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Evaluating the Health Opportunity Costs of COVID-19 Pandemic Prevention, Preparedness, and Response Investment: A Comparative Analysis With Primary Healthcare System Strengthening

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Abstract

This study evaluates the health opportunity costs associated with the allocation of global health resources toward pandemic prevention, preparedness, and response (PPPR) for COVID-19 compared to alternative investments in primary healthcare system strengthening. A central tension in global health policy involves the allocation of finite resources between vertical programs targeting specific diseases and horizontal investments that strengthen foundational health systems. This research addresses this critical resource allocation question by quantifying the health gains derived from $15.25 billion invested through the International Finance Facility for Immunization (IFFIm) and the COVAX Advance Market Commitment (AMC) for COVID-19 vaccine procurement during 2020-2024. Using disability-adjusted life years (DALYs) as the primary outcome measure, the study constructed a counterfactual scenario in which identical resources were allocated to the World Bank's Essential Universal Health Coverage (EUHC) package for low-income countries. Under benchmark assumptions employing a median vaccine price of $13.17 per dose and a number needed to vaccinate (NNV) of 1,000, the factual PPPR investment yielded 22.1 million DALYs averted, while the counterfactual primary healthcare investment would have averted 16.01 million DALYs. The resulting opportunity cost of -6.09 million DALYs indicates that PPPR investment outperformed the alternative scenario. Sensitivity analyses confirmed the robustness of this finding across most parameter variations, with positive opportunity costs emerging only under highly optimistic assumptions regarding primary healthcare delivery efficiency. These findings suggest that emergency pandemic vaccine procurement represented a cost-effective resource allocation strategy from a population health perspective, though sustained investment in primary healthcare remains essential for long-term health system resilience.

Keywords

COVID-19; Pandemic Preparedness; Health Opportunity Cost; DALY; Universal Health Coverage; Primary Healthcare; Vaccine Investment; Global Health Financing.

1. Introduction

The COVID-19 pandemic precipitated an unprecedented mobilization of global health financing resources toward pandemic response interventions, most notably through vertical programs such as international vaccine procurement initiatives. This substantial reallocation of resources has intensified a fundamental and long-standing debate within global health policy: whether targeted, disease-specific investments generate superior health returns compared to strengthening the horizontal foundations of national health systems (World Health

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Organization & World Bank, 2022). This question carries profound implications for resource allocation decisions that affect millions of lives worldwide.

The magnitude of the financing challenge is substantial. A joint World Health Organization and World Bank report prepared for the G20 estimated the total international financing gap for pandemic prevention, preparedness, and response (PPPR) at $10.5 billion annually (World Health Organization & World Bank, 2022). Concurrently, research published in BMJ Global Health indicated that establishing basic national health security capabilities in eligible countries would require at least $76 billion over a three-year period, a figure that far exceeds the operational capacity of major global health institutions such as the Global Fund to Fight AIDS, Tuberculosis and Malaria (Eaneff et al., 2023). This context of persistent resource scarcity underscores the critical importance of allocation efficiency in global health decision-making.

Innovative financing mechanisms played a pivotal role in channeling substantial resources toward COVID-19 pandemic response. The International Finance Facility for Immunization (IFFIm) and the Gavi COVAX Advance Market Commitment (AMC) collectively directed billions of dollars toward COVID-19 vaccine procurement and distribution. IFFIm committed $3.3 billion to Gavi for the 2021-2025 period, with $2.8 billion disbursed by March 2025 (Lay, 2025), while the COVAX AMC provided $1.2 billion to support vaccine access in low-income countries by the end of 2021 (Gavi, 2021). However, critics have argued that such vertical investments may have diverted resources from long-term health system strengthening efforts that could potentially yield higher returns and that they may have introduced market inefficiencies (Tacheva et al., 2025).

This study directly addresses the core of this ongoing debate by conducting a rigorous comparative health gain analysis. The research focuses on a specific, substantial investment: $15.25 billion directed through IFFIm and AMC mechanisms for COVID-19 vaccine procurement during the 2020-2024 period. A precise counterfactual scenario is constructed to address the following research question: What health gains would have been realized if this identical sum had been invested in the World Bank's Essential Universal Health Coverage (EUHC) package for low-income countries? By quantifying and comparing the health gains measured in disability-adjusted life years (DALYs) averted from both scenarios, this analysis explicitly calculates the health opportunity cost of the chosen vaccine investment strategy. The findings provide an evidence-based assessment of a critical resource allocation decision in global health policy.

The remainder of this paper is organized as follows. Section 1 presents a detailed accounting of the capital disbursed through IFFIm and COVAX AMC mechanisms during the study period and examines the allocation of these funds. Section 2 calculates the health gains achieved under the factual PPPR scenario. Section 3 constructs the counterfactual scenario and estimates the health gains that would have resulted from equivalent investment in primary healthcare through the EUHC package. Section 4 presents the conclusions, discusses policy implications, and acknowledges the limitations of the analysis.

2. Capital Disbursement Analysis (2020-2024)

To calculate the opportunity cost of innovative financing for pandemic response, a comprehensive accounting of the total capital actually disbursed is essential. This section presents a systematic analysis of IFFIm disbursements to Gavi during the 2020-2024 period and examines the allocation patterns of funds raised through this mechanism, drawing upon data from official trustees' reports and audited financial statements disclosed by IFFIm.

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2.1. IFFIm Disbursements to Gavi

Table 1 presents annual disbursement data compiled from IFFIm's official financial reports for the 2020-2024 period. The data reveal substantial year-to-year variation in disbursement levels, with a pronounced peak during the acute phase of the COVID-19 pandemic response.

Table 1. IFFIm Disbursements to Gavi (2020-2024)

Year	Annual Disbursements (USD Millions)
2020	406
2021	1,214
2022	829
2023	435
2024	366
Total	**3,250**

Note. Data compiled from IFFIm annual financial reports (IFFIm, 2020, 2021, 2022, 2023, 2024).

Figure 1 illustrates the allocation patterns of IFFIm funds during the study period. The analysis reveals that IFFIm disbursed a cumulative total of $3.25 billion over the five-year period. Notably, disbursements reached their peak during 2021-2022, corresponding to the height of global COVID-19 vaccine procurement efforts, before declining and stabilizing in 2023-2024 as programmatic focus shifted back toward routine immunization programs. This sum of funds represents resources that, by definition, could not simultaneously be allocated to alternative health system strengthening investments.

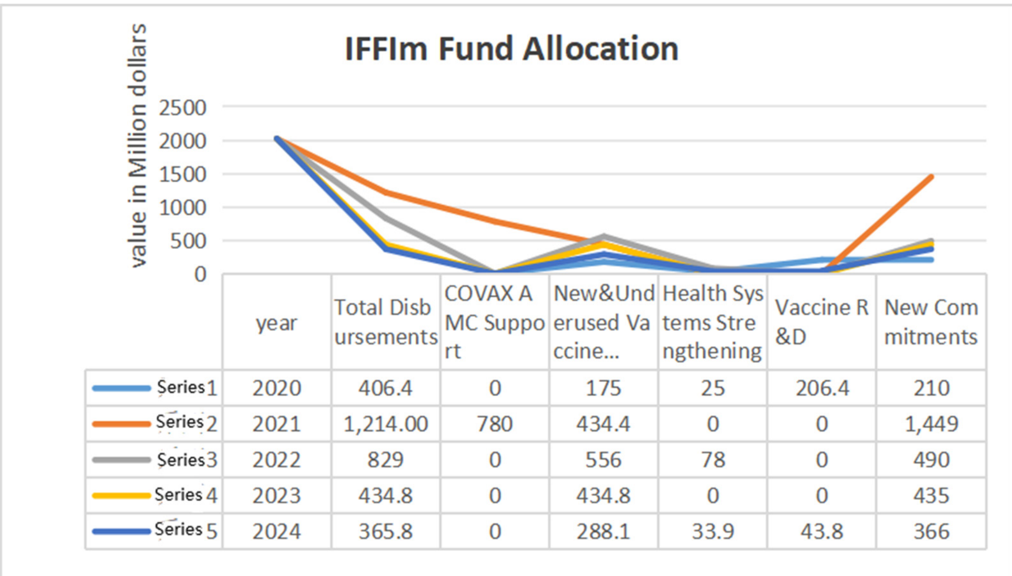

Figure 1. IFFIm Fund Allocation by Program Category (2020-2024)

Note. Author's analysis based on IFFIm Annual Report of the Trustees and Financial Statements (2020-2024).

According to official reports, IFFIm has made substantial contributions to routine childhood immunization, COVID-19 pandemic response, and polio eradication efforts, with claimed

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impacts including improved health outcomes across multiple countries in Africa and other regions (IFFIm, n.d.). However, it is important to distinguish between official institutional claims and independent empirical validation. The effectiveness of these investments in generating health gains requires systematic quantitative assessment, which this study aims to provide.

2.2. COVAX Advance Market Commitment

The COVAX Advance Market Commitment (AMC) represents another major innovative financing mechanism dedicated to promoting equitable vaccine distribution and ensuring access to COVID-19 vaccines for low- and middle-income countries. According to Gavi's official documentation, the COVAX AMC mechanism supported 92 low- and middle-income economies in mobilizing a cumulative total exceeding $12 billion for vaccine procurement and distribution (Gavi, 2024).

Figure 2 presents the funding allocation plan for the COVAX AMC in 2022, illustrating how a substantial majority of resources were directed toward vaccine procurement to address COVID-19 mortality. This allocation pattern raises a critical evaluative question: Did the investment of these funds generate optimal health returns? Could equivalent resources allocated to alternative healthcare investments have achieved greater health gains? These questions form the analytical foundation for the counterfactual analysis presented in Section 3.

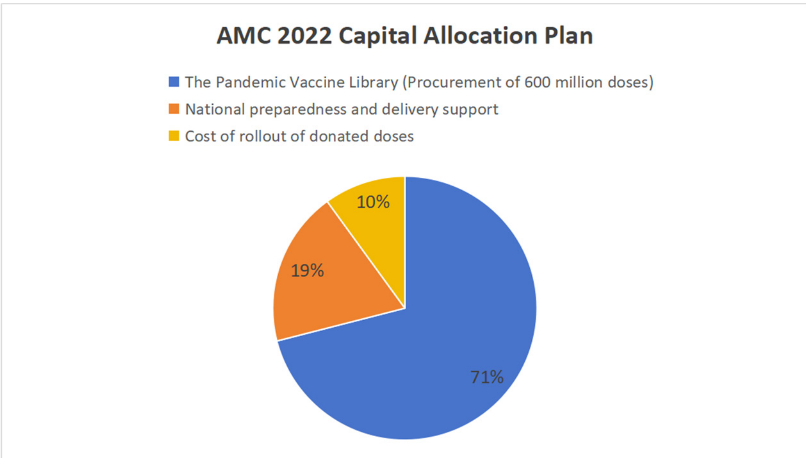

Figure 2. COVAX AMC 2022 Funding Allocation by Category

Note. Author's analysis based on Gavi (2021).

2.3. Total Capital Mobilization

Table 2 presents the aggregate capital mobilized through both IFFIm and COVAX AMC mechanisms during the 2020-2024 study period. The combined total exceeds $15.25 billion, representing the baseline financial input for subsequent health gain calculations.

Table 2. Total Capital Disbursed for COVID-19 PPPR (2020-2024)

Mechanism	Time Period	Total Amount (USD Billion)
IFFIm	2020-2024	3.25
COVAX AMC	2020-2023	>12.00
Total		**>15.25**

3. Health Gains under the Factual PPPR Scenario

This section presents the methodology and results for estimating health gains attributable to the factual COVID-19 vaccine investment scenario. The analysis employs disability-adjusted life years (DALYs) as the primary health outcome metric, enabling standardized comparison with alternative investment scenarios.

3.1. Analytical Framework

To estimate vaccine procurement capacity under IFFIm and COVAX AMC investments, descriptive statistics were calculated based on publicly available UNICEF COVID-19 vaccine price data. The distribution of vaccine prices exhibited the following parameters: minimum = $7.00, first quartile (Q1) = $8.00, median = $13.17, third quartile (Q3) = $18.00, and maximum = $20.00 (UNICEF, n.d.). Based on this distribution, a three-tier analytical framework was constructed to ensure robust findings.

The benchmark analysis employed the median price of $13.17 per dose as the primary estimate, representing the central tendency of observed market prices. The sensitivity analysis utilized quartile values of $8.00 per dose and $18.00 per dose to test the robustness of core findings when prices fluctuate within the interquartile range. Finally, the boundary analysis employed extreme values of $7.00 per dose and $20.00 per dose to determine the full range of possible opportunity costs under observed market conditions. This multi-tier framework ensures that study results are not dependent on a single price assumption and enables comprehensive assessment of uncertainty in opportunity cost estimates.

3.2. Number Needed to Vaccinate (NNV) Parameters

The number needed to vaccinate (NNV) represents the number of individuals who must receive vaccination to prevent one COVID-19 death. Lower NNV values indicate higher return on vaccine investment. To capture the inherent uncertainty in NNV estimates, this study employed a comprehensive sensitivity analysis spanning values from 100 to 10,000. This range encompasses multiple authoritative empirical studies. The lower bound of 100 was derived from observations by Adams et al. (2023) of high-risk populations during the Omicron variant epidemic in the United States. Medium to high values ranging from 1,000 to 10,000 were based on official modeling conducted by the UK Health Security Agency (2023), which demonstrated substantial variation in NNV across different age groups and risk categories during the Omicron period, reflecting high sensitivity of NNV to disease incidence rates.

Table 3. Number Needed to Vaccinate (NNV) Scenario Parameters

Scenario Description	NNV Value
Most Favorable Scenario	100
Favorable Scenario	250-500
Benchmark Scenario	1,000
Unfavorable Scenario	5,000
Least Favorable Scenario	10,000

3.3. DALY Calculation Methodology

To convert deaths averted into a standardized health outcome metric, this study employed disability-adjusted life years (DALYs), specifically calculating years of life lost (YLL). The mean age at death from COVID-19 in low-income countries was estimated at 37.71 years based on

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data extracted from the Global Burden of Disease (GBD) Research Database using the following parameters: Measure = Deaths; Cause = COVID-19; Location = World Bank Low Income; Age = all age groups; Sex = Both; Year = 2023. The weighted average age was calculated using the number of deaths by age group, weighted by median age within each group. Detailed calculations are provided in Supplementary File S1.

Remaining life expectancy was derived from the United Nations Population Division Data Portal using the indicator Life expectancy E(x)-abridged for low-income countries in 2023. Based on available data, remaining life expectancy for the 35-39 age group was 37.9 years and for the 40-44 age group was 33.6 years. Through linear interpolation, the remaining life expectancy for the calculated mean age of 37.71 years was determined to be 37.7 years. Thus, each COVID-19 death averted prevents the loss of 37.7 DALYs.

Assuming a two-dose vaccination regimen, health gains were calculated using the following formula:

$$\text{Health Gains (DALYs)} = (\text{Total Vaccine Doses} / 2 / \text{NNV}) \times 37.7$$

3.4. Sensitivity Analysis Results

Table 4 presents the results of the sensitivity analysis across critical scenarios. The complete sensitivity matrix is provided in Supplementary File S2.

Table 4. Sensitivity Analysis of Health Benefits in the Factual PPPR Scenario

Analysis Type	Scenario	Price (USD/dose)	NNV	Health Benefits (Million DALYs)
Boundary	Most Favorable	$7.00	100	+415.1
Sensitivity	Favorable	$8.00	250	+145.3
Benchmark	Benchmark	$13.17	1,000	+22.1
Sensitivity	Unfavorable	$18.00	5,000	+3.2
Boundary	Least Favorable	$20.00	10,000	+1.5

4. Counterfactual Analysis—Primary Healthcare Investment

To assess the opportunity cost of the PPPR investment strategy, a rigorous counterfactual scenario must be constructed. This section estimates the health gains that would have resulted from investing the identical $15.25 billion in primary healthcare system strengthening rather than COVID-19 vaccine procurement.

4.1. Counterfactual Scenario Design

The counterfactual assumes that $15.25 billion is invested in primary healthcare systems of low-income countries through the Essential Universal Health Coverage (EUHC) package as outlined in the World Bank's Disease Control Priorities project. This choice of counterfactual is grounded in the long-standing debate in global health regarding the allocation of scarce resources between vertical programs targeting specific diseases and horizontal investments that strengthen foundational primary care systems (Jamison et al., 2018).

The EUHC package represents a comprehensive intervention portfolio designed to provide primary healthcare to low- and middle-income countries, comprising 218 specific interventions across multiple domains including maternal, newborn, and child health; infectious disease prevention; and non-communicable disease and mental health services (Watkins et al., 2018).

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This intervention package represents one of the most cost-effective investment strategies for strengthening primary healthcare systems globally.

4.2. Population Coverage Calculation

According to data from the Disease Control Priorities project, in low-income countries, governments could spend $76 per capita per year on the EUHC package to provide a service package that significantly improves population health (Jamison et al., 2018). The population coverage under the counterfactual scenario is calculated as:

Population Coverage = Total Funds / Annual Per Capita Cost = $15.25 billion / $76 = 200.66 million person-years

4.3. Deaths Averted Calculation

According to the World Bank's DCP3 assessment, implementing the EUHC package in low-income countries with an annual investment of $68 billion would prevent 2 million deaths among individuals under age 70 (Jamison et al., 2018). Based on this relationship, the per capita mortality reduction rate for EUHC investments is calculated as:

Per Capita Death Avoidance Rate = 2 million deaths / ($68 billion / $76) = 0.002235 deaths per person-year

Thus, the number of deaths averted under the counterfactual scenario is:

Deaths Averted = 200.66 million × 0.002235 = 448,500 deaths

4.4. DALY Calculation for Counterfactual Scenario

To estimate years of life saved from deaths averted through the EUHC package, the average age at death for individuals under 70 was calculated using data from the IHME GBD Results Tool with parameters: Location = World Bank Low Income; Cause = All Causes; Age = 5-9, 10-14, through 65-69; Year = 2023; Sex = Both. Infant deaths (under age 5) were excluded to avoid downward bias in the age estimate, as EUHC interventions predominantly benefit youth and middle-aged populations. The calculated weighted average age at death was 40.1 years with a standard deviation of 18.8 years.

Remaining life expectancy was calculated using actual life tables for low-income countries from the UN World Population Prospects rather than standard reference life expectancy from the GBD study, to better reflect realistic conditions in the target population. Based on the mean age at death of 40.1 years and linear interpolation from UN life tables, remaining life expectancy was determined to be 35.7 years. Thus, each death averted through EUHC investment prevents the loss of 35.7 DALYs.

The health gains under the counterfactual scenario are therefore:

Counterfactual Health Gains = 448,500 deaths × 35.7 DALYs/death = 16.01 million DALYs

4.5. Opportunity Cost Calculation

The health opportunity cost of the PPPR investment strategy is calculated as the difference between counterfactual and factual health gains:

Opportunity Cost = 16.01 million DALYs - 22.1 million DALYs = -6.09 million DALYs

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The negative opportunity cost indicates that the factual PPPR investment strategy generated greater health gains than the counterfactual primary healthcare investment would have achieved.

4.6. Sensitivity Analysis of Counterfactual Parameters

To assess the robustness of the opportunity cost estimate, sensitivity analysis was conducted on two key parameters: the EUHC per capita annual cost ($76 baseline) and the DALYs recovered per death averted (35.7 baseline). The per capita cost was varied by -30% ($55) to account for potential scale economies and +50% ($120) to account for frictional costs and inflation during implementation. The DALYs per death parameter was varied by ±20% (28.56 to 42.84) to capture uncertainty in mortality patterns.

Table 5. Sensitivity Analysis of Opportunity Cost Estimates

Scenario	Per Capita Cost ($)	DALYs/Death	DALYs Averted (Million)	Opportunity Cost (Million DALYs)
Base Case	76	35.7	16.01	-6.09
Low Per Capita Cost	55	35.7	22.15	0.05
High Per Capita Cost	120	35.7	10.41	-11.69
Low DALYs/Death	76	28.56	12.81	-9.92
High DALYs/Death	76	42.84	19.21	-2.89
Pessimistic Scenario	120	28.56	8.25	-13.85
Optimistic Scenario	55	42.84	26.6	4.5

Note. Pessimistic scenario represents conditions most unfavorable for PPPR (highest per capita cost, lowest life-years saved). Optimistic scenario represents conditions most favorable for primary healthcare investment (lowest per capita cost, highest life-years saved).

The sensitivity analysis demonstrates that the core conclusion—that COVID-19 PPPR investment yielded greater health gains than the counterfactual EUHC investment—is robust across a wide range of parameter values. The opportunity cost remains negative (favoring PPPR) in the pessimistic scenario and becomes positive only under the optimistic scenario, which combines the most favorable assumptions for primary healthcare delivery efficiency. This indicates that the conclusion regarding optimal investment strategy is context-dependent, though the base-case finding that PPPR investment did not incur a health opportunity cost remains robust across most plausible parameter variations.

5. Discussion and Conclusion

5.1. Summary of Findings

This study evaluated the health opportunity cost of allocating $15.25 billion to COVID-19 vaccine procurement through IFFIm and COVAX AMC mechanisms compared to an alternative investment in essential health services for low-income countries. Under benchmark assumptions, the analysis found that investing in pandemic vaccines did not result in a net health loss relative to horizontal health system investment. This finding holds across most plausible parameter scenarios. A positive opportunity cost—indicating that primary healthcare investment would have generated superior health gains—emerges only under highly optimistic assumptions regarding the efficiency and effectiveness of primary healthcare delivery systems.

5.2. Policy Implications

These findings carry several important implications for global health policy. First, emergency vaccine procurement during a pandemic can represent an efficient allocation of resources from a population health perspective. The substantial health gains achieved through COVID-19 vaccination demonstrate the value of rapid, large-scale vertical interventions during acute health emergencies. However, this finding should not be interpreted as a general endorsement of vertical over horizontal investments. The analysis is specific to COVID-19 vaccination and cannot be extrapolated to other vaccines or disease-specific programs without additional study.

Second, sustained investment in primary healthcare remains essential for long-term health system resilience. While pandemic-specific interventions may be justified during emergencies, the foundation of effective health systems lies in robust primary care infrastructure. Policymakers should consider both short-term response capacity and long-term system strengthening when allocating scarce health resources. The tension between vertical and horizontal investments is not necessarily a zero-sum competition; rather, effective pandemic response often depends upon pre-existing health system capacity.

5.3. Limitations

Several limitations should be acknowledged. First, the estimates presented are sensitive to key parameters, including the average annual cost of EUHC implementation and the DALYs recovered per death averted. Although sensitivity analysis explored plausible ranges, these parameters carry substantial estimation uncertainty. Second, methodological differences between scenarios may introduce bias. Due to data availability constraints, the factual scenario used mortality statistics across all age groups, while the counterfactual scenario was restricted to individuals under age 70, potentially underestimating primary care benefits and biasing results in favor of PPPR.

Third, the analysis did not account for non-health benefits of vaccine investment, such as technological advancement and capacity building, in the factual scenario. Conversely, the counterfactual scenario implicitly assumed that all invested funds would convert directly to health benefits without accounting for management costs, implementation challenges, or resource leakage that would occur in practice. Fourth, the study conducted a static comparison and did not incorporate dynamic effects such as herd immunity benefits that would accrue under real-world conditions, potentially underestimating health gains in the factual scenario.

5.4. Conclusion

Despite these limitations, this study provides evidence that allocating substantial resources to vertical COVID-19 vaccine procurement was, under a wide range of plausible conditions, a justified investment from a health perspective when compared to strengthening primary healthcare. The negative opportunity cost observed in the benchmark scenario indicates that pandemic response investment generated greater health gains than the alternative. Nonetheless, the potential for high returns from efficient horizontal system investments—as demonstrated in the optimistic scenario—underscores the importance of sustained funding for foundational health services to build long-term health system resilience and preparedness for future health emergencies.

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