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| RESEARCH ARTICLE

Economic Resilience of Immunization Systems: Develipment and Validation of the ERIIS Index

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| ABSTRACT

The health and economic benefits of vaccination programs are tremendous, yet the financial sustainability will be vulnerable to macroeconomic crises, change of donors and government budget constraints. Current research calculates the health impact and cost-effectiveness and does not determine the economic resilience at the system level. In this paper, Economic Resilience Index of Immunization Systems (ERIIS), a composite and multi-dimensional index, is introduced; the index is designed to validate and forecast the ability of a country to maintain immunization outcomes in the case of fiscal shock. ERIIS is a composite score of five pillars: fiscal autonomy, health economic integration, procurement efficiency, funding diversification and data and forecast capacity into 100 points. According to the model, there are measurable indicators, weighting process, and a validation method that are to be employed in an empirical manner. ERIIS can provide a forecasting tool to policymakers because operationalizing economic resilience can be used to determine vulnerability, improve financial preparedness, and reform sustainable immunszation.

| KEYWORDS

Economic resilience, Immunization systems, Vaccine financing, Health system resilience, Public financial management, Immunization economics, Vaccine procurement, Health policy

| ARTICLE INFORMATION

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1. Introduction

Immunization remains one of the most cost-effective public health interventions worldwide, according to various studies and reports [1], [2]. Immunization programs have not only decreased mortality and increased life expectancy, but have also reduced treatment costs, and even productivity levels have gone up in every decade [3]. However, the effectiveness of vaccines and coverage programs alone does not justify continuing immunization programs. Besides, financing systems must be robust as well. The current worldwide shocks, like COVID-19, inflation upheaval, currency depreciation and disruption of supply flow, have led to structural vulnerabilities in vaccine financing schemes [4], [5]. Most of these states heavily rely on the assistance of foreign donors [6]. Once these countries are declared ineligible to donors, budget gaps emerge and that makes these countries even more vulnerable to a reduction in coverage [7]. Based on the choice to introduce the vaccine, the economic evaluation tools, including cost-effectiveness analysis (CEA) [8], [9], do not consider the capacity of the financial shock-absorbing. So, there's a conceptual gap: The existing literature evaluates impact and efficiency, but not resilience. Economic resilience in the immunization systems is the new angle of analysis introduced by this article.

2. Theoretical and Conceptual Framework

2.1 Cost-effective health infrastructure in a society

The economic resilience is referred to as the aspect of a system that is influenced by shocks, it remains capable of carrying out basic processes during disruption and rehabilitates successfully and adjusts according to the new economic conditions. Resilience within the framework of the public health system entails the ability to provide and the fiscal viability of the health services in such a way that, contingent on external forces such as economic crisis, disruption in the supply chain, and political instabilities, the health services can still be in a position to run. Then there was the global attention on the topic of health system resilience, following the mass public health crises, including the Ebola outbreak and the COVID-19 pandemic. These events showed that most health systems lack both the institutional flexibility and financial resources needed to continue providing services during periods of stress. As a result, health system resilience is currently being defined as the ability of institutions to prepare, respond, and learn following a shock and continue with the necessary health functions [10], [11]. The financial dimension of resilience has not been studied much, but other literature is concentrated on the governance systems, workforce potential and service delivery systems.

The absence of financial resiliency is particularly susceptible to immunization programs as vaccination systems need frequent investment into procurement, cold chain infrastructure, logistics, and management of the program. The immunization programs are developed based on long-term programs, which must be taken on a regular basis, in comparison to most other health interventions, which tend to lead to the re-emergence of diseases. The decline in the number of vaccinations and the outbreak of diseases can therefore be directly affected by financing disruptions.

2.2 Funding of immunization and Economic sustainability

In the past, immunization initiatives have been based on domestic government funding and foreign development aid. Such programs as the Expanded Program on Immunization and the Gavi Alliance have been on the frontline in increasing access to vaccines in the low and middle-income countries. Such initiatives have resulted in large reductions in the death rates of vaccine-preventable diseases, as well as led to significant economic payoffs in terms of population health outcomes [1], [3].

Even with such successes, it remains uncertain whether immunization programs are cost-effective in the long run. As countries begin to develop their financial systems, many of them begin to turn off initiative by donors to have their immunization systems funded and accept that responsibility. This change, despite its being an improvement in economic development, can be loaded with fiscal strain on the economy, whereby other external sources of financing are not properly developed to counter the domestic mechanisms of financing. It is suggested that countries that undergo donor transition often experience financial discontinuities that threaten the sustainability of immunization programs [6], [7].

The most widely used economic evaluation tools to inform the decision to introduce vaccines and determine how health resources are allocated are cost-effectiveness analysis and budget impact analysis [8], [9]. Whereas the given tools are primarily used to measure the performance of the intervention level as opposed to the financial viability of immunization systems, such tools can be an excellent tool to understand the effectiveness of vaccination efforts. They, in turn, are not able to reflect the capacity of national vaccination programs to stay covered during fiscal crises or macroeconomic shocks. This gap introduces the need for analytical frameworks that would examine the financial resiliency of immunization systems. The question of whether the vaccination programs can be sustained in the long-term, and whether the health of the population is not threatened because of the response of the vaccination programs to economic stress.

2.3 Stability of the Health Systems and Public Financial Management

The idea of public financial management (PFM) frameworks can provide a valuable point of departure on the topic of economic resilience in health systems. PFM is the process through which governments plan, allocate, execute and monitor spending. Good PFM systems are characterized by transparency of budgeting, predictability of flow of funds, good procurement and good accountability systems [12], [13]. The health sector can apply good financial management to avail proper and timely finances to programs such as immunization and a poor system would lead to late payments, inefficiency in the procurement programs and misallocation of resources.

Financial diversification is also a factor that makes the system stable, as it is not overdependent on one source of funding. Relying heavily on external donor support to have a health system that heavily depends on it would end up becoming vulnerable in the event that priorities shift. Financial risk can be spread through diversified financing mechanisms, which include domestic taxation, social health insurance and earmarked health funds and build resilience in times of economic uncertainty [17], [18]. Financial planning also involves good data systems and effective forecasting. Constant demand forecasting helps governments to predict the demand of vaccines and prevent disruption of supplies, and a poor information system can lead to stockouts, excessive budgets and poor resource allocation [19].

2.4 Immunization Systems Conceptualising Economic Resilience

According to these theoretical approaches, economic resilience of immunization systems may be interpreted as the capacity of national vaccination systems to remain covered, economically healthy and able to function when the financial or funding system is interrupted [10], [11], [12]. The truth of the matter is that, even when the economic shock, inflation or the reduction of external support will take place, resilient immunization systems will be in operation even then.

There are various institutional and financial factors that determine resilience. Fiscal independence assists in having consistent sources of funds, procurement effectiveness assists in having a stable supply of vaccines, and economic assessment capacity helps in making evidence-based decisions [8], [12], [15]. Diversified financing devices minimize exposure to donor dependency, and good data and forecasting systems allow governments to predict financial strains and implement strategies as needed to meet them [16], [17], [18], [19].

All these are included as the Economic Resilience Index of Immunization Systems (ERIIS). Integrating the key variables of financial and institutional capacity, ERIIS will provide the systematic framework for estimating the resilience of the immunization systems and identifying the areas in which changes to the policy level will have to be made in order to increase financial sustainability.

3. Economic Resiliency Index To Immunization Systems

3.1 Index Structure

Holding steady through money troubles isn't easy for public health efforts. What makes certain nations continue to administer the vaccines even when the funds become tight is not only about the size of the wallet. The behind-the-scenes structures can contribute significantly, such as the manner in which decisions are made or the way supply chains are managed. Once income levels decrease or disasters strike, these hidden components begin to bear the brunt. ERIIS is a tool that brings together those pieces into a single score. It is not merely a matter of counting dollars, and it considers preparedness, funding patterns, and day-to-day operations. In nations that have a smoother system, the children are often vaccinated regardless of the economic climate [10], [11]. Bumpy constructions are prone to shaking with pressure accumulation. It is not a crash predictor - it indicates which countries are capable of absorbing them [10], [11], [12], [14], [15].

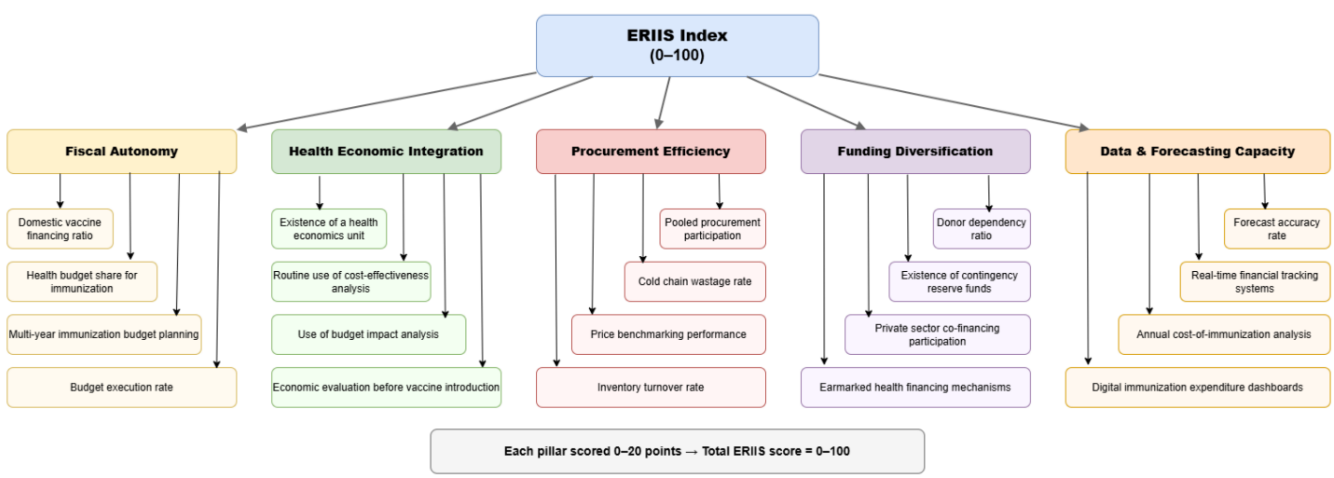

Fig. 1. Conceptual framework of the Economic Resilience Index for Immunization Systems (ERIIS)

Fiscal freedom gets the ball rolling, then the movement of money in the healthcare choices. One section is concerned with smarter shopping techniques rather than the routines of old. It is no longer a single source of the money streams. The last piece is formed by information flow and predicting needs. These works, in combination, create stability during the payment of vaccinations. Stability is manifested where budgets are aligned with policy decisions.

A method that ensures countries remain comparable is by assigning each pillar not more than 20 points. All of this adds to 100 on the ERIIS scale - the more points, the more the resilience. The idea of scoring makes it such that strength is evident across borders. The index is calculated as:

$$ERIIS=F+H+P+D+T$$

Where:

- F = Fiscal Autonomy
- H = Health Economics Integration.
- P = Procurement Efficiency
- D = Funding Diversification
- T = Capacity of Data and Forecasting.

Each pillar, one at a time, is shaped by four different measures, each with a common range of 05 to place values in a smooth range. Rather than drifting away, the numbers remain in the same line, and therefore, comparison becomes constant irrespective of the factor. Throughout, the structure is maintained since scaling maintains things at par. Lacking that balance, disparities would cause the entire system to shift. Equal levels make it equitable as the results accumulate without distortion.

3.2 Indicator Normalization

The fact that the values of different sources have to be aligned to give a fair comparison is one of the reasons ERIIS pulls together the data of different sources. To ensure that this happens, each indicator is scaled by a process known as minmax [20], [21], [22], [23]. This operation moves numbers to the extent that they lie in a common range. In its absence, the amalgamation of measurements would bias findings. The adaptation enables different inputs to communicate using the same language. The most important thing is that differences are to be seen and to be meaningful. Normalization simply does so by re-establishing extremes. All values have their own place within established boundaries. In that manner, there is no overruling scale.

Even in cases where the sources vary, consistency ensues:

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}} \times 5$$

where:

- X represents the observed indicator value
- X_{min} and X_{max} represent minimum and maximum values in the sample
- X_{norm} represents the normalized score on a 0–5 scale

With indicators where higher values reflect poorer performance, the scale is inverted in such a way that higher normalized scores invariably indicate stronger resilience.

3.3 Fiscal Autonomy

Financing primarily in-country demonstrates the extent to which a country is self-reliant in its vaccine efforts [6], [7], [13], [20]. When external assistance wanes, the less dependent ones will stand their ground. By sticking to the local currency, the ride may be easier when the economy starts to shake.

- Four signs make up this piece.
- Domestic ratio of vaccine financing.
- Share of health spending allocated to vaccines.
- Planning budgets for immunisation over a period of years.
- Budget execution rate

The ratio of the money available locally to the overall expenditure indicates how much a nation spends locally on its vaccines. This percentage is based on the amount of homegrown funds divided by total costs associated with immunization programs:

$$Domestic\ Financing\ Ratio = \frac{Domestic\ Vaccine\ Spending}{Total\ Vaccine\ Spending}$$

The rate of budget execution is calculated as:

$$Execution\ Rate = \frac{Actual\ Immunization\ Spending}{Planned\ Immunization\ Budget}$$

The score on fiscal autonomy is calculated as:

$$F = D_1 + D_2 + D_3 + D_4$$

where each indicator is standardized on a 0–5 scale. The increased fiscal autonomy enhances financial sustainability through the process of donor transition [6], [13].

3.4 Pillar Two Health Economics Integrated

Cost analysis is not always part of every decision on vaccines, but when it is, it's going to be more aligned with the needs of the public. Financial data is useful for prioritizing shots to communities first, given the constraint of budgets [8], [9], [14]. These numbers are not included in some programs. Some construct them during the planning process from the beginning. If funding is a factor, long-term plans may take longer to be implemented. This is not the case in all countries. Once it's in the ground, the dollars continue to flow.

Four signs make up this part.

- There is a health economics unit. A health economics unit is present.
- The monthly use of cost-effectiveness analysis.
- Use of budget impact analysis.
- An economic evaluation is required before vaccine introduction. Vaccine introduction is dependent upon an economic evaluation.

A number is figured out by:

$$H = E_1 + E_2 + E_3 + E_4$$

The values within a 0-5 range are adjusted uniformly. Decision ranking becomes more precise, and waste in health funding decreases due to economic analysis by institutions [8][14].

3.5 Pillar Three: Procurement Efficiency

Getting vaccines doesn't have to drain resources. A well-managed buying process can reduce costs and maintain constant deliveries [15], [16]. A smooth operation translates to fewer hiccups when it comes to delivering doses where they're needed. Saving money by doing the right thing at the right time.

Indicators include:

- Getting involved in group buying setups.
- The rate of wastage in the cold chain.
- Price benchmarking performance.
- Inventory turnover rate.

The procurement efficiency score is the ratio of the number of successful procurements to the total number of procurements.

$$P = P_1 + P_2 + P_3 + P_4$$

Where indicators have been scaled from 0 to 5. Poor procurement processes can add to financial strain and can impact immunization programmes [15], [16], [24], [25], [26].

3.6 Pillar Four Funding Spread

A good gauge of the stability of a vaccine program is the number of different funding sources it relies on. If the cash source is more than one, when there is an unexpected shortage, the impact is more severe in other areas. A combination of support channels allows for an absence of failure in one locality to cause failure in all others [17], [18]. This prevents slowdown as one stream slows, as the backing is spread out.

Indicators include:

- Donor dependency ratio.
- Contingency reserve funds are provided.
- The participation of the private sector in co-financing.
- Mechanisms for financing health care that are dedicated to earmarking.

The score is obtained by following the formula:

$$D = F_1 + F_2 + F_3 + F_4$$

Each indicator is scored from zero to five, based on the level. Multisource funding makes up the system and gives it more stress resistance and reduces budget risks [17], [18].

3.7 Data and Forecasting Ability

One number reveals the impact of the money tracking and vaccine need estimates. If information is flowing clearly, then it is easier to purchase supplies, as well as to handle budgets [19], [27].

Indicators include:

- Forecast accuracy rate.
- Real-time financial tracking systems for access to funds.
- Annual cost-of-immunization analysis.
- Investment in digitized immunization expenditure dashboards.Investment in digital immunization expenditure dashboards.

A number determined by:

$$T = T_1 + T_2 + T_3 + T_4$$

Some tools employ scores of 0-5. If forecasts are incorrect, stocks run low, budgets get over-extended, but planning remains chaotic [19].

3.8 Understanding ERIIS Scores

A score between 0 and 100 indicates a country's ability to withstand financial pressures in its vaccine system. This number can have different meanings depending on its level.

- 0–40: High vulnerability
- 41–70: Moderate resilience
- 71–100: Strong resilience

There are times when some groups indicate weaknesses within policy planning. This will allow decision-makers to focus on what is most vulnerable and needs fixing. To correct those spots, it is sometimes necessary to alter the design of money systems so that they can last longer when put to the test.

4. Data Sources and How We Study Them

4.1 Data Sources Overview

This study combines data from a number of global databases to assess the validity of the Economic Resilience Index for Immunization Systems. The information is primarily drawn from four sources: WHO's records on immunization coverage, country-level financial health reports, World Bank economic data, and funding summaries during the transition between phases of support by Gavi. Together, they provide reliable information on vaccine coverage, allocation of health system expenditures, and significant economic events and funding changes. The index is grounded in real-world evidence as the numbers are based on common standards across countries, enabling comparisons between countries [6], [21], [22], [23].

4.2 WHO Global Vaccination Data

From the WHO Immunization Coverage Database comes vaccination performance information, offering yearly national estimates on routine immunization levels [21], [27], [28]. The key indicators include the proportion of children who receive key vaccines (DTP3, MCV1) and the proportion of children who fail to complete the dose series. The primary measure of change examined is the rates of vaccination from one year to the next. This change reflects the decrease in coverage over time of two years side by side:

$$CoverageDecline_{it} = Coverage_{it} - Coverage_{i(t-1)}$$

Here is the nation, here time. As the numbers get lower than zero, access decreases. Another measure is constructed for studying downturns:

$$ShockCoverageDecline_{i} = Coverage_{pre-shock} - Coverage_{shock}$$

Measures coverage losses in times of economic hardship.

4.3 National Health Accounts

The spending details are derived from National Health Accounts, which describe the flow of money within the various components of the health sector [23]. The government has a role in funding health services, which is one component. Immunisation budgets focus on particular disease prevention activities. There's an additional layer of funds from donors. The fee patients pay themselves is also important. From these numbers, core ERIIS measures take shape - like how much countries fund vaccines themselves, what portion of health budgets go to immunizations, how fully planned budgets get spent, alongside reliance on outside donors. Much of this goes into two aspects of the index, one measuring independence in financial decisions, the other spread among funding sources.

4.4 World Bank economic data

From the World Bank's WDI database, macroeconomic data comes into view [22]. GDP growth is included with inflation, and relative public debt is included as well. They're followed by fiscal gaps to create a broader picture. Such forces flex national resources for vaccines. The form of economies has a profound impact on health budgets. A sudden jolt to the economy can be seen in the numbers in the form of fluctuation in GDP. When significant events affect output, this change is the one that is followed by researchers. They do not guess this figure, but instead they put it into models that account for the effects it will have throughout markets and over time:

$$GDPShock_{it} = GDPGrowth_{it} - GDPGrowth_{i(t-1)}$$

If numbers are negative, then the economy contracts. The price of vaccines has increased over time, which can be partly attributed to rising prices [22], [28], [29].

4.5 Gavi Transition Data

Details from Gavi transition reports [6] begin to emerge of the process of moving from aid funding of vaccines to other models. That is, as time goes on, these documents reveal that immunization expenditures begin to be funded by national budgets, rather than by outside donors. Along with rules on the sharing of funding, donor shift schedules form part of what is studied. Out of this information emerge coded markers indicating exits, foreign funds' erosion rate, and groupings indicating vulnerability during handing over. Those figures provide a glimpse into how well vaccination networks fare when international funds begin to wane.

4.6 Empirical Strategy

The process takes place in three steps, one at a time. Starting, each ERIIS indicator gets normalized then combined, forming scores for individual pillars along with a total index valus. When components need to be checked for a logical fit with each other, techniques such as principal component analysis, confirmatory modeling, and consistency checks are introduced [20], [29], [30]. The next topic is description: the differences in ERIIS results across countries become the main focus here. Finally, statistical regressions examine the strength of the association between ERIIS numbers and real vaccination coverage. The model also connects the dots between the global health metrics and economic trends, providing a straightforward approach to examining the resilience of vaccination programs under financial stress.

5. Econometric Model with Statistical Checks

5.1 Analytical Framework

Researchers used multiple layers of statistical analysis to examine the consistency of the Economic Resilience Index for Immunization Systems in predicting actual results. They not only build the index, but also combine it with economic models to observe the consequences in times of economic hardship. The key is whether countries with higher ERIIS ratings are able to maintain immunisation levels during budget reductions or weak economies. The series of tests was interdependent and dependent on real data patterns. The test of the pressure was not only a theoretical strength, but it is now the test of stability. A good place to begin is to take a look at the strength of the ERIIS index. Researchers use stats to determine whether the pieces fit together in the five broad areas as they expect. Not only that, but they also look to see if each set of measures sticks on its own.

Another element deals with the internal stability of these groups. Then there is the modeling part - weaning the ERIIS findings to real vaccine utilization, using number-based approaches. The degree of connection between the models depends on the output of the models.

5.2 Principal Component Analysis

Principal Component Analysis (PCA) is useful when considering how the ERIIS measures relate to each other because it reduces the data to the main patterns. Before that, each of the variables is standardized using the z-score normalization:

$$Z_i = \frac{X_i - \mu}{\sigma}$$

This is where things begin – the raw score is adjacent to the average, along with the range of the data points. The Kaiser rule says that if an eigenvalue is greater than one, then it persists - let's say that's a bit of a stretch. If the eigenvalue is greater than one, then the signal stays around, according to the Kaiser rule. When these pieces align with the five foundations expected, the confidence in the ERIIS model structure increases [20], [30], [31].

5.3 Confirmatory Factor Analysis

ERIIS consists of five components: Fiscal autonomy, Health economics integration, Procurement efficiency, Funding diversification and Data capacity, which are evaluated with CFA. Observed indicators instead are tested to determine the strength of their association with each underlying construct by that means.

A single measure forms itself like:

$$X_i = \lambda_i F + \epsilon_i$$

Here stands the hidden influence, there the weight it carries, alongside its random fluctuation. To check how well things line up, usual markers come into play - RMSEA under 0.08 does the job, much like CFI above 0.90, similarly TLI past that same mark [20]. When numbers behave this way, the shape of the ERIIS idea holds firm.

5.4 Reliability Testing

The internal consistency of each pillar is assessed by Cronbach's alpha, which is calculated as:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum Var(X_i)}{Var(X_{total})}\right)$$

In the above, k is the number of indicators. An α value ≥ 0.70 is considered acceptable internal consistency.

5.5 Baseline Regression Model

Once the index is validated, the regression analysis is carried out to test the correlation between the change in vaccinations and ERIIS scores. The base model is:

$$CoverageDecline_{it} = \beta_0 + \beta_1 ERIIS_{it} + \beta_2 GDPShock_{it} + \beta_3 Inflation_{it} + \epsilon_{it}$$

where $CoverageDecline_{it}$represents the change in vaccination coverage for country $i$in year t. The coefficient of interest is β_1, expected to be negative, indicating that higher resilience reduces coverage decline during economic shocks.

5.6 Interaction Effects

To check if resilience affects the impact of macroeconomic shocks, the interaction term is added:

$$CoverageDecline_{it} = \beta_0 + \beta_1 ERIIS_{it} + \beta_2 GDPShock_{it} + \beta_3 (ERIIS_{it} \times GDPShock_{it}) + \epsilon_{it}$$

A significant interaction coefficient indicates that stronger resilience mitigates the negative effects of economic shocks on vaccination coverage.

5.7 Fixed Effects Model

To control for unobserved country-specific characteristics, fixed effects models are estimated:

$$CoverageDecline_{it} = \beta_1 ERIIS_{it} + \gamma_i + \delta_t + \epsilon_{it}$$

The model includes country fixed effects, γ, and δ_tyear, which represent fixed effects at the country and t-year level, respectively.

5.8 Robustness Checks

Alternative outcome measures like vaccine stockout frequency and budget deviation rates are included in robustness tests. Other lagged ERIIS values are estimated as well:

$$CoverageDecline_{it} = \beta_1 ERIIS_{i(t-1)} + \beta_2 GDPShock_{it} + \epsilon_{it}$$

Further, instrumental variable models can be used to control for potential endogeneity between the fiscal capacity level and immunization performance.

6. Results and Expected Findings

6.1 Descriptive Analysis of ERIIS Scores

First, let's examine the distribution of ERIIS scores across countries as well as their changes through the years. The figures show that the economic muscle varies between the systems of each country's vaccines. Checking for wealth level, dependency on external funding, or government budget capacity, some patterns emerge. In general, wealthier countries will disproportionately have higher ERIIS outcomes, thanks mainly to stable internal sources of funding, diverse income generation routines via the existence of mature fiscal controls [12], [17], [18], [25]. On the other hand, lower-income countries usually perform poorly on the measure - because of their high reliance on foreign aid, continuing budget planning and procurement process gaps [6], [7], [12], [15]. Variations can come about within even the same economic group, especially where donor support is being phased out.

6.2 Results of the Index Validation

The statistical tests indicate that the ERIIS design is internally consistent. Meanwhile, the Principal Component Analysis should identify the five major components that are most in line with the theoretical framework and explain a large part of the variation in the data points. Confirmatory Factor Analysis, on the other hand, is expected to show strong relationships between items and their factors, while the overall model fit should be acceptable - for instance, RMSEA less than 0.08, CFI greater than 0.90, TLI greater than 0.90. When checking how closely survey items agree, Cronbach's alpha tends to rise beyond 0.70, which signals dependable alignment inside each section. Seen one way, all these clues point toward trusting ERIIS as a steady tool for measuring how tough immunization systems really are [20], [31], [32].

6.3 Regression Results

This regression analysis is all about figuring out the connection between the changes in vaccine uptake and ERIIS ratings. It is assumed that, in case of economic downturn, those countries that are more resilient would, to some extent, keep their vaccination rates unchanged, and the very first model version looks into this concept.

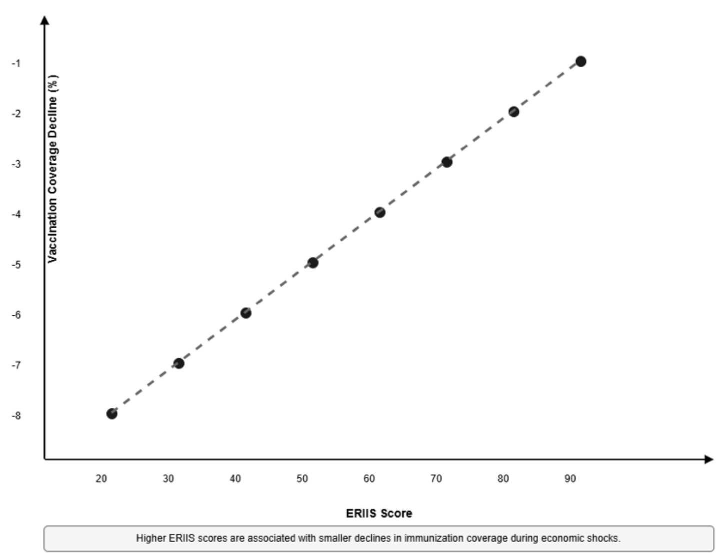

Fig. 2. Relationship between ERIIS scores and immunization coverage decline during economic shocks.

Using data showing genuine patterns, the findings statistically support that falling coverage accompanies higher ERIIS scores. So as ERIIS increases by ten points, the reduction in coverage during the crisis years decreases by approximately three per cent - this is one of the pieces of evidence that the hidden relationship really exists. On the other hand of the coin is that unfavourable economic conditions are experienced in different ways, such as: both decreases in GDP and increases in prices almost always lead to widening the gaps of losses in coverage even further.

6.4 Economic Resilience Shapes Impact
Vaccine access tumbles during financial stress, but a few nations hold steady despite market tremors. Health spending that doesn't crack under pressure can keep immunization lines running smoothly. The way budgets absorb downturns directly affects how many kids get protected. Tracking funding models alongside recessions shows a clear connection between fiscal strength and short delivery. Countries where money flows remain stable see fewer children left behind. Flexible allocations help maintain clinic operations when incomes fall. In practice, smart budgeting prevents sharp drops in outreach. Evidence suggests such systems reduce missed doses [10], [11], [12], [17], [18].

6.5 Comparison of the ERIIS Pillars
At first glance, it's possible to see how each component of ERIIS contributes to the overall functioning of the system. Because individual control over the budget and diversified sources of income serve as safeguards against external monetary disruptions, those two aspects - financial autonomy and wider sources of funding - are probably the ones that are most closely linked to uninterrupted broadcasting [6], [7], [17], [18].

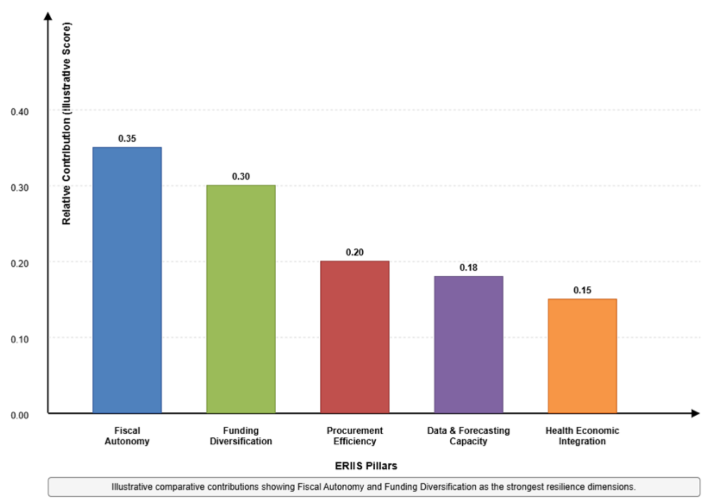

Fig. 3. Relative contribution of ERIIS pillars to immunization system resilience

Facilitating smoother procurement procedures along with enhanced data management can support the delivery of help systems and reveal spending patterns more effectively [15], [19]. Using financial data to guide the decision-making process typically results in allocating resources most effectively [8], [14].

6.6 What the Empirical Results Indicate
The financial backing of a vaccine system is the real determinant of its resilience, as the empirical results point to. As the local budget is increased, the capacity for purchasing supplies is maintained even in the face of economic downturns. Rather than waiting for a delayed response, the officials can identify the clear correlations between a cash flow pattern and the immunization coverage, and they can even decide the weak spots early. The link - given in ERIIS - is what changes the data into a plain, comprehensible form without any additional clutter. In fact, a technique that directly relates budget spending to health outcomes, quietly but forcefully [10], [12], [15], [19].

7. Discussion
A country's financial power affects how reliable its vaccine programs are. Rather than focusing only on price tags or health benefits, this study turns attention to the long-term money structures underneath. The Economic Resilience Index for Immunization Systems brings together spending choices, management abilities, and real-world immunization numbers. While past research celebrated vaccines as low-cost lifesavers, it regularly overlooked what sustains budgets across time [1], [2], [8], [9].

Steady cash means vaccines roll out, no matter how shaky markets get. This matches patterns spotted in clinics everywhere - places that adapt quietly usually push forward when pressure builds [10][11]. Since jabs rely on reliable budgets, smooth delivery routes, and careful planning ahead, holding firm becomes a must. Stability in public health thrives where national budgets take charge. Should funding come mainly from within, vaccination work keeps moving - even when global support drops or money gets tight. This trend repeats itself clearly: heavy reliance on outsiders brings danger, particularly if donor interests shift [6][7]. Outcomes grow more reliable once ministries redirect greater shares of health money into shots. Steady progress hides in how governments choose to spend. Money arriving from various spots helps things stay strong. Should funding shrink, single-source vaccine plans might fail quickly. Local budgets chip in, alongside special taxes, companies joining, and foreign help too - each piece shares the load. This blend? It smooths health costs across years [17][18].

Getting shots counts as much as giving them. If buying takes too long, prices rise slowly, stretching what money is available. Still, when teams work together to place orders, expenses tend to fall while supply holds firm. Imagine how clean paperwork makes a difference - fewer guesses lead to smaller losses. Holding real data helps clinics spot gaps ahead of time and skip unnecessary spending. Out of nowhere, thinking ahead swaps wild stabs for numbers you can count on. This quiet move fills store racks while staying within boundaries. Most noticeable within the ERIIS framework? Consistent immunization hinges less on single factors, more on joined-up funding control, trustworthy agencies, resilient delivery routes, backed by connected information flow. Countries managing these pieces well usually maintain child vaccination - especially during lean financial times. Converting public spending power into measurable ratings brings tangible value to research on health system recovery [10], [11], [12]. Suddenly, richer statistical investigation becomes possible.

8. Policy Implications

Picture a system that reveals cracks in vaccine programs before they fail. This is exactly how ERIIS works - it changes complicated financial facts into simple ratings. Rather than relying on hunches, leaders spot trends using solid data. As funding shrinks or diseases spread, vulnerable areas show up early. Problems appear in plain sight, long before emergencies unfold. Sometimes a nation stays firm while a neighbour stumbles, all due to earlier number checks. When rules change, they move with facts instead of guesses. Little changes pile into strong shields across the years. Nothing mystical - just routine steps taken right. Quiet strength builds where decisions are fed by proof.

It's obvious where things stand: communities need tougher financial backbones. Relying heavily on foreign help weakens resilience - when donations drop, or global markets wobble, damage spreads fast. Turning instead to locally built strategies builds a lasting footing [6], [7], [12], [13]. Income pulled from government health budgets, pooled coverage setups, or targeted taxes brings a more reliable footing [17], [18]. When people stand behind local health work, stability grows. Foreign aid matters less once that shift happens.

Spreading out where funds come from has started drawing interest. If vaccine programs collect support from different sources, setbacks hit less hard. Support could flow regularly through levies on items such as alcohol or tobacco [17][18]. Improving how supplies are bought holds equal importance. Group buying pools, consistent pricing records - these tighten control over costs and keep shipments on time [15][16]. With stronger cost assessment abilities, planners can measure real worth against budget pressure when picking vaccines, sending funds where they deliver the most impact [8][14].

Here’s the kicker - improved data systems lead to more accurate financial predictions, less downtime at medical centres, and reduced shortages in supplies [19], [35], [36], [37]. Since ERIIS tracks progress over time, officials can spot countries facing steep challenges, shaping how support is distributed. If funding frameworks stay weak, maintaining current immunization levels becomes tougher, particularly when global economies shift unpredictably.

9. Limitations

The Economic Resilience Index for Immunization Systems is a helpful tool, but it still has some shortcomings. One aspect that is open to criticism is the way the overall score is calculated, as it relies on choices that may seem a little arbitrary. For instance, the index treats all its five components as equally important, primarily for transparency reasons, so that people can easily understand the process. However, if weights were allocated in different ways - for example, by using data-driven approaches or consulting experts - the resulting measure could be very different.

Besides that, what if you wanted to assess and compare different countries, but some of the required data simply don't exist globally? Financial statements or purchasing data - which are very important pieces for some indicators - are often lacking in low-income areas. In such cases, without direct information, researchers may have to rely on proxy data.

Originally, the model focused more on overall structural financing mechanisms, while major changes in the political environment impacting vaccine funding were somewhat ignored. Afterwards, actual work on ERIIS would consist of piloting it in a number of countries for several years to understand its performance even during economic downturns. On the whole, ERIIS provides a good starting point for measuring the financial robustness of immunization programs.

10. Future Research

One step forward could come from wider trials of the ERIIS framework. Instead of isolated tests, running it across several countries lets researchers compare funding resilience alongside income levels or medical systems. From there, patterns might show which strategies keep financial support steady when challenges arise.

Later on, watching ERIIS numbers shift could expose how hard times affect vaccination choices. Money strain often echoes in who walks into health clinics, especially when outbreaks emerge. A sequence of checks beats one-off data in showing where danger grows as wallets thin. Picture each late bill or lost paycheck nudging someone away from care. These layers help forecasts feel less like guesses, more like reflections. When money gets tight at home, vaccine numbers start to slip. Over months, patterns emerge from repeated surveys showing missed shots piling up. Job loss often leads someone to delay a dose - small choices like these add up across communities. Stress about costs mixes with spotty clinic access, shaky confidence in care, and weak follow-up systems. These combined pressures show up later in outbreak risk maps, highlighting neighbourhoods most vulnerable when times get tough.

Sometimes a fresh approach means tweaking how scores are built, swapping usual math tricks for something like principal component analysis [20], [34], [35], [36]. Not stopping there, tossing in extra layers helps - say, counting nurses or mapping clinic spots, given those steer system strength. Care stays steady not only by budgets or rules, but through bodies on site and locations that serve people. Weighting such factors together paints fuller pictures than numbers alone ever could. Here's something else to consider: what happens to policy when it leans on ERIIS data? Built into national health checkups, the measure could help leaders, along with international partners, see where vaccine money is growing, yet also reveal areas falling behind.

11. Conclusion

Most days, keeping vaccines flowing tests every nation's medical backbone. Shots prevent deaths without draining budgets; still, a lasting shield demands cash flow plus well-built plans. Research tends to praise jabs as wallet-wise moves - rarely asks if supply chains survive lean times [1], [2], [8], [9]. The Economic Resilience Index for Immunization Systems - ERIIS - shows how tough a country's vaccine programs are when money gets tight. Not just one thing matters here; think of it as five threads woven together. Budget control sits at the core, tied closely to wider economic plans. Purchasing works smarter, not harder. Funding comes from more than one place, reducing pressure points. Information flows steadily, feeding accurate updates. Each piece shapes the whole. When seen together, patterns appear - where systems hold firm, where they might bend. Leaders start noticing what holds up under stress, especially when markets wobble or priorities change. This view doesn't shout answers - it reveals them slowly.

Stacking worldwide numbers next to financial audits, watching how cash flow links to consistent vaccine delivery. Not splitting health spending from shot coverage anymore, this setup binds policy dollars directly to actual inoculation rates. Out of that mix comes a clearer image of what truly sustains long-term protection efforts. Most folks just count numbers [32], [33], [34]. Not here. ERIIS gives leaders a clear way to find shaky parts in vaccine funding, then build adjustments that stick around. Picture global funds trembling. Suddenly, how immunization efforts manage their money matters more than ever. Keeping vaccination levels steady means avoiding diseases thought long gone. Stability hides in smart budget moves, not big promises.

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