% CI: 0.55–0.65) and showed a gradient demonstrating the lack of association of the BFP in those people with higher wealth (aRR: 1.00; 95% CI: 0.85–1.17) (Table 3).

In the stratified analyses according to race and ethnicity, another gradient was evident among individuals of Indigenous, Black or Pardo, and White ethnicity, both for TB incidence (aRR: 0.37 (95% CI: 0.32–0.42) for Indigenous, aRR: 0.58 (95% CI: 0.57–0.59) for Black or Pardo, aRR: 0.67 (95% CI: 0.66–0.69) for White) and TB mortality (aRR: 0.35 (95% CI: 0.20–0.62) for Indigenous, aRR: 0.69 (95% CI: 0.64–0.73) for Black or Pardo, and aRR: 0.83 (95% CI: 0.73–0.94) for White), while the estimates for TB case-fatality rate was not statistically significant (Table 3). In terms of education, the association between the BFP and reductions in TB incidence was greater in people with less education (aRR: 0.58 (95% CI: 0.57–0.59) versus aRR: 0.80 (95% CI: 0.77–0.83) for people with higher education) (Table 3). The BFP was also associated with a higher reduction in TB mortality rates in females than in males

Table 2 | Estimates of the association between the BFP and tuberculosis incidence, mortality and the case-fatality rate in the Brazil adjusted Poisson model (with robust standard errors), 2004–2015

Adjusted model	Outcomes, aRR (95% CI)		
	Incidence	Mortality	Case-fatality rate
BFP	0.59 (0.58–0.60)	0.69 (0.65–0.73)	0.90 (0.76–1.05)
Sex			
Male	1 (base)	1 (base)	1 (base)
Female	0.58 (0.57–0.59)	0.40 (0.38–0.42)	0.69 (0.59–0.79)
Age ^a	1.19 (1.19–1.20)	1.63 (1.61–1.65)	1.44 (1.38–1.50)
Race or ethnicity			
White	1 (base)	1 (base)	1 (base)
Black or Pardo ^b	1.42 (1.40–1.44)	1.70 (1.60–1.81)	1.02 (0.86–1.21)
Indigenous	3.63 (3.43–3.84)	4.50 (3.59–5.65)	1.58 (0.92–2.70)
Education			
Illiterate, never attended school	1 (base)	1 (base)	1 (base)
Elementary school	1.83 (1.80–1.86)	1.05 (0.99–1.11)	0.94 (0.79–1.12)
High school	2.21 (2.17–2.25)	0.99 (1.93–1.06)	0.77 (0.62–0.94)
More than high school	1.74 (1.70–1.77)	0.60 (0.54–0.67)	0.52 (0.37–0.73)
House construction materials			
Bricks and cement	1 (base)	1 (base)	1 (base)
Wood and other vegetal materials	1.22 (1.20–1.24)	1.21 (1.14–1.29)	1.15 (0.98–1.37)
Number of people in the family			
≤2	1 (base)	1 (base)	1 (base)
3 to 4	0.97 (0.96–0.99)	0.83 (0.78–0.88)	0.89 (0.89–1.28)
≥5	1.20 (1.18–1.21)	0.99 (0.92–1.06)	1.07 (0.76–1.05)
Per-salary expenses—% MW ^c			
Below the median	1 (base)	1 (base)	1 (base)
Above the median	0.77 (0.78–0.79)	0.71 (0.66–0.75)	0.89 (0.75–1.05)
Lighting			
Electricity	1 (base)	1 (base)	1 (base)
Non-electric ^d	1.34 (1.32–1.36)	1.54 (1.45–1.65)	1.09 (0.91–1.31)
Inadequate sanitation ^e	1.00 (0.99–1.02)	1.08 (1.02–1.15)	0.96 (0.81–1.14)
Garbage disposal ^f	0.78 (0.77–0.80)	0.77 (0.71–0.83)	1.03 (0.82–1.30)
Water supply			
Public network	1 (base)	1 (base)	1 (base)
Other ^g	0.95 (0.93–0.96)	0.99 (0.92–1.06)	0.95 (0.79–1.15)
TB incidence cohort	1.00 (1.00–1.00)	1.00 (1.00–1.00)	0.99 (0.99–1.00)
AIDS	–	–	1.93 (1.39–2.68)
Diabetes	–	–	0.87 (0.68–1.10)
DOT	–	–	1.54 (1.34–1.77)
Pulmonary TB	–	–	0.54 (0.42–0.69)
PHC ^h			
Coverage	1 (base)	1 (base)	1 (base)
No coverage	0.99 (0.99–1.00)	1.00 (0.99–1.00)	1.00 (0.99–1.00)
Specialized clinics per 1,000 inhabitants	0.63 (0.59–0.67)	0.54 (0.39–0.73)	1.15 (0.54–2.42)
Doctors per 1,000 inhabitants	1.11 (1.10–1.12)	1.19 (1.00–1.10)	1.08 (0.94–1.25)
Nurses per 1,000 inhabitants	0.95 (0.92–0.98)	0.80 (0.70–0.91)	1.11 (0.75–1.66)
Unemployment rate (%)	1.01 (1.01–1.02)	1.03 (1.02–1.04)	1.00 (0.98–1.02)
Gini index	0.99 (0.99–1.00)	1.00 (0.99–1.00)	0.98 (0.97–1.00)
Year of entry into the cohort	Yes	Yes	Yes
Obs	54,565,735	54,571,434	46,344

^aAge categorized every 10 years. ^bRace or ethnicity: Black or Pardo, self-declared. ^cProportional to the baseline MW. ^dLighting: non-electric—no meter, lamps, candles and others. ^ePercentage of the municipal population with inadequate baseline sanitation. ^fPercentage of the municipal population with baseline garbage collection. ^gWater supply: other—well, spring and others.

^hPercentage of coverage.

Table 3 | Estimates of the association between the BFP and TB incidence, mortality and case-fatality rate in Brazil in adjusted Poisson models (with robust standard errors), 2004–2015

Adjusted models	Incidence		Mortality		Case-fatality rate	
	aRR	95% CI	aRR	95% CI	aRR	95% CI
Wealth ^a						
Lower wealth	0.49	(0.49–0.50)	0.60	(0.55–0.65)	0.80	(0.64–1.01)
Obs	18,476,834		18,479,518		20,752	
Medium wealth	0.55	(0.54–0.57)	0.69	(0.63–0.77)	1.08	(0.82–1.43)
Obs	17,714,018		17,715,984		16,74	
Higher wealth	0.95	(0.93–0.98)	1.00	(0.85–1.17)	0.92	(0.60–1.42)
Obs	18,596,773		18,597,844		8,979	
Race or ethnicity						
White	0.67	(0.66–0.69)	0.83	(0.73–0.94)	1.26	(0.93–1.71)
Obs	18,612,330		18,613,587		12,288	
Black or Pardo ^b	0.58	(0.57–0.59)	0.69	(0.64–0.73)	0.84	(0.69–1.00)
Obs	35,641,321		35,645,701		33,328	
Indigenous	0.37	(0.32–0.42)	0.35	(0.20–0.62)	0.16	(0.007–3.33)
Obs	312,084		312,146		717	
Education						
Illiterate, never attended school	0.58	(0.57–0.59)	0.72	(0.68–0.78)	0.90	(0.66–1.23)
Obs	35,830,269		35,833,532		7,741	
Elementary school	0.58	(0.57–0.60)	0.63	(0.56–0.71)	0.93	(0.71–1.21)
Obs	11,160,783		11,162,535		17,185	
High school and university education	0.80	(0.77–0.83)	0.90	(0.71–1.14)	1.06	(0.84–1.35)
Obs	7,577,703		7,578,387		25,267	
Sex						
Male	0.60	0.59–0.61	0.78	0.72–0.84	0.94	0.78–1.13
Obs	25,432,661		25,435,955		25,681	
Female	0.61	0.59–0.62	0.63	0.57–0.69	0.90	0.66–1.23
Obs	29,142,346		29,144,751		20,663	
Prisons in the municipality						
Yes	0.62	0.61–0.64	0.74	0.68–0.80	0.92	0.75–1.15
Obs	26,078,654		26,081,968		26,777	
No	0.55	0.54–0.56	0.64	0.59–0.70	0.89	0.71–1.25
Obs	28,487,075		28,489,460		19,567	
Brazilian region						
North	0.48	0.47–0.50	0.47	0.39–0.56	0.97	0.55–1.71
Obs	6,224,529		6,225,218		5,859	
Northeast	0.51	0.49–0.52	0.57	0.52–0.63	0.81	0.63–1.06
Obs	18,246,282		18,248,820		14,703	
Southeast	0.67	0.66–0.68	0.88	0.80–0.97	1.09	0.82–1.44
Obs	19,438,441		19,439,952		17,926	
South	0.66	0.64–0.69	0.68	0.56–0.82	0.62	0.44–0.87
Obs	6,306,963		6,307,614		5,775	
Middle-West	0.58	0.54–0.62	0.68	0.50–0.92	1.37	0.56–3.36
Obs	4,349,514		4,349,824		2,081	

All models were adjusted for the same demographic and socioeconomic variables described in Table 2. ^aMeasured by per capita expenses proportional to the baseline MW in terciles 1, 2 and 3, 33,33% each one; lower wealth: tercile 1, medium wealth: tercile 2 and higher wealth: tercile 3. ^bRace or ethnicity: Black or Pardo, self-declared.

(aRR: 0.63 (95% CI: 0.57–0.69) versus aRR: 0.78 (95% CI: 0.72–0.84), respectively). According to analyses by Brazilian regions, the strongest associations between the BFP and both TB incidence and mortality

reductions were observed in the poorest areas, specifically the north and northeast regions. When carrying out a stratified analysis according to the existence or not of prisons in the municipality, we observed

a greater association between the BFP and reductions in TB incidence (aRR 0.55 (95% CI: 0.54–0.56) versus aRR 0.62 (95% CI: 0.61–0.64)) and mortality (aRR 0.64 (95% CI: 0.59–0.70) versus aRR 0.74 (95% CI: 0.68–0.80)) in municipalities without prisons.

Sensitivity and triangulation analyses

We developed a wide range of several sensitivity analyses (for details, see Methods and Supplementary Tables 1–7), fitting models with different specifications and adjusting variables. We also performed two different triangulation analyses²²: Cox multivariate regression and propensity score matching (PSM) (Extended Data Table 4). All sensitivity tests confirmed the association estimates, and the triangulation analyses showed a high degree of confidence in the causal inference.

Discussion

In this study, we systematically analyzed the BFP effect among individuals living in situations of social marginalization, evaluating the associations between participation in a CCT and the burden of TB according to their ethnoracial and socioeconomic conditions. We observed strong effects of the BFP in decreasing both TB incidence and mortality rates. Notably, the effectiveness of the BFP showed a marked gradient based on race, ethnicity and socioeconomic conditions, revealing significantly stronger effects among individuals with Indigenous or Black or Pardo ethnicity and individuals living in extreme poverty.

Our findings reveal a gradient of BFP effectiveness based on the baseline wealth level of its beneficiaries: the BFP shows a significant effect on TB incidence and mortality in individuals living in extreme poverty, while demonstrating a lower effect on TB incidence in the less poor, with no discernible effects on TB mortality. The strongest effect of the BFP in the individuals living in extreme poverty can be explained by two factors. First, extreme poverty has consistently been shown to be a significant risk factor for TB, with TB risk levels correlating directly with poverty levels⁴. Therefore, lifting someone out of extreme poverty can be associated with a substantial reduction in their TB risk and burden. In addition, BFP benefits increase with poverty levels, providing a more significant improvement in socioeconomic position for individuals living in extreme poverty compared with those living in poverty, resulting in a more pronounced reduction in TB risk and burden for the former group.

Regarding the mechanisms by which CCT can affect TB, it has to be considered that the BFP, through the direct transfer of money to the families living in extreme poverty and in situations of social marginalization in Brazil, promotes greater access to food, both in quantity and quality, reducing food insecurity and malnutrition, an important TB risk factor, besides improving immune host defenses¹¹. Moreover, housing conditions could improve, reducing crowding and poor ventilation, which are also recognized risk factors for TB²³. Households could also transition from cooking with burning fuels such as wood, charcoal, coal and kerosene to cleaner fuels. This change can help reduce indoor air pollution, which has been recognized as a factor contributing to increased TB incidence. Smoking habits and alcoholism, which are strongly associated with poverty, could also decrease among BFP beneficiaries, thereby reducing the risk of contracting TB. The prevalence of diabetes, HIV and AIDS, which is higher in the individuals living in social vulnerability, could also be reduced by poverty-reduction interventions^{24–26}. Consequently, this reduction can be associated with a decrease in the incidence and mortality from TB. Moreover, individuals affected by TB who are living in extreme poverty are more likely to avoid seeking diagnosis at health centers or to interrupt their treatment owing to direct costs, such as transportation expenses, and opportunity costs, such as the difficulty of missing a day of work due to their precarious employment and subsistence conditions. These costs could represent a barrier even if prevention, diagnosis and treatment are available free in the Unified Health System

(Sistema Único de Saúde)²⁷. In addition to providing monetary transfers, the conditions that qualify for the BFP could also contribute to reducing TB. These conditions are linked to requirements such as school attendance, education and access to health services for pregnant women and children under 5 years old, which could facilitate the recognition and early diagnosis of TB¹³. In summary, the BFP promotes a greater access to income, food and healthcare. This can be associated with a reduction on TB incidence, facilitate TB early diagnosis and treatment adherence, increase the TB cure rate^{3,28,29} and reduce complications and death from the disease³⁰.

Moreover, we found that the BFP has a strong reduction effect on TB incidence and mortality in Indigenous populations in Brazil, who have a significantly higher risk of TB infection and mortality³¹. While this could be explained by the same mechanisms listed above, particularly in the context of Indigenous populations, the receipt of the BFP could alleviate extreme poverty and socioeconomic vulnerability. This could reduce food insecurity and malnutrition, which are particularly high among Indigenous populations, and lessen the significant geographic barriers that hinder access to even basic healthcare services³².

It is worth elucidating the greater effect of the BFP on TB incidence among people of Black and Pardo race and ethnicity as more than 60% of new diagnoses of pulmonary TB in Brazil occurred among people who self-identified as Black and Pardo¹⁹. This could potentially be explained by the identical mechanisms detailed earlier. Particularly among individuals of Black and Pardo ethnicity in Brazil, the BFP could act on historical and structural social inequities^{18,33}, increasing income and improving education through its conditionalities, providing access to health services and, in this way, reducing the TB burden. The mechanisms described above can also explain the greater effect of the BFP in the north and northeast regions, which are the poorest and less developed areas of the country, with the worst infrastructures and healthcare resources³⁴.

The BFP has also a stronger reduction effect on mortality from TB in women. This can be explained by the fact that a woman is often primarily responsible for the family in registering and receiving the BFP. Furthermore, pregnant and breastfeeding women follow the conditions for receiving the BFP (pre- and postnatal care, vaccination, and health and nutrition surveillance)¹³. In this way, women who benefit from the BFP have greater access to health services, which could be associated with a greater reduction in TB mortality in this group, when compared with men.

We also observed that the protective effects of the BFP and lower incidence and mortality are greater in municipalities that do not have prisons. Prisons usually act as ‘institutional amplifiers’ or ‘reservoirs’ of TB, affecting the TB incidence not only in prison but also in non-prison populations³⁵. The lower effect of BFP in these municipalities could be attributed to the program not reaching these populations, or not affecting their infection dynamics, leading to a higher and more resilient level of TB incidence in the community despite the coverage of the BFP³⁶.

TB prevention and care for economically vulnerable populations became an even greater challenge during and after the COVID-19 (coronavirus disease) pandemic³⁷. Each of these populations living in economic vulnerable conditions has specificities and complexities when it comes to implementing TB prevention, diagnosis and treatment interventions. Furthermore, inequalities linked to local contexts, health facilities, and social, behavioral and cultural factors can superimpose on the organization of health services, influencing the care provided to these populational groups³⁷. In this sense, it becomes urgent to intensify the actions of prevention and comprehensive care aimed at people in situations of social vulnerability, as well as intersectoral articulations and the inclusion of TB in the agendas of Social Assistance and Human Rights, among others. For this purpose, an Inter-Ministerial Committee for the Elimination of Tuberculosis and Other Socially Determined Diseases was created in 2023 in Brazil³⁸.

Our study has certain limitations that should be acknowledged. The first limitation is that, despite our efforts to control for all relevant confounding variables and use propensity-score-based models with IPTW, these approaches may not fully account for unobservable confounding variables and for potential selection biases. To address this concern, we have developed a multifaceted approach. First, we used a wide range of adjusting variables related to demographic, socioeconomic, healthcare and environmental determinants at the individual, household and municipal level, in both the logistic regression, for the construction of the propensity score, and in the Poisson regression for the estimation of BFP effects. This approach has been successfully used in previous studies on the impact of BFP and other public interventions on several health outcomes^{14–16,18,23,33}. Second, we incorporated as adjusting variable—in the logistic and Poisson models—the average municipal rate of the TB indicator over the study period for each outcome under study (incidence, mortality and case-fatality rate). These rates were estimated among individuals from the same municipalities in the cohort. This allowed us to adjust for baseline endemic levels of the specific TB outcome under study in the municipalities and, consequently, for potentially associated unobservable variables—controlling for selection biases correlating BFP implementation levels with endemic TB levels in the community. Third, extensive sensitivity analyses were conducted (Supplementary Tables 1–7 and Methods), showing that the inclusion of additional independent variables or the substitution of existing ones, besides many other changes in the models' specifications, did not significantly affect the BFP effect estimates. Fourth, to increase our confidence in the causal inference, and eliminate the possibility of significant selection biases, we performed two different triangulation analyses: survival analysis with Cox regressions and PSM (Extended Data Table 4), showing that even with different methodological approaches, BFP effect estimates were still strong and statistically significant.

Another limitation is related to the external validity of our study: the 100 Million Brazilian Cohort—and our derived study cohort—consist of individuals obtained from the linkage between the Unified Registry for Social Programs (Cadastro Único (CADU)) and health data. Individuals registered in the CADU represent the poorest half of the Brazilian population. As a consequence, our cohort includes only individuals with extremely low-income or low-income who need to be registered in the CADU to access governmental assistance programs. This limitation affects the external validity of the cohort at the national level, as high-income individuals are not represented.

Moreover, although the Notifiable Diseases Information System (Sistema de Informação de Agravos de Notificação (SINAN)) has high sensitivity in Brazil, there may be underreporting of TB notifications¹⁹. However, our study design and analytic strategy limit the possibility that underreporting could bias our results. Additionally, results from municipalities selected for the high quality of vital information and low under-notifications confirm our findings (Supplementary Table 6).

A third limitation is that individuals with missing information in any of the adjusting variables were excluded. Although this exclusion may enhance the internal validity of the study, as records with missing values are often considered of lower quality, it also partially limits the generalizability of the results. However, analyses that included individuals with missing values yielded similar BFP effect estimates (Supplementary Table 7).

In this study, it was not possible to perform a cost-effectiveness analysis owing to its additional complexity and to the need for data not available in our datasets.

Our study presents strengths that contribute to its overall value. Firstly, we leveraged a large longitudinal dataset, which, when combined with effect evaluation methods, allowed us to assess the effects of interventions on an unprecedented scale. This unique approach enabled us to include a significant number of individuals

and subpopulations that are often overlooked or underrepresented in traditional epidemiological studies and randomized controlled trials. This comprehensive inclusion is crucial for policy evaluations, as it highlights the potential differential impacts of public interventions based on the characteristics and baseline conditions of the BFP beneficiaries. In addition, our study's strength lies in the extensive range of sensitivity analyses conducted. These analyses provided further validation and reinforcement of the study's findings, ensuring their robustness and reliability. Furthermore, using various triangulation analyses instilled a high level of confidence in the causal inference, further bolstering the credibility of our findings.

We conclude that CCT programs can greatly reduce the incidence of and mortality from tuberculosis, particularly among individuals living in extreme poverty and self-declared as Indigenous and Black or Pardo ethnicity, who are usually at higher risk for TB and its devastating impacts. Therefore, the expansion of CCT programs in low- and middle-income countries can significantly strengthen the global response to TB, reducing social inequalities in the TB burden and contributing to the achievement of the End TB Strategy and the TB-related Sustainable Development Goals.

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at <https://doi.org/10.1038/s41591-024-03381-0>.

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Methods

Study design, population and ethics

This study has a cohort study design, based on the longitudinal information of 54.5 million individuals from 1 January 2004 to 31 December 2015 (the period for which tuberculosis data were available). First, we constructed a conceptual framework to explain the mechanisms of possible associations between CCT and TB outcomes and to drive the analysis (Extended Data Fig. 1). The study population was developed by selecting a subgroup of individuals of the 100 Million Brazilian Cohort²⁰, a consolidated cohort created through the validated linkage²¹ between the Federal Government Unified Registry for Social Programs (CADU)—which gathers data from the Brazilian population living in poverty, identifying and characterizing low-income families for social program eligibility, and including information on exposure to the BFP—and health-related datasets from the Brazilian Ministry of Health. The selection criteria for the inclusion of the study population were individuals registered in the CADU, diagnosed or not with TB and who received or not the BFP for more than 30 days during the study period (from 2004 to 2015). And the exclusion criteria were (1) individuals with follow-up time of less than 1 day, duplicate individuals or individuals with inconsistent dates and (2) individuals with missing data for the demographic and socioeconomic adjusting variables. The selection process of the study cohort is detailed in the flowchart of Fig. 1.

The criteria for the development and consolidation of the 100 Million Brazilian Cohort, including handling of misclassification, underreporting and missing data, are described elsewhere²⁰.

Data sources, outcomes and intervention

Two individual-level health-related datasets were linked to CADU: the Notifiable Diseases Information System (SINAN) and the Mortality Information System (Sistema de Informação sobre Mortalidade (SIM)). SINAN contains records of notifiable diseases, including TB. SIM registers deaths by all causes, according to the International Classification of Diseases (ICD-10). The linkage codes and algorithms were built based on five identifiers: date of birth, municipality of residence, sex, name and mother's name of the individual in each database. The CADU and the health information datasets (SIM and SINAN) were individually matched in two steps, using The Centre for Data and Knowledge Integration for Health (Centro de Integração de Dados e Conhecimentos para a Saúde (CIDACS))—Record Linkage tool (version number 1). The quality of each link between CADU, SINAN and SIM has been extensively evaluated and validated²¹. An aggregate-level longitudinal dataset—containing a wide range of yearly municipal-level information on TB endemicity levels, municipal infrastructures and health-care resources—was also linked to the cohort through the individuals' municipal code of residence.

Tuberculosis outcomes defined for the study were incidence, mortality and case-fatality rates. The beneficiary group was defined as eligible individuals who received BFP benefits for more than 30 days, and their exposure started with receipt of the benefit until the end of their follow-up. The non-beneficiary group was defined as individuals who had never benefited from the BFP throughout their follow-up period. In the case of non-receipt of the benefits, eligible individuals were classified in the non-beneficiary group.

Statistical analyses

First, in the descriptive analysis, we estimated the rates of the study outcomes as follows: (1) TB incidence: new TB diagnoses divided by person-years at risk and multiplied by 100,000; (2) TB mortality: TB deaths divided by person-years at risk and multiplied by 100,000; and (3) case-fatality rate: TB deaths among people affected by TB divided by person-years at risk and multiplied by 100. The follow-up time for each individual in the cohort, that is, person-years, started on the date of entry into the cohort until the date of TB diagnosis (for TB

incidence), the date of death due to TB (for TB mortality rate), the date of death from other causes or the end date of the cohort (31 December 2015). For the TB case-fatality rate, the start date began with the date of diagnosis and ended with the TB-related death, the date of death from other causes or the final date of the cohort. Afterward, we performed a descriptive analysis of new people affected by TB and deaths according to each independent variable. At the individual level, the demographic and socioeconomic covariables were age, self-reported sex, self-identified race or ethnicity (White, Indigenous, Black and Pardo—these last categories were analyzed together), education, per capita expenditure (as a proxy for the per capita wealth and calculated as a percentage of the yearly minimum wage, categorized by above or below the median) and year of entry into the cohort. At the family level, the independent variables were related to household characteristics: number of people, water supply, household construction material, sanitation, garbage disposal and lighting. At the municipal level, the covariables were unemployment rate, Gini index and a set of variables related to health services: Family Health Strategy (Estratégia de Saúde da Família) coverage (the main model of primary healthcare in Brazil), the number of doctors, nurses and specialized clinics per 1,000 inhabitants. To control for any potential selection bias associating BFP implementation with endemic TB levels in the community, the mean TB incidence rate in the cohort during the study period was included as a covariate in the models. When the study outcome was the case-fatality rate, we also included clinical classification of TB, percentage of directly observed therapy (DOT), AIDS comorbidity and diabetes as independent variables. All the variables used in the study are described in the conceptual model (Extended Data Fig. 1).

To estimate the association between BFP exposure and TB incidence, mortality and case-fatality rates, we used multivariable Poisson regression models, adjusted for all the relevant demographic and socioeconomic confounding variables listed above, with follow-up time as an offset variable, robust standard errors and observations weighted through stabilized, truncated, IPTW^{39,40}. Poisson regression models are common for cohort data analyses⁴¹, and IPTW Poisson regression models have been used in cohort studies that investigate the impacts of public and social policies on health outcomes, including several evaluation studies that used the 100 Million Brazilian Cohort^{14–16,25,42,43}.

The process of IPTW consists of two primary stages. Initially, the likelihood, also known as the propensity, of encountering the risk factor or intervention under consideration is computed based on an individual's attributes (that is, propensity score). Subsequently, weights are calculated as the inverse of the propensity score. By applying these weights to the study's population, a simulated population is generated in which potential sources of bias are equally balanced between the exposed and unexposed groups^{39,44}.

We consider a scenario with two potential treatments: one involving exposure to the BFP (treatment) and the other being unexposed (control). Within the potential outcome's framework, each individual is associated with a pair of potential outcomes (TB outcomes): $Y_i(1)$ and $Y_i(0)$. These outcomes represent the results under the treatment and control conditions, respectively, when subjected to the same conditions. However, each individual is assigned either the treatment or control, but not both. We denote Z as an indicator variable for treatment (exposure to BFP) ($Z = 1$ for treatment and $Z = 0$ for control). Consequently, only a single outcome, Y_i , is observable for each individual: this is the outcome linked to the actual treatment they received. The observed outcome, denoted by Y_i , is determined by $Y_i = Z_i Y_i(1) + (1 - Z_i) Y_i(0)$. Thus, Y_i is equivalent to $Y_i(0)$ if $Z_i(0)$, and is equivalent to $Y_i(1)$ if $Z_i(1)$. Let $\mathbf{X}$ represent a vector of observed baseline covariates. Initially, we used logistic regression to get the propensity score. The logistic regression equation models the probability of a binary outcome (usually 0 or 1) as a function of one or more predictor variables. The logistic function, also known as the sigmoid function,

is used to transform the linear combination of predictors into the probability of the event occurring.

$$P(Z = 1 | \mathbf{X}) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p)}}$$

where $P(Z = 1 | \mathbf{X})$ is the probability of the binary outcome being 1 given the predictor variables $\mathbf{X}$; e is the base of the natural logarithm; and $\beta_0, \beta_1, \beta_2, \dots, \beta_p$ are the coefficients corresponding to the predictor variables $X_1, X_2, \dots, X_p$. We estimated the probability of each individual to receive the BFP (propensity score (PS)), in two ways. For the first equation, we calculated the marginal probability of treatment (PS_t) and then we estimated the multivariable PS (PS_{mul}), adjusted for all relevant covariates.

We used PS_t and PS_{mul} as weights to calculate the stabilized IPTW using the formulas:

$$w_{Z=1} = \frac{PS_t}{PS_{mul}} \quad w_{Z=0} = \frac{(1 - PS_t)}{(1 - PS_{mul})}$$

where $w_{Z=1}$ is the weight for the beneficiaries and $w_{Z=0}$ is the weight for the non-beneficiaries. To correct for possible extreme weights, we set thresholds, with weights exceeding the set value converted to that threshold value⁴⁵. In this study, the weights were truncated based on the distribution of their values for the 1st and 99th percentiles, which represented these thresholds, as in previous similar studies^{14–16,25,42,43}. IPTW uses the propensity score to balance baseline characteristics in the exposed and unexposed groups by weighting each individual by the inverse probability of receiving treatment^{39,44}.

The Poisson equation with IPTW is a framework used to analyze count data or event occurrences, while accounting for the potential bias introduced by non-random treatment assignment in observational studies. In this context, the Poisson equation models the relationship between the event outcomes and covariates while incorporating IPTW to adjust for treatment selection bias.

$$\log Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots + \beta_p X_{ip} + \log IPTW_i$$

where $\log Y_i$ is the natural logarithm of the rate for individual i ; $X_{i1}, X_{i2}, \dots, X_{ip}$ are the covariates for individual i ; $\beta_0, \beta_1, \beta_2, \dots, \beta_p$ are the coefficients associated with the covariates; and $\log IPTW_i$ represents the logarithm of the inverse probability treatment weight for individual i . Finally, multivariable Poisson regressions, adjusted by stabilized, truncated IPTW, were estimated with the same socioeconomic and demographic variables adopted in the logistic model for all TB outcomes.

Moreover, to understand BFP association heterogeneity, we fitted these IPTW Poisson regression models stratified by age, sex, race and ethnicity, education, wealth terciles (per capita expenditure), existence of prisons in the municipality and Brazilian regions.

To confirm the robustness of the findings, we applied several sensitivity analyses: (1) we fitted the same regressions without and only with the TB endemicity level variable (Supplementary Tables 1 and 2); (2) we fitted models with only individual-level variables and tested the inclusion of different aggregate-level variables (Supplementary Table 3); (3) we estimated and compared all models without IPTW (Extended Data Table 5); (4) to evaluate the adoption of per capita expenses as a proxy for wealth, we carried out the same analyses with other proxies, such as per capita income (Supplementary Table 4); (5) we adjusted the same models with different specifications (including different sets of individual-level covariates, inclusion or exclusion of robust standard errors (Supplementary Table 5), only in municipalities with adequate vital information (Supplementary Table 6)); and (6) we redid the estimates including individuals with missing category (Supplementary Table 7). Finally, to have a greater degree of confidence

in the causal inference of our impact evaluation, we performed two different triangulation analyses²², verifying the existence of BFP associations also using alternative methods: survival analysis with Cox multivariate regression and PSM (Extended Data Table 4).

All statistical analyses were performed in Stata Version MP 15.1.

Inclusion and ethics statement

This project was designed through a longstanding partnership among the Institute of Collective Health (Instituto de Saúde Coletiva (ISC)) of the Federal University of Bahia (Universidade Federal da Bahia (UFBA)) and The Center for Data and Knowledge Integration for Health (CIDACS) of the Oswaldo Cruz Foundation (Fundação Oswaldo Cruz (FIOCRUZ)), both based in Salvador, Brazil. The 100 Million Brazilian Cohort was created by CIDACS in collaboration with ISC researchers, and the subset of data used for this study was selected and analyzed by a collaborating group of ISC and CIDACS researchers. All team members collaborated on data ownership, intellectual property and authorship of publications related to the work. Roles and responsibilities were agreed upon among collaborators ahead of the research. Previous work and articles from the analyses of these datasets, most of them developed by co-authors of this article, were used to guide the design of this study, as well as connect our findings to similar research, and have been considered in the citations for this paper.

Ethics approval

This study was approved by the Research Ethics Committee of the Institute of Collective Health of the Federal University of Bahia (ISC, UFBA), under number 41691315.0.0000.5030 (assessment number 3.783.920). In this study, participant consent was waived owing to the use of administrative data.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The data underlying this article will be shared on request to ISC of UFBA, and CIDACS of FIOCRUZ, and after ethical approval. All data supporting the findings presented were obtained from The Center for Data and Knowledge Integration for Health (CIDACS). Importantly, restrictions apply to access to the data, which contain sensitive information, were licensed for exclusive use in the current study and, due to privacy regulations from the Brazilian Ethics Committee, are not openly available. Upon request and with express permission from CIDACS (email: cidacs.curadoria@fiocruz.br) and approval from an ethical committee, controlled access to the data is possible. The dataset is registered under the following DOI handle: <https://hdl.handle.net/20.500.12196/CIDACS/65>, which provides metadata and a register of all versions of the database.

Code availability

The algorithms and code used in this Article will be shared on request to ISC of UFBA, and CIDACS of FIOCRUZ, and after ethical approval. Due to the confidentiality of the data and the presence of lines of code that deal with sensitive variables, their characteristics and their values, access to the codes will be granted upon request and with express permission from CIDACS (email: cidacs.curadoria@fiocruz.br) and approval from an ethical committee. If approved, the code will be available within 1 month from the initial application.

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Acknowledgements

This study was supported by the Wellcome Trust, grant reference number: 109949/ Z/15/Z; by the National Institute of Allergy and Infectious Diseases (National Institutes of Health), grant reference number: 1R01AI152938; and by the Brazilian Ministry of Health, grant reference number: VPGDI-003-FIO-19. We acknowledge support from grant CEX2023-0001290-S funded by Ministerio de Ciencia, Innovación y Universidades/Agencia Estatal de Investigación (MCIN/AEI)/10.13039/501100011033 and support from Generalitat de Catalunya through the Centres de Recerca de Catalunya Program. D.R. acknowledges funding from CEX2018-000806-S funded by MCIN/AEI/10.13039/501100011033. We thank researchers from the Institute of Collective Health for the invaluable discussions and suggestions during the development of this study and the CIDACS members responsible for linkage of the 100 Million Brazilian Cohort.

Author contributions

G.S.J.: formal analysis—accessed and verified the data, investigation, methodology, and writing—original draft, review and editing. P.F.P.S.G.: formal analysis—accessed and verified the data, investigation, methodology, and writing—original draft, review and editing. D.M.C.: methodology, and writing—original draft, review and editing. A.F.S.: formal analysis—accessed and verified the data, investigation, methodology, and writing—original draft, review and editing. I.L.: formal analysis—accessed and verified the data, methodology, and writing—original draft, review and editing. M.Y.I.: data curation, funding acquisition, resources and writing—review and editing. M.L.B.: data curation, funding acquisition, resources, and writing—review and editing. M.N.S.: writing—original draft, review and editing. D.B.: writing—review and editing. D.R.: conceptualization, project administration, funding acquisition, investigation, methodology, supervision—accessed and verified the data, decision to submit the paper, and writing—review and editing.

Competing interests

The authors declare no competing interests.

Additional information

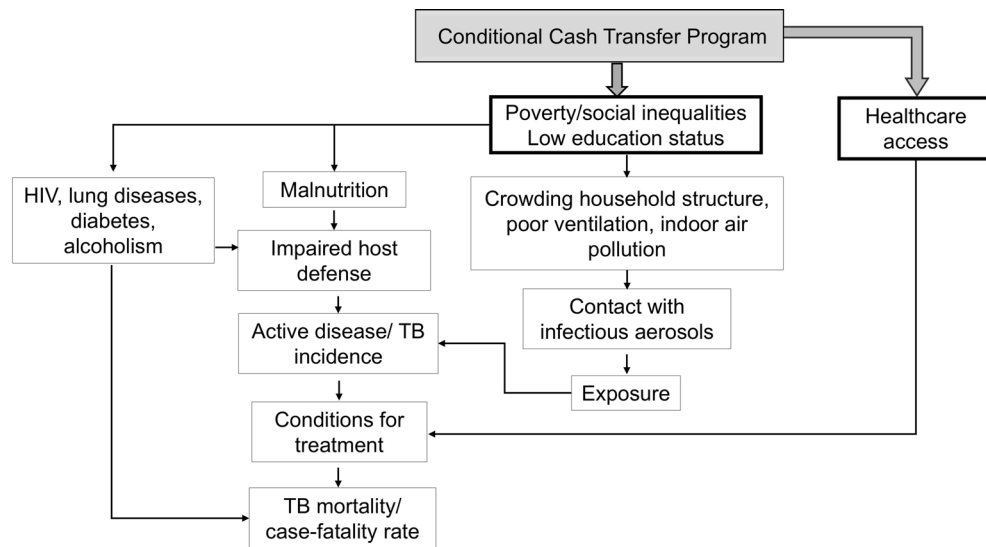
Extended data is available for this paper at <https://doi.org/10.1038/s41591-024-03381-0>.

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s41591-024-03381-0>.

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Peer review information *Nature Medicine* thanks Julio Croda, Pascal Geldsetzer, Weiming Tang and the other, anonymous, reviewer(s) for their contribution to the peer review of this work. Primary Handling Editor: Ming Yang, in collaboration with the *Nature Medicine* team.

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Extended Data Fig. 1 | Conceptual framework about determinants and possible effects of the conditional cash transfers (CCT) on tuberculosis (TB) outcomes. TB=Tuberculosis. Source: the authors.

Extended Data Table 1 | Number of observations per Tuberculosis (TB) new case, death from TB and TB deaths among TB new cases by Bolsa Familia Program (BFP) beneficiaries (BF) and non-beneficiaries (N-BF)

<u>Variables</u>	<u>Bolsa Familia Program (BFP^c)</u>		<u>Total</u>
	<u>N-BF</u>	<u>BF</u>	
<u>New TB cases^a</u>			
No	30,584,786	23,821,172	54,405,958
Yes	75,956	83,821	159,777
Total	30,660,742	23,904,993	54,565,735
<u>TB deaths^b</u>			
No	30,659,117	23,904,324	54,563,441
Yes	4,359	3,634	7,993
Total	30,663,476	23,907,958	54,571,434
<u>TB deaths/new TB cases^{a,b}</u>			
No	14,496	30,606	45,102
Yes	495	751	1,246
Total	14,991	31,357	46,348

Notes: a New Tuberculosis cases, defined with new cases, relapse cases of TB and re-entry by adapted by Brazilian Ministry of Health criteria; b Deaths from tuberculosis, considering as underlying cause the International Classification of Diseases (ICD-10) codes A15 to A19, J65, 0980 and P370. c *Bolsa Familia* Program

Extended Data Table 2 | Logistic regression prediction models for individuals benefiting or not from the Bolsa Família Program (BFP), for Tuberculosis (TB) incidence, mortality, and case-fatality rate, Brazil, 2004-2015. Estimates from the Propensity Score (PS)

Adjusted Model	Outcomes (aRR ^a – CI ^b 95%)	
	Incidence and Mortality	Case-Fatality Rate
Sex		
Male	1 (base)	1 (base)
Female	1.17 (1.17-1.18)	1.73 (1.65-1.81)
Age (years)	0.84 (0.84 - 0.85)	0.76 (0.75-0.77)
Race or ethnicity^c		
White	1 (base)	1 (base)
Black and Pardo	1.15 (1.15-1.16)	1.25 (1.19-1.32)
Indigenous	3.09 (3.06-3.12)	3.50 (2.68-4.58)
Education		
Illiterate, never attended school	1 (base)	1 (base)
Elementary school	1.07 (1.07-1.08)	1.06 (0.99-1.14)
High school	1.08 (1.08-1.09)	0.93 (0.86-0.99)
More than high school	0.83 (0.83-0.84)	0.65 (0.59-0.70)
Household construction material		
Bricks/cement	1 (base)	1 (base)
Wood, other vegetal materials ^d	0.94 (0.93-0.94)	0.91 (0.86-0.97)
Number of people in the family		
1	1 (base)	1 (base)
2		
3 a 4	1.52(1.51-1.52)	2.03 (1.93-2.14)
> 5	2.03 (2.02-2.04)	3.56 (3.33-3.80)
Per salary expenses - % MW^e		
Below median	1 (base)	1 (base)
Above median	0.88 (0.88-0.89)	0.51 (0.48-0.54)
Lighting		
Electricity	1 (base)	1 (base)
Non-electric ^f	1.22 (1.21-1.22)	1.53 (1.43-1.64)
Inadequate sanitation^g		
	1.02 (1.02-1.03)	1.06 (1.00-1.12)
Garbage disposal	1.08 (1.08-1.09)	1.04 (0.96-1.12)
Water supply		
Public network	1 (base)	1 (base)
Other ^h	1.11 (1.11-1.12)	1.17 (1.10-1.25)
TB Incidence Cohort	1.00 (1.00- 1.00)	1.00 (1.00- 1.00)
AIDS	-	0.93 (0.86-1.01)
Diabetes	-	0.94 (0.86-1.03)
DOT	-	0.99 (0.94-1.04)
TB Classification	-	0.91 (0.85-0.97)
Primary Health Care		
Coverage	1 (base)	1 (base)
no coverage ⁱ	0.99 (0.99-0.99)	0.99 (0.99-0.99)
Specialized clinics per 1,000 inhabitants	0.27 (0.26-0.27)	0.27 (0.21-0.34)
Doctors per 1,000 inhabitants	1.14 (1.13-1.14)	1.17 (1.11-1.22)
Nurses per 1,000 inhabitants	0.99 (0.98-0.99)	0.84 (0.73-0.97)
Unemployment rate (%)	1.01 (1.01- 1.01)	1.01 (1.01- 1.02)
Gini index	1.01 (1.01- 1.01)	1.01 (1.01- 1.02)
Year of entry into the cohort	yes	yes
Obs.:	54,571,434	46,344

Abbreviations: a Adjusted Rate Risks. b Confidence interval. c Race or ethnicity: Black/Pardo self-declared. d Household construction Material: No – Coated clay, uncoated clay, wood, and others. e Proportional to the baseline minimum wage (MW) f Lighting: Non-electric – No meter, lamps, candles, and others. g % of the municipal population with inadequate baseline sanitation. h Water supply: Other – well, spring, and others. i Primary Health Care (PHC) percentage coverage.

Extended Data Table 3 | Estimates by adjusted Poisson models of the association between the Bolsa Família Program (BFP) and Tuberculosis incidence, mortality and case-fatality rates stratified by wealth quartile, Brazil, 2004-2015)

Wealth ^a	Incidence ^f		Mortality ^f		Case-Fatality ^f	
	aRR ^g	95% CI ^h	aRR	95% CI	aRR	95% CI
Wealth ^c						
Quartile 1^b	0.49	(0.49-0.50)	0.60	(0.55-0.61)	0.80	(0.64-1.01)
Obs.	18,476,834		18,479,518		20,752	
Quartile 2^c	0.48	(0.47-0.49)	0.56	(0.50-0.63)	0.86	(0.60-1.22)
Obs.	10,565,846		10,567,091		10,350	
Quartile 3^d	0.71	(0.69-0.73)	0.86	(0.76-0.99)	1.20	(0.82-1.75)
Obs.	11,599,362		11,600,410		8,865	
Quartile 4^e	0.99	(0.96-1.02)	1.01	(0.83-1.23)	0.86	(0.53-1.40)
Obs.	14,145,583		14,146,327		6,460	

Notes: ^a Measured by *per capita* expenses proportional to the baseline minimum wage (MW). ^b Quartile 1: 0%–0.1%. ^c Quartile 2: > 0.1% a 18.5%. ^d Quartile 3: >18.5% a 56.5%. ^e Quartile 4: > 56.5%. ^f Calculated by person-years at risk. ^g Adjusted rate risk ^h Confidence Interval

Extended Data Table 4 | Estimates of the association between the Bolsa Familia Program (BFP) and Tuberculosis (TB) incidence, mortality, and the case-fatality rate using Survival Analysis and Propensity Score Matching models, 2004-2015

Adjusted Model	Survival Analysis			Propensity Score Matching Analysis		
	Incidence	Mortality	Case-Fatality	Incidence	Mortality	Case-Fatality
	aHR ^a (CI ^b 95%)	aHR ^a (CI ^b 95%)	aHR ^a (CI ^b 95%)	aOR ^c (CI ^b 95%)	aOR ^c (CI ^b 95%)	aOR ^c (CI ^b 95%)
BFP^d	0.54 (0.54-0.55)	0.65 (0.61-0.69)	1.04 (0.89-1.22)	0.43 (0.29-0.55)	0.32 (0.30-0.34)	0.53 (0.18-1.50)
Sex						
Male	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)
Female	0.58 (0.58-0.59)	0.39 (0.37-0.41)	0.69 (0.60-0.79)	-0.16(-0.17:-0.16)	-0.16 (-0.17:-0.16)	0.69 (0.60-79)
Age^e	1.18 (1.18-1.19)	1.62 (1.61-1.64)	1.47 (1.41-1.53)	0.16 (-0.17:-0.16)	0.16 (-0.17:-0.16)	1.47(1.41-1.53)
Race or ethnicity^f						
White	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)
Pardo/Black	1.42 (1.41-1.45)	1.70 (1.60-1.81)	1.03 (0.86-1.22)	0.14 (0.14-0.15)	0.14 (0.14-0.15)	1.03 (0.87-1.22)
Indigenous	3.70 (3.49-3.91)	4.56 (3.63-5.72)	1.38 (0.81-2.33)	1.13 (1.12-1.14)	1.13 (1.12-1.14)	1.38 (0.81-2.33)
Education						
Illiterate, never attended school	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)
Elementary school	1.82 (1.79-1.85)	1.04 (0.98-1.10)	0.93(0.78-1.10)	0.07(0.71-0.74)	0.07(0.71-0.74)	0.93 (0.78-1.10)
High school	2.20(2.16-2.24)	0.98 (0.92-1.05)	0.78(0.63-0.95)	0.08 (0.08-0.08)	0.08 (0.08-0.08)	0.78 (0.63-0.95)
More than high school	1.72 (1.68-1.75)	0.60(0.53-0.67)	0.53(0.38-0.75)	-0.18 (-0.18:-0.17)	-0.18 (-0.18:-0.17)	0.53 (0.38-0.75)
Household construction material (brick)						
Yes	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)
No ^g	1.22 (1.20-1.24)	1.21 (1.13-1.29)	1.14 (0.97-1.34)	-0.06 (-0.06:-0.05)	-0.06 (-0.06:-0.05)	1.14 (0.97-1.34)
Number of people in the family						
2	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)
3 a 4	0.98 (0.97-0.99)	0.83(0.78-0.88)	0.91 (0.78-1.07)	0.41 (0.41-0.42)	0.41 (0.41-0.42)	0.91 (0.78-1.07)
> 5	1.21 (1.19-1.23)	1.00 (0.93-1.07)	1.05 (0.89-1.25)	0.70 (0.70-0.71)	0.70 (0.70-0.71)	1.05 (0.89-1.25)
Per salary expenses - % MW^h						
below median	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)
above median	0.77 (0.76-0.78)	0.70 (0.65-0.74)	0.89 (0.75-1.05)	-0.12 (-0.12:-0.12)	-0.12 (-0.12:-0.12)	0.89 (0.75-1.05)
Lighting						
Electricity	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)
Non-electric ⁱ	1.35 (1.33-1.37)	1.55 (1.45-1.67)	1.19* (1.03-1.38)	0.19 (0.19-0.20)	0.22 (0.22-0.23)	1.10 (0.92-1.31)
Inadequate sanitation^j	1.00 (0.99-1.02)	1.08 (1.02-1.14)	1.00 (0.99-1.01)	0.29 (0.27-0.30)	0.29 (0.27-0.30)	0.98 (0.83-1.15)
Garbage disposal	0.78 (0.77-0.80)	0.76(0.70-0.82)		0.08 (0.07-0.08)	0.08 (0.07-0.08)	1.00 (0.80-1.26)
Water supply						
Public network	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)
Other ^k	0.95 (0.93-0.97)	0.99 (0.92-1.06)		0.11(0.11-0.11)	0.11(0.11-0.11)	0.98 (0.82-1.15)
Mun. average TB^l incidence rate	1.00 (1.00-1.00)	1.00 (1.00-1.00)	1.00 (0.99-1.00)	0.01 (0.01-0.01)	0.00 (0.00-0.00)	1.00 (0.99-1.00)
Primary Health Care^m						
Coverage	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)	1 (base)
no coverage	1.00 (0.99-1.00)	0.99 (0.99-0.99)	1.00 (0.99-1.00)	-0.00 (-0.00:-0.00)	-0.00 (-0.00:-0.00)	1.00 (0.99-1.00)
Specialized clinics per 1,000 inhabitants	0.64 (0.60-0.68)	0.54 (0.39-0.73)	1.09 (0.52-2.26)	-1.30 (-1.31:-1.30)	-1.30 (-1.31:-1.30)	1.09 (0.52-2.26)
Doctors per 1,000 inhabitants	1.01 (1.01-1.13)	1.19 (1.14-1.25)	1.04 (0.91-1.20)	0.12 (0.12-0.13)	0.12(0.12-0.13)	1.04 (0.91-1.20)
Nurses per 1,000 inhabitants	0.93 (0.90-0.96)	0.78 (0.69-0.89)	1.12 (0.76-1.65)	-0.00 (-0.01:-0.00)	-0.00 (-0.01:-0.00)	1.12 (0.76-1.65)
Unemployment rate (%)	1.01 (1.01-1.02)	1.03(1.02-1.03)	1.01 (0.99-1.02)	0.01 (0.01-0.02)	0.01 (0.01-0.02)	1.01 (0.99-1.02)
Gini index	0.99 (0.99-1.00)	1.00 (0.99-1.00)	0.99 (0.98-1.00)	0.01 (0.01-0.01)	0.01 (0.01-0.01)	0.99 (0.98-1.00)
Individual's year of entry into the cohort	yes	yes	yes	yes	yes	yes
Obs.:	54,571,434	54,571,434	46,344	54,571,434	54,571,434	46,344

Notes: a Adjusted Hazard Ratio b Confidence interval. c Adjusted Odds Ratio d Bolsa Familia Program e Age categorized every 10 years. f Race or ethnicity: self-declared. g Household construction material: No – Coated clay, uncoated clay, wood, and others. h Proportional to the baseline minimum wage (MW). i Lighting: Non-electric – No meter, lamps, candles, and others. j % of the municipal population with inadequate baseline sanitation. k Water supply: Other – well, spring, and others. l Tuberculosis m Primary Health Care (PHC) percentage coverage.

Extended Data Table 5 | Estimates by adjusted Poisson models without inverse probability of treatment weighting (IPTW) of the association between the *Bolsa Família* Program (BFP) and Tuberculosis incidence, mortality, and the case-fatality rate, 2004-2015

Outcomes (RR ^a – CI ^b 95%)			
Models	Incidence	Mortality	Case-Fatality
Adjusted	0.58 (0.57-0.58)	0.65 (0.62-0.69)	0.90 (0.77-1.03)
Unadjusted	0.59 (0.58-0.59)	0.44 (0.42-0.46)	0.49 (0.44-0.56)
Obs	54,565,735	54,571,434	46,344
Notes ^a Adjusted Rate Risk. ^b Confidence Interval			

Extended Data Table 6 | Estimates by adjusted Poisson models of the association between the Bolsa Família Program (BFP) and Tuberculosis incidence, mortality and case-fatality rate, Brazil, 2004-2015 - Modelling with interaction terms included in the logistic regression for the estimation of the Propensity Score

Models	Outcomes (aRR ^a – CI ^b 95%)		
	Incidence	Mortality	Case-Fatality
Adjusted	0.59 (0.58-0.60)	0.69 (0.65-0.73)	0.91 (0.78-1.06)
Obs	54,565,729	54,571,428	46,344

Notes: Interaction terms entered into logistic regression to estimate propensity score: sex vs race, sex vs wealth and race vs wealth. ^a Adjusted Rate Risk. ^b Confidence Interval.

Extended Data Table 7 | Estimates by adjusted Poisson models of the association between the Bolsa Família Program (BFP) and Tuberculosis (TB) incidence, mortality and case-fatality rate, Brazil, 2004-2015 - includes time of exposure to BFP as cohort censoring

	Outcomes (aRR ^a – CI ^b 95%)	
	Incidence	Mortality
Adjusted Model	0.64 (0.63-0.65)	0.79 (0.75-0.84)
Obs	63,122,383	63,129,089

Notes: ^a Adjusted Rate Risk. ^b Confidence Interval.

Extended Data Table 8 | Estimates by adjusted Poisson models of the association between the Bolsa Família Program (BFP) and Tuberculosis (TB) incidence, mortality and case-fatality rate in Brazil, 2004-2015 – includes as adjustment variable the existence of prisons per municipality

	Outcomes (aRR ^a – CI ^b 95%)		
	Incidence	Mortality	Case-Fatality
Adjusted Model	0.59 (0.58-0.60)	0.69 (0.65-0.73)	0.91 (0.78-1.06)
Obs	54,565,729	54,571,428	46,344

Notes: ^a Adjusted Rate Risk. ^b Confidence Interval.

Extended Data Table 9 | Estimates by adjusted Poisson models (with robust standard errors) of the association between the Bolsa Família Program (BFP), and Tuberculosis (TB) incidence, mortality, and case-fatality rate in Brazil including the TB incidence in the municipality of residence and TB incidence standardized by age, 2004-2015

Model adjusted by	TB ^a incidence in the municipality of residence			TB ^a incidence standardized by age		
Outcomes	TB ^a incidence	TB ^a mortality	TB ^a case-fatality rate	TB ^a incidence	TB ^a mortality	TB ^a case-fatality rate
aRR ^b (CI ^{95%})	0.58 (0.57-0.59)	0.68 (0.64-0.72)	0.90 (0.77-1.05)	0.58 (0.57-0.59)	0.69 (0.65-0.73)	0.90 (0.77-1.05)

Notes: a Tuberculosis b Adjusted Rate Risk. c Confidence Interval.

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☐	☒ A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☐	☒ The statistical test(s) used AND whether they are one- or two-sided <i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i>
☐	☒ A description of all covariates tested
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☐	☒ For null hypothesis testing, the test statistic (e.g. <i>F</i> , <i>t</i> , <i>r</i>) with confidence intervals, effect sizes, degrees of freedom and <i>P</i> value noted <i>Give P values as exact values whenever suitable.</i>
☐	☒ For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☐	☒ For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☐	☒ Estimates of effect sizes (e.g. Cohen's <i>d</i> , Pearson's <i>r</i>), indicating how they were calculated

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

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Data collection	The Centre for Data and Knowledge Integration for Health (Centro de Integração de Dados e Conhecimentos para a Saúde - CIDACS)-Record Linkage tool (version number 1) was used to linkage. https://github.com/gcgbarbosa/cidacs-rl-v1
Data analysis	All statistical analyzes were performed in Stata Version MP 15.1

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The data underlying this article will be shared on request to ISC/UFBA and CIDACS/Fiocruz and after ethical approval. All data supporting the findings presented were obtained from The Center for Data and Knowledge Integration for Health (Centro de Integração de Dados e Conhecimentos para a Saúde - CIDACS). Importantly, restrictions apply to access to the data, which contains sensitive information, were licensed for exclusive use in the current study and, due to privacy

regulations from the Brazilian Ethics Committee are not openly available. Upon request and with express permission from CIDACS (mail to cidacs.curadoria@fiocruz.br) and approval from an ethical committee, controlled access to the data is possible. The dataset is registered under the following DOI handle: <https://hdl.handle.net/20.500.12196/CIDACS/65>, which provides metadata and a register of all versions of the database.

Research involving human participants, their data, or biological material

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Reporting on sex and gender

We only use the term sex, as in the following statements

Data sources, outcomes, and intervention section: "The linkage codes and algorithms were built based on five identifiers: date of birth, municipality of residence, sex, name, and mother's name of the individual in each database".

Statistical Analyses section: "At the individual level, the demographic and socioeconomic covariables were age, sex, self-identified race/ethnicity (white, Indigenous, Black and pardo - these last categories were analysed together), education, per capita expenditure (as a proxy for the per capita wealth and calculated as a percentage of the yearly minimum wage, categorised by tertiles), and year of entry into the cohort" and "Moreover, in order to understand BFP effects heterogeneity, we fitted these IPTW Poisson regression models stratified by age, sex, race/ethnicity, education, and wealth- tertiles (per capita expenditure)."

Reporting on race, ethnicity, or other socially relevant groupings

We specify in the main text that the variables were obtained from The 100 Million Brazilians Cohort and that race/ethnicity is self-identified. Furthermore, we explain how we use the family wealth variable (per capita expenditures).

Study design, population, and ethical issues: "The study population was achieved by selecting a subgroup of individuals of the 100 Million Brazilians Cohort, a consolidated cohort created through the validated linkage between the Federal Government Unified Registry for Social Programs (Cadastro Único) – that gathers data from the poorest half of the Brazilian population, identifying and characterising low-income families for social programs eligibility, and including information on exposure to the BFP - and health-related datasets from the Brazilian Ministry of Health's."

Statistical Analyses section: "At the individual level, the demographic and socioeconomic covariables were age, sex, self-identified race/ethnicity (white, Indigenous, Black and pardo - these last categories were analysed together), education, per capita expenditure (as a proxy for the per capita wealth and calculated as a percentage of the yearly minimum wage, categorised by tertiles), and year of entry into the cohort" and "Moreover, in order to understand BFP effects heterogeneity, we fitted these IPTW Poisson regression models stratified by age, sex, race/ethnicity, education, and wealth- tertiles (per capita expenditure)."

Population characteristics

BFP beneficiaries and non-beneficiaries showed similar demographic and socioeconomic characteristics. In comparison with non-beneficiaries, BFP beneficiaries are younger (mean age 24.2 vs 25.3 years), had a slightly higher percentage of people self-identified as Black or Pardo race/ethnicity (62.1% vs 68.7%), people with no education (32.5% vs 37.1%), households with 3 or more individuals (66.0% vs 78.9%), lesser wealth (43.9% vs 58.0%), without adequate sanitation (23.9% vs 38.7%), and without a public network for water supply (70.6% vs 76.1%).

Recruitment

In the Results section: "After excluding individuals of the 100 Million Brazilians Cohort who were outside the study period 2004-2015, and who had missing information on demographic or socioeconomic variables, 54,571,434 individuals were selected, of which 23,907,958 were BFP beneficiaries (43.8%), and 30,663,476 non-BFP beneficiaries (56.2%), with a total of 159,777 new TB diagnoses and 7,993 TB deaths"

Ethics oversight

This study was approved by the Research Ethics Committee of the Institute of Collective Health of the Federal University of Bahia (ISC/UFBA), under number 41691315.0.0000.5030 (Assessment nº:3.783.920)

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

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For a reference copy of the document with all sections, see [nature.com/documents/nr-reporting-summary-flat.pdf](https://www.nature.com/documents/nr-reporting-summary-flat.pdf)

Life sciences study design

All studies must disclose on these points even when the disclosure is negative.

Sample size

The entire eligible population was considered, i.e., individuals registered in the Cadastro Único (CADU) between 2004 and 2015, with or without a diagnosis of tuberculosis, whether or not they were beneficiaries of the BFP. From this initial selection, which is a subgroup of the Cohort of 100 Million Brazilians, individuals with less than 1 day of follow-up, diagnosed with TB or who received the BFP before 2004, Individuals with inconsistent dates, duplicates, Individuals who received BFP <30 days and Individuals with missing values for socioeconomic variables were excluded (as described in Figure 1 - Flowchart). After these exclusions, the entire final population was considered for the analysis, i.e., 54,571,434 individuals, being Non-BFP beneficiaries (n=30,663,476) and BFP beneficiaries (n=23,907,958).

Data exclusions

In the Results section: "After excluding individuals of the 100 Million Brazilians Cohort who were outside the study period 2004-2015, and who had missing information on demographic or socioeconomic variables, 54,571,434 individuals were selected, of which 23,907,958 were BFP beneficiaries (43.8%), and 30,663,476 non-BFP beneficiaries (56.2%), with a total of 159,777 new TB diagnoses and 7,993 TB deaths" (as described in Figure 1 - Flowchart).

Replication	We performed several sensitivity and triangulation analyses. All results confirmed the results obtained in the main analysis. Sensitivity and triangulation analyses section: "We developed a wide range of several sensitivity analyses (for details see the Methods section and Supplementary Tables S1-S7) fitting models with differed specifications and adjusting variables. We also performed two different triangulation analyses: Cox multivariate regression and propensity score matching (PSM) (Extended Data Table 4). All sensitivity tests confirmed the association estimates, and the triangulation analyses showed a high degree of confidence in the effect evaluation causal inference."
Randomization	The allocation was not random. In the Data sources, outcomes, and intervention section: "The beneficiary group was defined as eligible individuals who received BFP benefits, and their exposure started with receipt of the benefit, until the end of their follow-up. The non-beneficiary group was defined as individuals who had never benefited from BFP throughout their follow-up period. In case of non-receipt of the benefits, eligible individuals were classified in the non-beneficiary group"
Blinding	The blinding is not relevant to this study because it is not an experimental study. In this study the main exposure was the receipt of BFP and the researcher has this information through an administrative database without the names of the individuals.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Plants

Seed stocks	n/a
Novel plant genotypes	n/a
Authentication	n/a