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Socioeconomic and fiscal returns of expanded investment in immunization: a case for life-course vaccination in Colombia

Jose Alejandro Soto-Moreno[1], Martha Coe[1], Cintia Parellada[2], Anupama Tantri[3],*, Maria Clara Angarita-Contreras[3], Paula Acosta[1]

[1]ThinkWell, Lutherville, MD 21093, United States
[2]MSD, Brazil, São Paulo, São Paulo 04583-110, Brazil
[3]Merck & Co, Inc, Rahway, NJ 07065, United States
*Corresponding author: Merck & Co, Inc, Rahway, NJ 07065, United States. Email: anupama.tantri@merck.com

Abstract

Despite the health, societal, and economic benefits of immunization, many countries focus primarily on childhood immunizations and lack robust policies and sufficient resources for immunizations that can benefit populations across the life course. While the benefits of childhood vaccination are well documented, there is limited evidence on the financial and social return on investment that policymakers can use to inform decisions around administering a life-course immunization program. We developed a cost-benefit model from a societal perspective to evaluate the inclusion of 5 vaccines across the life course in Colombia's national immunization program. This model estimated a return of US$1.3 per US $1.0 invested in the first 2 decades, increasing to US$3.9 after 60 years. Primary benefits were productivity gains, followed by fiscal savings and household averted expenditure on health care. Furthermore, vulnerable households are predicted to receive 3.2 times greater income protection than formally employed households under a life-course immunization program. Consequently, there is a potential to reduce Colombia's income inequality and poverty rate by increasing access to immunization for all ages.

Key words: life course; immunization; vaccination; policy; public health; health financing; health economics; cost-benefit; return on investment.

Introduction

Immunization benefits individuals, communities, and society at large through direct reduction in disease risk, the protective effects of herd immunity, and reduced health care utilization and associated costs.[1] In a 2020 report, Remes et al[2] found that, across 200 countries, immunization had the highest potential among all proven health interventions to add healthy life years and, consequently, to increase gross domestic product (GDP). Likewise, an econometric modeling study suggested that a significant and sustained increase in the GDP growth rate was associated with a lagged increase in vaccination rates; this elasticity increased over time.[3]

Despite these findings, there are limited cost-benefit economic evaluations, and immunization-related evidence on cost-effectiveness typically assesses individual vaccines.[4] Moreover, current cost-effectiveness models use measures such as cost per quality-adjusted life-year gained or cost per disability-adjusted life-year averted, failing to characterize socioeconomic impacts in monetary metrics. Assessments that only examine the impact of vaccination on direct and indirect health outcomes ultimately undervalue immunizations across the life course and can overlook the introduction of new and underutilized vaccines, potentially limiting investment in immunization programs and preventing populations from receiving the full benefits of vaccination.[5] Because of these modeling limitations, decision makers within ministries of health and finance—especially those responsible for budgeting, allocating, and releasing public funds—cannot evaluate the full range of economic and fiscal benefits from improved budget allocation and increased public investment in immunization.[6] Cost-benefit analysis offers an approach for examining health and economic benefits from immunization and can guide policy and programmatic decisions by expressing costs and benefits using summary metrics, which include either return on investment or net monetary benefit.[7-10]

However, there is a dearth of data on cost-benefit analysis and program or policy analysis on life-course immunization. As countries face demographic transitions and an aging population, it will be central to ensuring the health and well-being of individuals across their lifespans.[11,12] However, almost 40% of countries do not have national routine adult immunization programs,[13] and immunization-related cost-benefit analysis focuses almost exclusively on pediatric vaccinations,[14,15] outside of a few studies conducted in high-income countries.[9,16,17] This gap in assessment data suggests a lack of comprehensive understanding about the cost savings that routine vaccination for adolescents and adults could generate through health, economic, and social gains in the short and long term.[18] Developing this evidence has the potential to support advocacy for increasing investment in national immunization programs that offer a full range of vaccines across

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the life course. To address this gap in evidence, we developed and implemented a model to analyze cost-benefit analysis and return on investment from a societal perspective, and we used Colombia as a case study.

The case of Colombia

Colombia is an upper-middle-income country whose adolescent and adult immunization schedules trail behind most Latin American countries.[19] Although Colombia has a relatively strong health care system and a robust childhood immunization program,[20] several factors make it an important case study for life-course immunization investment, including changing population demographics,[21] lack of recent vaccine introduction for adults, and low national spending on immunization programming.[22,23]

As of May 2023, the Colombian immunization schedule for children was comprehensive and included 9 vaccines: bacille Calmette-Guerin; hepatitis B; influenza; rotavirus; pneumococcal; measles, mumps, and rubella; oral poliovirus; pentavalent (diphtheria, pertussis, tetanus, *Haemophilus influenzae* type b, and hepatitis B); hepatitis A; and varicella.[20] On the other hand, the nonpediatric immunization program offers a more limited range of vaccines, focusing on vaccination against the human papillomavirus (HPV) for adolescent females, seasonal influenza to pregnant women and adults aged 60 years and older, and tetanus and diphtheria (Td) for women of reproductive age.[24] Colombia is also experiencing a rapid demographic transition, with projections estimating that the proportion of people over 60 years old will double by 2040 despite a total population increase of only 18%.[25] Therefore, the current national immunization program does not meet the needs of the present and future generations of adults.[26]

The Colombian immunization program is a public sector program that is predominantly centrally funded and provides vaccines free of charge for target cohorts according to its schedule.[27] The Ministry of Finance and Public Credit allocates funding to the Ministry of Health and Social Protection to procure vaccines, primarily through the Pan American Health Organization (PAHO) Revolving Fund.[20] Based on budget data provided by the National Planning Department and the Ministry of Finance, the immunization budget in Colombia represented a small proportion of the overall annual health sector budget between 2010 and 2019, ranging from 1.1% to 1.9%.[22,23]

We assessed the potential expansion of the Colombian immunization program across the life course, evaluating economic impacts beyond just the health care sector.[28] We included productivity impacts from improved health outcomes by considering indirect effects of life-course immunization on other domains—eg, GDP, household income, and broader public finances. This novel comprehensive perspective has the potential to drive policy action.

In Colombia, the informal employment rate is higher than 60%,[29] 73% of households whose income is below the poverty line belong to the informal sector,[30] and the average salary for informal (i.e., employment that is not registered, regulated or protected by existing legal or regulatory frameworks) workers amounts to 38% of the average salary for formal workers.[31] In Colombia, social protection mechanisms, such as social security salary income protection (sick-day payments), do not apply to this workforce. To address the anticipated benefit of expanded immunization for vulnerable populations, we included analysis on households' income protection from the estimated productivity gains. This allowed us to assess potential positive impacts across the 2030 Sustainable Development Goals (SDGs), such as reduced income inequality.[32] To our knowledge, assessing income protection implications from expanding immunization services is novel.

Data and methods

Cost-benefit model structuring

We structured a Markov model to assess the impact of 5 vaccines that are not recommended for adolescents and adults across the life course in Colombia. These vaccines include dengue and meningococcal conjugate (men-ACWY) for adolescents, 23-valent pneumococcal polysaccharide vaccine (PPSV23) for the population aged 60 years or older, and the extension of Td and HPV vaccine for male cohorts. As of May 2023, the selected vaccines are not included in the Colombian national immunization program and HPV vaccination is limited to female indication. The selected vaccines were based on the burden of disease and existing immunization schedules in reference countries in Latin America, such as Argentina, Brazil, and Panama and recommendations from the World Health Organization.[19] Figure 1 presents a summary of the cost and benefit components that were included in the cost-benefit analysis. The model tracked costs and effects over a 60-year time frame based on life expectancy in Colombia, utilizing constant (2021) prices without applying discounting rates.[33] Additional details on the proposed expansion package and the identified vaccine-preventable diseases are available in Appendix S1. A deterministic 1-way sensitivity analysis was conducted to assess the impact on the return on investment by varying all vaccine efficacy parameters by ±20%.[25] To ensure accuracy, when the vaccine efficacy parameters exceeded 100%, a truncation technique was applied to limit the efficacy to 100%.

Cost estimation

Cost estimates were based on official age-group population projections,[25] vaccination coverage trend assumptions (Appendix S2), 2021 PAHO Revolving Fund vaccine pricing[34] where available, and local cost structures for vaccine delivery. This includes health maintenance organizations (HMOs)[35] and subnational governments.[36] Since the dengue vaccine is not yet available through the PAHO Revolving Fund as of May 2023, the vaccine price was estimated using a proxy of a referential willingness-to-pay study.[37] In 2023, a dengue vaccine was introduced in the Brazilian national immunization program and the price submitted for the Brazilian health technology agency was used in the 1-way sensitivity analysis.[38] Using these inputs, we were able to account for funds needed to (1) procure necessary vaccines for the targeted cohorts at assumed coverage rates, (2) pay providers to deliver vaccinations through Colombia's National Health Insurance System, and (3) account for other program costs for subnational governments, such as cold storage needs and educational and school-based programming campaigns at the local level. Costs (and benefits) were estimated in 2021 local prices, converted from Colombian pesos (COP) into US$ using the 2021 average exchange rate from the official macroeconomic assumptions included in the medium-term fiscal framework (May 2021 version; COP 3667 per US$).[39] A detailed

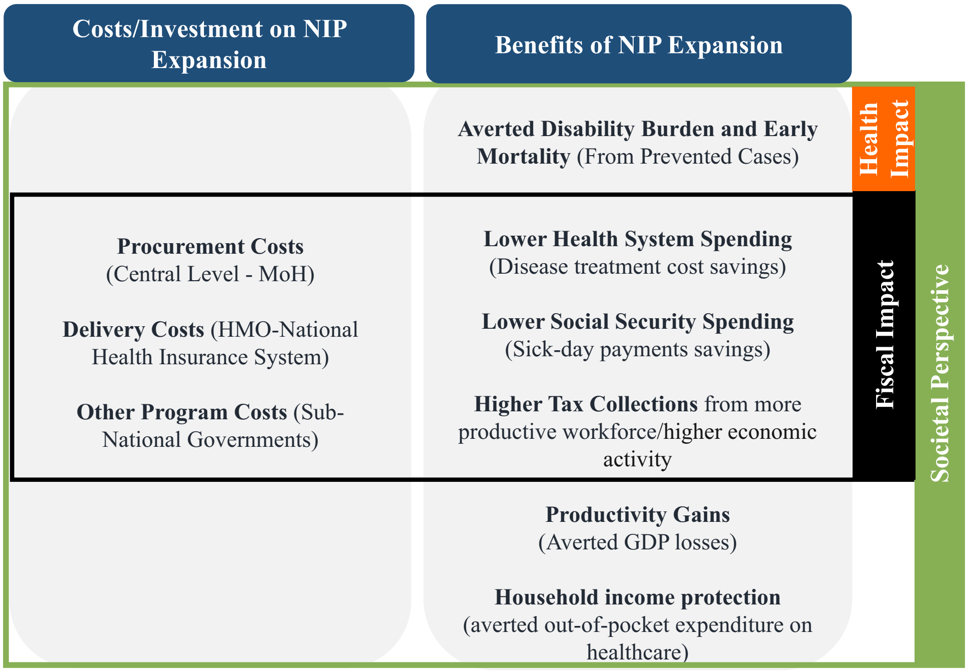

Figure 1. Cost-benefit analysis model for proposed national immunization program expansion. Source: Authors' original model. Abbreviations: GDP, gross domestic product; HMO, health maintenance organizations; MoH, Ministry of Health; NIP, national immunization program.

description of costs, data sources, and calculation methodology is included in Appendixes S3 and S5.

Benefits estimation—improved health outcomes

Economic benefits were estimated from improved health outcomes modeled for the 12 associated vaccine-preventable diseases according to vaccination coverage trend assumptions (Appendix S2), vaccine efficacy, attributable fractions, and resulting preventable burden by vaccine according to the literature (Appendix S6). For each vaccine-preventable disease, a baseline scenario of incidence and case-fatality rate by relevant age and gender group was developed from Colombia's disease burden data.[39] Prevented cases over the assessed period were estimated by first generating the status-quo policy scenario without national immunization program expansion, which was calculated as the number of annual expected cases of the 12 vaccine-preventable diseases by applying baseline incidence rates to population projections over time (Appendix S4.1). We then calculated the potential to avert cases of preventable diseases by applying assumed vaccination coverage trends and preventable burden. For each vaccine-preventable disease, the averted number of deaths and the prevented disability burden over the assessed period were estimated by applying the case-fatality rates and the disability weights, respectively, to the prevented cases.

Benefits modeling—the societal perspective

We modeled the societal perspective by assessing 3 types of economic benefits: (1) fiscal savings, (2) productivity gains, and (3) averted out-of-pocket health care expenditures. To calculate benefits, Colombia-specific data were gathered from local and global databases on disease burden (cases, deaths, disability weight) and health care expenditure.[35,40,41] Economic inputs (GDP per capita, formal and informal employment, and salaries) were aligned to the official macroeconomic assumptions included in the national medium-term fiscal framework.[39] Because of the pandemic's influence on national macroeconomic figures in 2021 (our baseline year), official predictions through 2023 were used to account for both pandemic impact and recovery in the cost-benefit analysis.[39] Detailed descriptions of benefits, data sources, and calculation methodology are included in Appendixes S4 and S5.

Fiscal savings

Lower health system expenditure was calculated by applying the average treatment cost by disease case (direct medical cost per case) according to baseline calculations from official health system expenditure databases to prevented cases.[35] Averted sick-day payments under the social security system were estimated by applying the share of formal employment in the labor force to the prevented cases in the working-age population (15–64 years), and then calculating the associated prevented disability burden according to the disability weights for this age group. The resulting prevented-disability metric is a proxy variable for the potential equivalent loss of annual formal workers, which was then valued at the average formal salary that is protected according to sick-day payments data.[41] Higher tax collection estimation draws on the prevented employer (firm) revenue loss, averted formal worker income loss, and local parameters of both effective corporate income tax rate and average tax rate to the formal workforce.

Productivity gains

Productivity gains (averted GDP losses) were estimated by valuing the total prevented disability and early mortality using per capita GDP. Following a human capital approach, we built in an assumption of a requisite family caregiver and their productivity loss for preventable disability in populations younger than 15 years old or older than 64 years old.[42]

Household income protection from averted out-of-pocket expenditure on health care

This metric was calculated by applying the proportional out-of-pocket health expenditure according to Ministry of Health estimations to the health-system prevented expenditure (see fiscal savings).[43]

Return on investment

The return on investment from the societal perspective was estimated as the ratio of aggregate benefits and aggregate costs of the proposed national immunization program expansion over time. A return on investment greater than 1.0 means that expanding the national immunization program is a cost-effective public investment.

Additional socioeconomic impacts beyond the economic return on investment

The cost-benefit analysis outcomes were leveraged to complement the economic approach and provide a more comprehensive view of the value of immunization by capturing potential positive impacts on critical goals that are part of the 2030 SDGs.[32] We independently estimate income protection in vulnerable (informal economy) households and formal households. Income protection in vulnerable households was calculated by first applying the share of informal employment to prevented disability and early mortality, which allowed for informal households' productivity gain to be expressed in additional workforce; then, the additional workforce was valued at informal salary. Income protection in formal households was estimated following the same procedure by using the parameters specific to the formal economy (share of formal employment, formal salary, and percentage of formal salary that is not covered by sick-day payments).

Model limitations

This study has several limitations because of the novelty of a model that is sensitive to policy scenarios and straightforward to explain, transfer, and adapt to different contexts.

With regard to the model design, we would like to highlight several points. While dynamic models are generally preferred for infectious diseases to estimate benefits in unvaccinated cohorts, we opted for a static model. This choice was made to provide a straightforward and easily adaptable approach that can be applied to different contexts and various infectious diseases. By using a static model, we aimed to strike a balance between clarity in assessing the fiscal impact and avoiding unnecessary analytical complexity. This conservative approach served as a means of providing a reliable estimate, ensuring that we presented a realistic depiction of the financial implications associated with life-course immunization. In assessing benefits, our model did not consider incomplete vaccination schedules, nor did it take into account indirect effects (community immunity).

In Latin America, impact studies have not demonstrated evidence of indirect effects from childhood pneumococcal vaccination to older adults in reducing hospitalizations or mortality rates due to pneumococcal disease.[44-46] On the other hand, studies have demonstrated the benefits of HPV vaccination in unvaccinated cohorts.[47] It is important to note that this model had specifically measured only direct benefits from HPV vaccination in males without considering community immunity in females. However, in a country like Colombia, where approximately 4700 women are diagnosed with cervical cancer each year and around 2490 die from the disease, the impact of community immunity will play a substantial effect as demonstrated in a previous dynamic model.[48-50] Accounting for such benefits would result in increased overall health outcomes and economic return. Furthermore, wastage rates were not included in the assessment of procurement costs.

In our HPV model, we account for a period of at least 9 years between vaccination and disease prevention by considering prevented cancer cases from the age of 18, when cohorts of vaccinated boys reach adulthood. However, for other diseases, the model assumes that disease prevention occurs immediately after vaccination. The primary objective of our work was not to refine the cost-benefit analysis for all possible immunization scenarios but to advocate for the value of an expanded national life-course immunization program to decision makers at the national level.

Results

Health impact

This model estimates a substantial health impact in terms of prevented disease cases and deaths over a span of 6 decades. The number of prevented disease cases increased rapidly over time, with the number of cases prevented by decade rising from 377 810 in the first decade to over 12 million cases by the end of the sixth decade. In terms of cumulative prevented deaths, the model projected a progressive increase from 10 006 in the first decade to 155 011 by the end of the sixth decade (Table 1). These findings highlighted the importance of the intervention in reducing disease burden and preventing illness and death over an extended period.

Return on investment results

The expansion package, which included 5 vaccines (dengue and men-ACWY for adolescents, PPSV23 for populations aged ≥60 years, and the extension of Td and HPV vaccine for male-gender cohorts), showed a positive return on investment in life-course immunization, starting in year 14. The return on investment progressively increased from US$0.7 per US$1.0 invested in the first decade, to US$1.3 after 20 years, reaching US$3.9 after 60 years (Table 2). In our 1-way sensitivity analysis, where vaccine efficacy parameters were varied by ±20% over a period of 60 years, the return on investment ranged from US$3.1 to US$4.6 per US$1.0 invested. Furthermore, when a higher price dose for dengue vaccine was taken into consideration, the return on investment ranged from US$2.2 to US$3.3 per US$1.0 invested. This positive trend in return on investment of expanded immunization was driven by a combination of factors. These factors included decreasing funding needs over the assessed period (primarily due to shifting demographics) and the increasing potential of life-course immunization to reduce disease burden previously described, which resulted in increased fiscal savings and productivity gains.

Table 1. Improved health outcomes associated with the proposed national immunization program expansion.

Decade	Prevented disease cases by decade	Cumulative prevented disease cases	Prevented deaths by decade	Cumulative prevented deaths
1	377 810	377 810	10 006	10 006
2	1 044 592	1 422 402	18 721	28 726
3	1 851 690	3 274 092	23 637	52 363
4	2 560 347	5 834 439	29 141	81 504
5	3 116 609	8 951 048	34 676	116 181
6	3 552 630	12 503 678	38 831	155 011

Source: Authors' analysis of original model outputs.

Costing results

In constant 2021 prices and under model assumptions, the national immunization program expansion would cost US$3.86 billion over the assessed 60-year period. Financial needs would decrease from US$688 million in decade 2 to US$589 million in decade 6. Procurement of vaccines would consistently account for a high proportion (79%–84% by decade) of total expected cost, which mirrors the current Colombian national immunization program funding and expenditure structure. The decreasing trend is mostly explained by the expected demographic change by age group, resulting in a decreasing target population for vaccination.

Benefits breakdown

According to the model, productivity gains would be the primary contributor to overall benefits of immunization program expansion, ranging from 63% to 65% of total benefits by decade (Table 2). Following productivity gains, fiscal savings accounted for 31% to 34% of total benefits and reduced out-of-pocket health care expenses for households represented 2% to 4% of total benefits. Fiscal savings were primarily driven by avoiding health system costs associated with disease treatment in the initial 3 decades (Appendix S7). However, starting from the fourth decade, the most significant source of fiscal benefits would become savings in sick-day payments for the social security system. This component experienced the most substantial growth in its contribution to fiscal savings, from 9% in the first decade to 36% in the third decade and 42% in the sixth decade. This trend reflects the time required for immunized cohorts to reach working age and the age groups with the highest incidence rates of vaccine-preventable diseases. Additionally, increased tax collections represented 22% to 27% of the fiscal returns on investment over each decade. When analyzing the return on investment broken down by vaccine, we observed that the results were driven by dengue vaccination for adolescents, PPSV23 vaccination in people aged 60 years or older, and HPV vaccination (Appendix S8).

Additional socioeconomic benefits

The expanded immunization model provided higher income protection for households in the informal sector compared with those in the formal sector, amounting to a difference of US$583 million over the assessed period (Table 3). Specifically, the cumulative income protection for informal households amounted to over US$2 billion, which was 1.4 times higher than that for formal households, totaling US

Table 2. Cost-benefit analysis and return on investment: results for proposed national immunization program expansion.

	Cost-benefit analysis components estimation; US$ million (2021 prices)										
	Cost by decade					Benefits by decade					
Decade	National procurement	Delivery (HMO)	Subnational program costs	Total cost	Cumulative cost (A)	Fiscal/public finances[a]	Productivity	Household OOP expenditure	Total benefits	Cumulative benefits (B)	ROI (= B/A)
1	561	78	33	672	672	151	311	18	480	480	0.7
2	573	81	34	688	1360	444	830	41	1314	1794	1.3
3	540	83	35	657	2017	715	1328	56	2099	3893	1.9
4	518	85	36	639	2656	993	1860	71	2923	6816	2.6
5	492	86	36	614	3270	1256	2392	85	3733	10 549	3.2
6	467	86	36	589	3859	1483	2901	98	4483	15 032	3.9

Abbreviations: GDP, gross domestic product; HMO, health maintenance organizations under the National Health Insurance System; OOP, out-of-pocket; ROI, return on investment.
Source: Authors' analysis of original model outputs.
[a]Comprises the following: lower health system spending (disease treatment cost savings), lower social security spending (sick-day payments savings), and higher tax collections from more productive workforce/higher economic activity.

Table 3. Households' income protection and additional workforce from productivity gains associated with the proposed national immunization program expansion.

Decade	Income protection by decade; US$ million (2021 prices)		Additional potential workforce by decade[a]		
	Informally employed households	Formally employed households	Due to prevented cases/disability	Due to averted mortality	Total additional potential workforce due to improved health outcomes
1	65	46	47 774	1792	49 566
2	173	122	125 598	6421	132 020
3	276	196	197 336	13 963	211 299
4	387	274	271 098	24 832	295 929
5	498	353	340 424	40 199	380 623
6	603	428	399 199	62 436	461 634

Source: Authors' analysis of original model outputs.
[a]Calculated by adding the potential equivalent loss of annual workers that was averted and that was used to estimate the productivity gains of the modeled national immunization program expansion.

$1.42 billion. In proportional terms, the impact on income protection in informal households was 3.2 times greater than that in the formal sector. This calculation considers that the baseline aggregated income of the informal workforce is only 44% of the aggregated income in the formal sector (3.2 = 1.4/0.44). As a result, under the assumptions of the model, expanded access to life-course immunization in Colombia would contribute to reducing income inequality.

Discussion

The Colombian case study provides compelling evidence in favor of expanding the national immunization program for adolescents and adults. Our study found a positive and increasing return on investment for including 5 vaccines across the life course. The primary economic benefits were observed in terms of productivity gains, followed by fiscal savings and reduced out-of-pocket health care expense for households. Expanding the availability of immunization throughout people's lives would not only have economic impact but also greater income protection for vulnerable households in the informal workforce, contributing to reducing income inequality and potentially alleviating poverty. This is particularly significant considering that a large proportion of households below the poverty line belong to the informal sector.

Furthermore, the proposed expansion is feasible within fiscal and operational capacities of the country, requiring a modest annual investment of 0.4% of the current health system budget for the administration of approximately 5 million vaccinations per year. The national government would handle most of the procurement, making it feasible for HMOs to deliver vaccination services.

The successful delivery of 75.5 million COVID-19 vaccinations in just 12 months further highlights the capacity of the system to administer additional vaccines.[51] This indicates that national immunization programs are well positioned for expansion. Policymakers have an opportunity to safeguard the capacity, infrastructure, and, to a degree, funding, in order to explore expanding routine vaccines to address comprehensive needs across all stages of life.

In addition to informing national decision making in Colombia, this study presents an innovative approach to blending fiscal, economic, social, and health outcomes to make the case for life-course immunization programs in other countries. It highlights the value of investing in life-course immunization beyond health outcomes, including building resilience in the health system, contributing to more equitable socioeconomic progress, particularly for countries facing aging populations, and supporting the 2030 SDGs related to reducing income inequality and alleviating poverty.

While this model provides powerful evidence for the return of investment of life-course immunization, its results should be interpreted and applied in the specific context of local diseases. Our model demonstrated a substantial range in return on investment among the different vaccines analyzed. Despite diphtheria, tetanus, and meningococcal meningitis showing a lower return on investment, it is crucial to acknowledge the life-threatening nature of these diseases and the potential severe long-term consequences. When evaluating these vaccines, it becomes essential to incorporate additional value judgments that go beyond traditional economic benefits. These judgments should account for factors such as disease severity and societal preferences to ensure a comprehensive assessment.[52]

As countries continue to recover routine immunization coverage rates post–COVID-19 and expand efforts to meet new public health needs, improved evidence will be critical in supporting investment decisions. The socioeconomic argument provided in this study, along with the preparedness gains demonstrated in national COVID-19 responses, should encourage scaling up investments in immunization across the life course. Acknowledging that further work is needed, the impact of life-course immunization on the poverty rate should be estimated. For example, using earlier model assumptions, the authors collaborated with Colombia's National Planning Department and utilized their modeling tools to conduct a separate analysis. In this analysis, general equilibrium and microsimulation models were used to determine the impact of improved health outcomes on poverty reduction by simulating labor markets. The simulations indicated a potential reduction in the poverty rate in Colombia by 3.5 points after 20 years of life-course immunization implementation. This reduction was driven by 236 930 additional workforce members under earlier assumptions. In contrast, under final model assumptions, the simulations projected 181 586 additional workforce members over the first 2 decades, as inferred from Table 3. In addition, further work is needed to estimate the positive effects on gender equality, considering that prevented disease cases reduce the burden on unpaid family caregivers, who are often women.

Conclusion

By performing a cost-benefit analysis on the inclusion of 5 vaccines across the life course in Colombia, our study offers evidence on the economic return on investment of incorporating these vaccines into the national immunization programs from a societal perspective. Unlike existing assessments measuring the broader impact of these vaccines in nonmonetary terms, our results inform both the economic benefits that overcome needed investment and broader social outcomes. If life--course immunization is sustained over time, the economic, fiscal, and social return will progressively increase.

The implementation of the proposed expansion of life-course immunization is feasible within the fiscal and operational capacities of Colombia. If this expansion is actively promoted, sustained, and protected as a national policy, and assessed from a more comprehensive, societal perspective, life-course immunization will pay off.

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Supplementary material

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Conflicts of interest

Please see ICMJE form(s) for author conflicts of interest. These have been provided as supplementary materials.

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Notes

1. Rodrigues CMC, Plotkin SA. Impact of vaccines; health, economic and social perspectives. *Front Microbiol*. 2020;11:1526.
2. Remes J, Linzer K, Singhal S, et al. *Prioritizing Health: A Prescription for Prosperity*. McKinsey & Company; 2020. Accessed July 26, 2022. https://www.mckinsey.com/industries/healthcare-systems-and-services/our-insights/prioritizing-health-a-prescription-for-prosperity
3. Masia NA, Smerling J, Kapfidze T, Manning R, Showalter M. Vaccination and GDP growth rates: exploring the links in a conditional convergence framework. *World Dev*. 2018;103:88-99.
4. Leidner AJ, Murthy N, Chesson HW, et al. Cost effectiveness of adult vaccinations: a systematic review. *Vaccine*. 2019;37(2):226-234.
5. Bärnighausen T, Bloom DE, Cafiero-Fonseca ET, O'Brien JC. Valuing vaccination. *Proc Natl Acad Sci USA*. 2014;111(34):12313-12319.
6. Glassman A, Cañón O, Silverman R. How to get cost-effectiveness analysis right? The case of vaccine economics in Latin America. *Value Health*. 2016;19(8):913-920.
7. McIntosh E, Clarke P, Frew EJ, Louviere JJ. *Applied Methods of Cost-Benefit Analysis in Health Care*. Oxford University Press; 2010.
8. Babigumira JB, Dolan S, Shade S, Puttkammer N, Bale J, Tolentino H. *Applied Economic Evaluation of Digital Health Interventions*. International Training and Education Center for Health; 2021. https://www.go2itech.org/wp-content/uploads/2021/02/I-TECH_HIS_Economic_Evaluation.pdf
9. Supporting Active Ageing Through Immunisation (SAATI) Partnership. *Adult Vaccination: A Key Component of Health Ageing*. Supporting Active Ageing Through Immunisation (SAATI) Partnership; 2018. https://ilcuk.org.uk/wp-content/uploads/2018/11/Adult-vaccination_a-key-component-of-health-ageing.pdf
10. Yuasa A, Yonemoto N, LoPresti M, Ikeda S. Use of productivity loss/gain in cost-effectiveness analyses for drugs: a systematic review. *Pharmacoeconomics*. 2020;39(1):81-97.
11. Kuruvilla S, Sadana R, Montesinos EV, et al. A life-course approach to health: synergy with sustainable development goals. *Bull World Health Organ*. 2018;96(1):42-50.
12. Privor-Dumm L, Vasudevan P, Kobayashi K, Gupta J. Archetype analysis of older adult immunization decision-making and implementation in 34 countries. *Vaccine*. 2020;38(26):4170-4182.
13. Williams SR, Driscoll AJ, LeBuhn HM, Chen WH, Neuzil KM, Ortiz JR. National routine adult immunisation programmes among World Health Organization member states: an assessment of health systems to deploy COVID-19 vaccines. *Eurosurveillance*. 2021;26(17):2001195.
14. Sim SY, Watts E, Constenla D, Brenzel L, Patenaude BN. Return on investment from immunization against 10 pathogens in 94 low- and middle-income countries, 2011-30. *Health Aff (Millwood)*. 2020;39(8):1343-1353.
15. Jimbo-Sotomayor R, Watts E, Armijos L, et al. Return on investment of 10-valent pneumococcal conjugate vaccine in Ecuador from 2010 to 2030. *Value Health Reg Issues*. 2022;31:148-154.
16. Ruggeri M, Brino ED, Cicchetti A. Estimating the fiscal impact of three vaccination strategies in Italy. *Int J Technol Assess Health Care*. 2020;36(2):133-138.
17. Carrico J, Talbird SE, La EM, et al. Cost-benefit analysis of vaccination against four preventable diseases in older adults: impact of an aging population. *Vaccine*. 2021;39(36):5187-5197.
18. Bonanni P, Bonaccorsi G, Lorini C, et al. Focusing on the implementation of 21st century vaccines for adults. *Vaccine*. 2018;36(36):5358-5365.
19. World Health Organization. WHO immunization data portal. 2023. Accessed April 14, 2023. https://immunizationdata.who.int/listing.html? topic=coverage&location=MYS
20. Coe M, Madan Y. *Sustainable Immunization Financing: Colombia Country Brief*. ThinkWell; 2018.
21. Barrera-Escobar A. *Fenómeno de envejecimiento demográfico en Colombia: una inmediata discusión de realidad [The Demographic Aging Phenomenon in Colombia: An Immediate Discussion of Reality]*. 2020. Accessed May 31, 2023. https://papers.ssrn.com/abstract=3717305. Accessed April 4, 2024.
22. Departamento Nacional de Planeación. Ejecución presupuesto general de la nación. 2021. Accessed April 8, 2024. https://www.dnp.gov.co/LaEntidad_/subdireccion-general-inversiones-seguimiento-evaluacion/direccion-programacion-inversiones-publicas/Paginas/ejecucion-presupuesto-general-de-la-nacion.aspx.
23. Ministerio de Hacienda y Crédito Público. Presupuesto General de la Nación—2002-2022; 2022. Accessed July 26, 2022. https://www.minhacienda.gov.co/webcenter/portal/EntOrdenNacional/pages_presupuestogralnacion/bitcoraeconmica

24. Ministerio de Salud y Protección Social. Esquema de vacunación de Colombia; 2019. Accessed July 26, 2022. https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/VS/PP/ET/afiche-esquema-vacunacion-col.pdf
25. Departamento Administrativo Nacional de Estadística. *Proyecciones de población*. Departamento Administrativo Nacional de Estadística; 2018. Accessed July 26, 2022. https://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/proyecciones-de-poblacion
26. World Health Organization. *WHO Recommendations for Routine Immunization*. Immunization, Vaccines and Biologicals; 2021. Accessed July 26, 2022. https://www.who.int/teams/immunization-vaccines-and-biologicals/policies/who-recommendations-for-routine-immunization—summary-tables
27. Ministerio de Salud y Protección Social. Manual técnico administrativo del PAI. Tomo 1; 2016. Accessed July 26, 2022. https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/VS/PP/PAI/manual-pai-2015-2016.zip
28. Drost RMWA, van der Putten IM, Ruwaard D, Evers SMAA, Paulus ATG. Conceptualizations of the societal perspective within economic evaluations: a systematic review. *Int J Technol Assess Health Care*. 2017;33(2):251-260.
29. International Labour Organization. *Informal Employment Rate*. ILOSTAT; 2023. Accessed May 15, 2023. https://ilostat.ilo.org/data/
30. Departamento Administrativo Nacional de Estadística. *Pobreza multidimensional Bogotá D.C.* Departamento Administrativo Nacional de Estadística; 2019. Accessed July 26, 2022. https://www.dane.gov.co/files/investigaciones/condiciones_vida/pobreza/2019/Boletin_Region_bt_pobreza_multidimensional_19_bogota.pdf
31. Departamento Administrativo Nacional de Estadística, Colombia. *Brecha Salarial De Género En Colombia*. Gobierno De Colombia; 2020.
32. United Nations. *Transforming Our World: the 2030 Agenda for Sustainable Development*. United Nations; 2015. Accessed July 26, 2022. https://sdgs.un.org/2030agenda
33. The World Bank. Life expectancy at birth, total (years)—Colombia; 2021. Accessed March 24, 2024. https://data.worldbank.org/indicator/SP.DYN.LE00.IN?locations=CO
34. Pan American Health Organization. PAHO revolving fund vaccine prices for 2021. 2021. Accessed July 26, 2022. https://www.paho.org/en/documents/paho-revolving-fund-vaccine-prices-2021
35. Ministerio de Salud y Protección Social. Estudiode Suficiencia. Base de Datos de Recobros. 2019.
36. Ministerio de Salud y Protección Social. FUT Budget – NIP Expenditure. 2019.
37. Godói IP, Santos AS, Reis EA, et al. Consumer willingness to pay for dengue vaccine (CYD-TDV, Dengvaxia®) in Brazil; implications for future pricing considerations. *Front Pharmacol*. 2017;8:41.
38. Ministerio da Saude do Brasil. Vacina TAK-003 (Qdenga®) tetravalente para a prevenção de infecção pelo vírus da dengue; 2023. Accessed March 24, 2024. https://www.gov.br/conitec/pt-br/midias/consultas/relatorios/2023/Relatrio_Vacina_Dengue_CP52.docx/view
39. National Planning Department—Ministry of Finance. *Medium-term Fiscal Framework—Macroeconomic Assumptions*. 2021.
40. Ministerio de Salud y Protección Social. *Base de Datos de Incapacidades*. 2019.
41. Global Health Data Exchange. *Global Burden of Disease Study 2019 (GBD 2019)*. GHDx; 2019. Accessed July 26, 2022. https://ghdx.healthdata.org/gbd-2019
42. World Health Organization. A life course approach to health, human capital, and sustainable development. 2019. Accessed April 8, 2024. https://www.paho.org/sites/default/files/2021-04/who-lc-brief-2019-eng.png
43. Ministerio de Salud y Protección Social. *Cifras Financieras del Sector Salud*. Ministerio de Salud y Protección Social; 2015. Accessed July 26, 2022. https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/VP/FS/cifras-financieras-sector-salud-No.9.pdf
44. Andrade AL, Afonso ET, Minamisava R, et al. Direct and indirect impact of 10-valent pneumococcal conjugate vaccine introduction on pneumonia hospitalizations and economic burden in all age-groups in Brazil: a time-series analysis. *PLoS One*. 2017;12(9):e0184204.
45. Urrego-Reyes J, Giglio N, Hirata L, et al. *Hospitalization and Case-Fatality Rates of Potential Pneumococcal Pneumonia in Argentina: A 12-Year Time-series Trend Analysis*. ISPPD; 2024. Accessed March 24, 2024. https://isppd.kenes.com/abstract-publication/
46. Parellada C, Cornejo D, Hirata L, et al. Childhood pneumococcal vaccination and pneumonia mortality rates across all ages in Mexico between 2004-2019: a time-series trend analysis. Accessed April 8, 2024. https://isppd.kenes.com/abstract-publication/.
47. Drolet M, Bénard É, Pérez N, Brisson M; HPV Vaccination Impact Study Group. Population-level impact and herd effects following the introduction of human papillomavirus vaccination programmes: updated systematic review and meta-analysis. *Lancet*. 2019;394(10197):497-509.
48. Bruni L, Albero G, Serrano B, et al. ICO/IARC Information Centre on HPV and Cancer (HPV Information Centre). Human Papillomavirus and Related Diseases in Colombia. Summary Report 10 March 2023. Accessed March 24, 2024. https://hpvcentre.net/statistics/reports/COL.pdf
49. Carrasquilla M, Alvis-Zakzuk NJ, Zakzuk Sierra J, et al. Estimating the impact of a gender-neutral quadrivalent human papillomavirus vaccination program in all HPV 6/11/16/18-related diseases in Colombia. *Value Health*. 2020;23(5):S170–S171.
50. Carrasquilla M, Alvis-Zakzuk NJ, Zakzuk Sierra J, et al. Public health and economic impact of a gender-neutral quadrivalent human papillomavirus vaccination program in Colombia. *Value Health*. 2019;19:S41–S42.
51. University of Oxford. COVID-19 Data Explorer: vaccine doses administered. Our World in Data; 2023. Accessed May 31, 2023. https://ourworldindata.org/explorers/coronavirus-data-explorer
52. Postma M, Biundo E, Chicoye A, et al. Capturing the value of vaccination within health technology assessment and health economics: country analysis and priority value concepts. *Vaccine*. 2022;40(30):3999-4007.