DTP Coverage

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Part 1 – Identify a Social Problem

1.1 Describe the Social Problem

DTP vaccination protects against diphtheria, tetanus, and pertussis and is one of the most cost-effective public health interventions, preventing an estimated 4.4 million deaths annually (UNICEF, 2024). Despite its inclusion in most national immunization programs, around 21 million children were under- or unvaccinated in 2023, with 14.5 million receiving no vaccines at all (UNICEF, 2024). This gap is most severe in low- and middle-income countries and reflects broader social inequalities in healthcare, education, and infrastructure (Our World in Data, n.d.; UNICEF, 2024).

Low DTP coverage often signals systemic issues such as poverty, conflict, and misinformation, making it a key indicator of healthcare system strength and social equity (UNICEF, 2024).

Research question: How does government healthcare spending per capita correlate with national DTP vaccination coverage across income groups?

1.2 Sources Identifying DTP Vaccination as a Social Problem

WHO and UNICEF warn of rising vaccine-preventable diseases due to declining coverage, misinformation, and funding cuts (WHO Media Team, 2025). DTP-preventable diseases remain deadly, especially in low-resource settings (UNICEF, n.d.). UNICEF data also show high dropout rates in DTP series completion, linked to systemic barriers like poor healthcare access and infrastructure (Wang et al., 2019).

1.3 Research Gap

While DTP coverage has been widely studied, few analyses directly link it to government healthcare spending across income levels. Most research focuses on micro-level factors or broad trends, often overlooking economic policy variables (UNICEF, 2024).

1.4 Contribution of This Report

This report explores the relationship between public healthcare spending and DTP coverage across income groups. It aims to provide insights into whether increased investment leads to better immunization outcomes, informing global health and development policy.

Part 2 - Data Sourcing

2.1 Load in the data

Source 1 (DTP vaccination coverage): https://immunizationdata.who.int/global/wiise-detail-page/diphtheria-tetanus-toxoid-and-pertussis-(dtp)-vaccination-coverage?CODE=AFR+EMR+EUR+AMR+SEAR+WPR&ANTIGEN=&YEAR=

Source 2 (Government healthcare spending): https://www.who.int/data/gho/data/indicators/indicator-details/GHO/current-health-expenditure-(che)-per-capita-in-us-dollar

Source 3 (Child death rates): https://www.who.int/data/gho/data/indicators/indicator-details/GHO/number-of-under-five-deaths

2.2 Provide a short summary of the dataset(s)

```r
head(raw_coverage_data)
```

```
## # A tibble: 6 x 11
##   GROUP       CODE  NAME      YEAR ANTIGEN ANTIGEN_DESCRIPTION COVERAGE_CATEGORY
##   <chr>       <chr> <chr>    <dbl> <chr>   <chr>               <chr>
## 1 WHO_REGIONS AFR   African~  2023 DTPCV3  DTP-containing vac~ WUENIC
## 2 WHO_REGIONS EMR   Eastern~  2023 DTPCV3  DTP-containing vac~ WUENIC
## 3 WHO_REGIONS EUR   Europea~  2023 DTPCV3  DTP-containing vac~ WUENIC
## 4 WHO_REGIONS AMR   Region ~  2023 DTPCV3  DTP-containing vac~ WUENIC
## 5 WHO_REGIONS SEAR  South-E~  2023 DTPCV3  DTP-containing vac~ WUENIC
## 6 WHO_REGIONS AFR   African~  2022 DTPCV3  DTP-containing vac~ WUENIC
## # i 4 more variables: COVERAGE_CATEGORY_DESCRIPTION <chr>, TARGET_NUMBER <dbl>,
## #   DOSES <dbl>, COVERAGE <dbl>
```

```r
head(raw_healthspending_data)
```

```
##                                            Indicator              Location
## 1 Current health expenditure (CHE) per capita in US$              Americas
## 2 Current health expenditure (CHE) per capita in US$                Africa
## 3 Current health expenditure (CHE) per capita in US$       Western Pacific
## 4 Current health expenditure (CHE) per capita in US$       South-East Asia
## 5 Current health expenditure (CHE) per capita in US$                Europe
## 6 Current health expenditure (CHE) per capita in US$ Eastern Mediterranean
##   Period   Value
## 1   2022 1256.40
## 2   2022  132.58
## 3   2022 1363.92
## 4   2022  240.99
```

```
## 5   2022 2937.83
## 6   2022  544.24
```

Source 1: DTP Vaccination Coverage

- **Credibility:** Published by WHO/UNICEF (WUENIC), the leading global authority on immunization data (World Health Organization, 2024).
- **Data Quality:** Combines administrative records, surveys, and expert review, enhancing reliability.
- **Relevance:** Provides DTP3 coverage rates by region and year—central to the research question.

Source 2: Government Healthcare Spending

- **Credibility:** Provided by the World Bank, using WHO's Global Health Expenditure Database (World Bank, 2024).
- **Data Quality:** Based on standardized, internationally accepted methods; updated annually.
- **Relevance:** Supplies the key independent variable—health spending per capita—for correlation analysis.

Source 3: Child Death Rates

- **Credibility:** From WHO's Global Health Observatory, a trusted source for global health statistics (World Health Organization, 2024).
- **Data Quality:** Derived from national systems, surveys, and statistical modeling.
- **Relevance:** Offers contextual insight into the broader social impact of vaccination and healthcare investment.

2.2.1 Complementarity of the Datasets

These datasets are complementary in structure and purpose:
- **DTP dataset**: Provides the **dependent variable** (vaccination coverage)
- **Health spending dataset**: Provides the **independent variable** (government health expenditure per capita)
- **Child death dataset**: Provides the **independent variable** (child mortality)

Together, they support cross-country analysis of how public investment and child mortality relate to immunization outcomes.

2.2.2 Suitability for the Research Topic

The research question explores the link between healthcare spending and DTP coverage across income groups. These datasets are suitable because:
- **Comprehensive and global**: Enable cross-country comparisons
- **Updated annually**: Support time-series and cross-sectional analysis
- **Standardized and well-documented**: Ensure data quality and reproducibility

2.2.3 Data Limitations

Despite their strengths, the datasets have some limitations:

WHO DTP Coverage & Child Death Data
- Missing or estimated values in conflict-affected countries

- Potential reporting bias and survey recall errors
- Limited insight into subnational disparities

World Bank Health Spending
- Reported in current USD, affected by inflation and exchange rates
- No detail on spending allocation (e.g., immunization vs. other services)
- Some countries have incomplete or outdated records

These limitations mean the analysis shows correlations, not causation, and may not capture all contextual factors.

2.3 Describe the type of variables included

WHO DTP Vaccination Coverage
- **Antigen**: DTP1, DTP3
- **Coverage**: % of vaccinated target population
- **Target Pop.**: Eligible population for vaccine
- **Years**: 1980–2023
- **Region**: WHO regions
- **Frequency**: Annual
- **Source**: WHO/UNICEF Joint Reporting, DHS, MICS
- **Method**: Admin data + surveys + expert review

World Bank Health Spending
- **Indicator**: Health expenditure per capita (USD)
- **Years**: 2000–2023
- **Region**: WHO regions
- **Frequency**: Annual
- **Source**: WHO Global Health Expenditure Database

WHO Child Deaths (Under 5)
- **Indicator**: Under-five mortality rate
- **Target Pop.**: Children aged 0–4
- **Years**: 1980–2023
- **Region**: WHO regions
- **Frequency**: Annual
- **Source**: WHO/UNICEF GHO, CRVS, DHS, MICS
- **Method**: National data + statistical adjustments + expert review

Part 3 - Quantifying

3.1 Data cleaning

3.1.1 Health Spending Data

Selected and renamed relevant columns; ensured `Year` and `Spending` were numeric for time-based analysis. This aligned the dataset with DTP data using `Region` and `Year`.

3.1.2 DTP Vaccination Coverage Data

Filtered for WHO regions and WUENIC estimates. Created `PeriodGroup` to group years into intervals for clearer trend analysis.

3.1.3 Child Mortality Data

Selected and renamed key columns; converted values to numeric. Prepared for merging on `Region` and `Year`.

3.1.4 Trade-offs

- Aggregating into 5-year periods reduces detail but clarifies trends
- Averages may mask outliers or skewed data

3.1.5 Error Handling and Fixes

- **Missing values**: Removed using `na.omit()` or `filter(!is.na(...))`
- **Non-numeric values**: Converted with `as.numeric()`
- **Inconsistent region names**: Standardized for merging
- **Data alignment**: Ensured consistent time format and regional aggregation

3.2 Generate necessary variables

To analyze trends, we created a `Period` variable to group years into 5-year intervals, enabling comparison of averages across consistent time blocks.

3.2.1 Average Health Spending

- **Variables**: `Spending`, `Region`, `Period`
- **Purpose**: Calculate average spending per region/period
- **Use**: Highlight investment trends
- **Analysis**: Compare across time and regions

3.2.2 Average DTP Coverage

- **Variables**: `Coverage`, `Region`, `PeriodGroup`
- **Purpose**: Compute average DTP coverage
- **Use**: Assess immunization performance
- **Analysis**: Track trends, link to outcomes

3.2.3 Average Child Mortality

- **Variables**: `Deaths`, `Region`, `Period`
- **Purpose**: Calculate average child deaths
- **Use**: Measure health outcomes
- **Analysis**: Identify trends, explore correlations

These transformations support cross-regional and temporal comparisons of health spending, vaccination coverage, and child mortality.

3.3 merge datasets together

3.3.1 Rationale for Merging Datasets

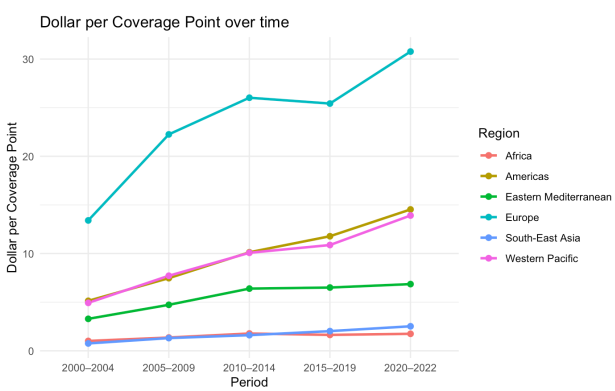
Merging the DTP coverage, health spending, and child mortality datasets enables a comprehensive analysis of global health system performance. Aligning by `Region` and `Period` allows exploration of relationships between investment, service delivery, and outcomes. Key derived indicators:
- **Coverage per dollar spent**
- **Cost per coverage point**
- **Child deaths per dollar spent**

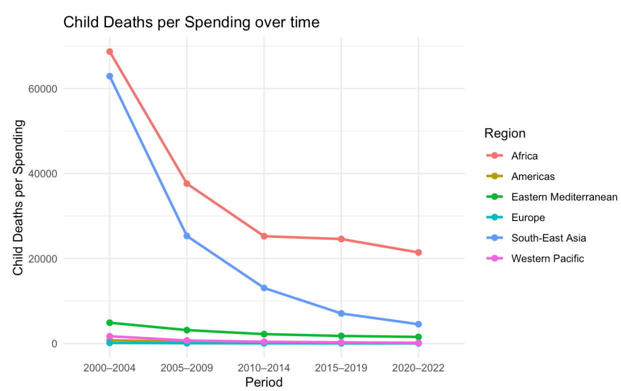
These metrics help assess health system efficiency across WHO regions over time.

3.3.2 Critique and Suggestions for Refinement

- **Period Grouping**: Replace repeated `case_when()` with a reusable function
- **Missing Data**: Consider imputation or flagging missing values before merging
- **Join Strategy**: Use `left_join` or `full_join` to retain more data and allow sensitivity analysis

3.4 Visualization





3.4.1 Temporal Trends in Health Investment and Outcomes

These two line graphs visualize how healthcare efficiency and outcomes have evolved across WHO regions over five-year periods from 2000 to 2022. They align closely with the research question by showing how healthcare spending relates to vaccination coverage and child mortality over time.

3.4.2 Graph 1: Dollar per Coverage Point over Time

- **What it shows**: The average cost (in USD) required to increase DTP3 vaccination coverage by one percentage point.
- **Trend**: Most regions show a relatively stable or slightly increasing cost over time.
- **Notable pattern**: The Western Pacific region shows a significant increase in cost per coverage point in recent years, suggesting rising marginal costs or reduced efficiency.
- **Interpretation**: While some regions maintain cost-effectiveness, others may be facing diminishing returns on investment in immunization programs.

3.4.3 Graph 2: Child Deaths per Spending over Time

- **What it shows**: The number of child deaths per unit of healthcare spending.
- **Trend**: A clear downward trend across all regions, indicating improved outcomes per dollar spent.
- **Notable pattern**: Africa and Europe show the most significant declines, suggesting major gains in healthcare efficiency or effectiveness.
- **Interpretation**: This trend reflects global progress in reducing child mortality, likely due to better-targeted spending, improved healthcare delivery, and expanded immunization coverage.

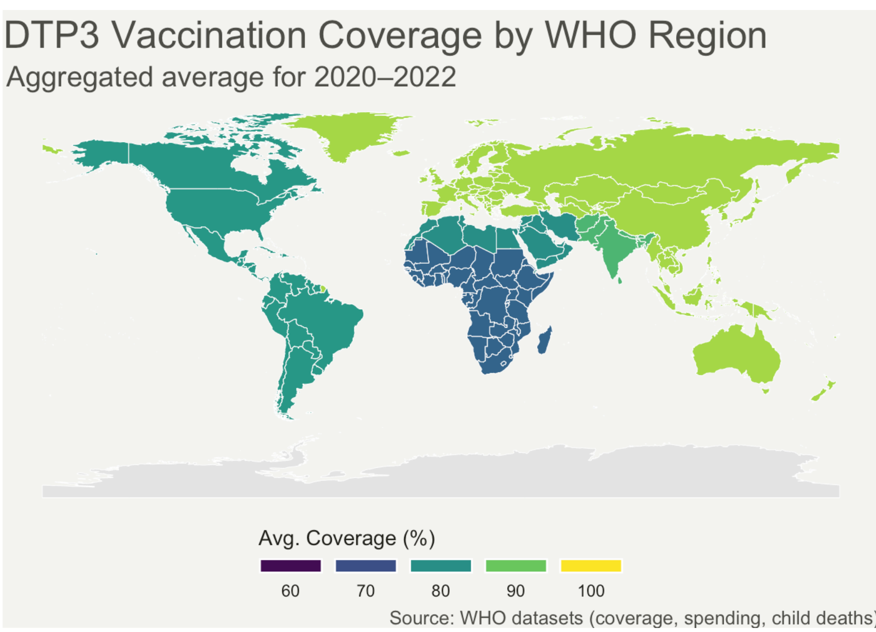
3.4.4 Comparison and Dynamics

- **Efficiency vs. Outcome**: While the cost of achieving additional vaccination coverage is rising or stabilizing, the impact of spending on reducing child deaths is improving.
- **Temporal Insight**: These trends highlight the evolving dynamics of global health investment—where spending may be increasing, but so is its effectiveness in saving lives.

3.4.5 Implications

- Policymakers should consider both cost and outcome metrics when evaluating healthcare strategies.
- The rising cost per coverage point in some regions may call for more efficient delivery models or targeted interventions.
- The declining child deaths per spending metric is a positive signal of global health progress and a justification for continued investment.

3.5 Visualize spatial variation



3.5.1 Spatial Analysis of DTP3 Vaccination Coverage (2020–2022)

This world map visualizes average DTP3 vaccination coverage by WHO region from 2020 to 2022, using a color gradient from purple (60%) to yellow (100%). The map reveals clear regional disparities: high-income regions such as Europe and the Western Pacific generally exhibit higher coverage (light green to yellow), while lower-income regions like Africa and parts of the Eastern Mediterranean show lower coverage (purple to blue).

3.5.2 Spatial Anomalies and Regional Comparisons

Notably, some middle-income regions, such as parts of South-East Asia, achieve relatively high coverage despite lower spending levels, suggesting efficient immunization programs. Conversely, certain countries in the Americas show unexpectedly moderate coverage despite higher average spending, indicating potential inefficiencies or access barriers.

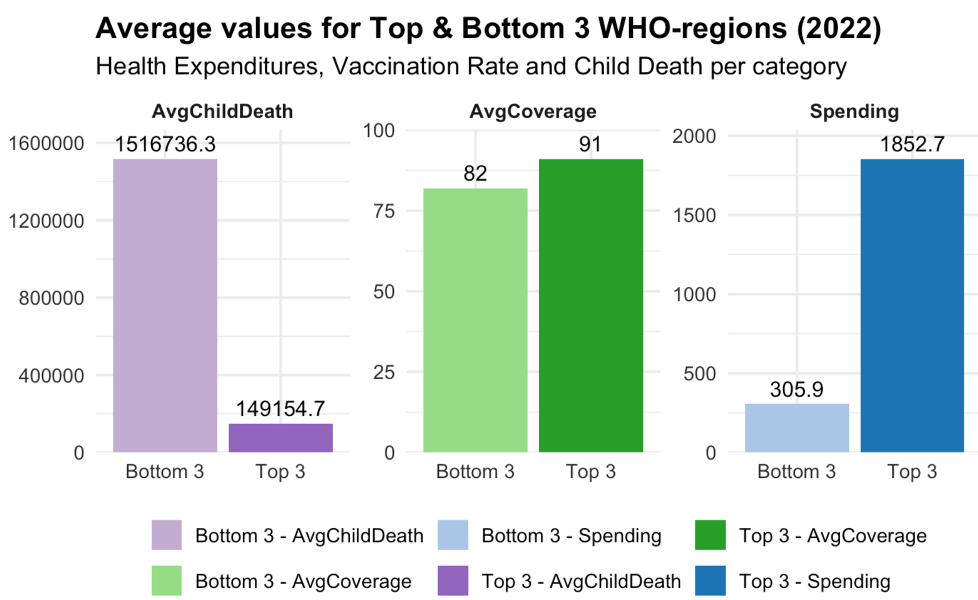
3.5.3 Interpretation and Mapping Critique

The map effectively communicates broad regional trends but may obscure within-region variation due to aggregation. For example, large countries with internal disparities (e.g., India, Brazil) are represented by a single color, which may oversimplify complex national dynamics. Additionally, the use of discrete color bands may exaggerate differences between countries near category thresholds.

3.5.4 Mapping Choices

While the color scheme is intuitive and accessible, a continuous gradient or country-level granularity could enhance interpretability. Including data labels or interactive elements (in a web-based version) would further support detailed analysis. Despite these limitations, the map serves as a compelling visual summary of global immunization equity and supports the research question by highlighting spatial patterns in vaccination coverage relative to regional healthcare investment.

3.6 Visualize sub-population variation



3.6.1 Subgroup Analysis: Top vs Bottom 3 WHO Regions (2022)

This bar chart compares the top 3 and bottom 3 WHO regions based on average healthcare spending per capita in 2022. It visualizes three key metrics: **- Average Health Spending (USD per capita) - Average DTP3 Vaccination Coverage (%) - Average Child Deaths**

3.6.2 Alignment with Research Topic

This visualization directly supports the research question by dividing regions into high- and low-spending groups, the plot highlights how investment levels relate to health outcomes across sub-populations.

3.6.3 Group Differences (Quantified)

Metric	Top 3 Regions	Bottom 3 Regions	Difference
Spending	\$1852.7	\$305.9	+\$1546.8
Coverage	91%	82%	+9%
Child Deaths	149,154.7	1,516,736.3	−1,367,581.6

- Top 3 regions spend over **6 times more** per capita on healthcare.
- They achieve **9 percentage points higher** vaccination coverage.
- They experience nearly **10 times fewer** child deaths.

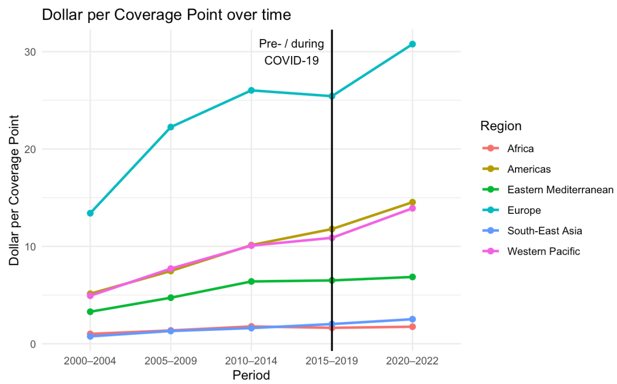
3.6.4 Evaluation of Subgroup Analysis

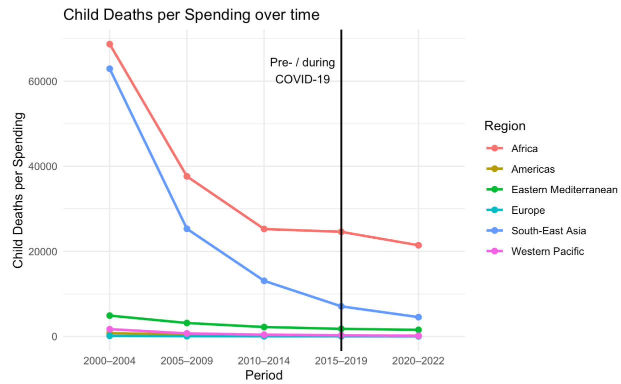
This subgroup comparison reveals a clear gradient: higher spending is associated with better vaccination outcomes and significantly lower child mortality. The differences are not only statistically meaningful but also socially and ethically significant, especially in the context of global health equity.

3.6.5 Implications

- **Policy Insight**: The data suggests that increasing healthcare investment in underfunded regions could substantially improve immunization coverage and reduce child mortality.
- **Equity Concern**: The stark contrast in child death rates underscores the urgent need for targeted support in low-spending regions.
- **Further Research**: This analysis invites deeper exploration into how efficiently funds are used and what other systemic factors (e.g., governance, infrastructure) influence outcomes.

3.7 Event analysis





Applying the findings related to the correlation between government healthcare spending per capita and national vaccination coverage rates worldwide, we can analyse a critical event period from 2020 to 2022 which relates to the COVID-19 pandemic. Unlike earlier gradual reforms such as GAVI's 2011-2015 financing activities (Phase 3 (2011–2015), 2025), the pandemic created an acute simultaneous shock to every healthcare system worldwide. This situation enables a unique opportunity to examine how external crises affect healthcare spending and vaccination coverage rates worldwide.

During COVID-19 routine immunizations were suspended or decreased as healthcare systems focused on pandemic response, meaning coverage declined regardless of funding. (Abad-Vergara, 2020).

Due to global lockdowns and border restrictions another major disruption was on the supply chain, as the struggle to transport vaccinations across borders and maintain cold storage systems increased, leading to decreased vaccination availability. Increasingly relevant to this study, a decrease in 7.7% DTP3 vaccine coverage worldwide was recognized compared to expected doses delivered in the absence of COVID (Causey & et., 2021).

The child deaths per spending data reveals a steady improvement pre COVID-19, but stagnation set during the pandemic in some regions. African regions kept stable child deaths per spending through the pandemic, suggesting resilience strategies such as community health worker programs which focused on under-five care while more formal health systems were focused on COVID related health issues. These systems, despite staffing shortages and movement restriction, prevented many children' deaths. (VanderZanden & et., 2024) However, the data might overstate these results as increased child mortality due to COVID-related health issues complicate the interpretation of spending efficiency.

The global coverage map reveals sharp regional disparities during 2020-2022, ranging from 60% to close to 100%. Underscoring, the disparity of pre-existing health care systems' resilience and adaptive mechanisms. Childhood vaccines declines were more prominent in low and lower-middle income countries (Lai & et., 2023), reaffirming that more developed countries with better resourced health systems managed to sustain coverage more effectively under strain.

Subpopulation comparisons show African regions maintained a 82% coverage during the pandemic while top performing regions achieved 91%. This supports the argument that stronger systems, such as the ones in Europe, were better equipped to mitigate coverage maintenance challenges.

Finally, the dollar per coverage point data shows a sudden spike in costs, which suggests that it became much more expensive to maintain coverage during the pandemic. Disrupted supply chains and service suspensions meant fewer doses were delivered while, while fixed costs such as cold chains remained. This then significantly increased the per-point cost.

3.7.1 Interpretation and Relevance

The data reveals a relationship between healthcare spending and improved vaccination coverage, which broke down during COVID-19. The sharp decline of cost-efficiency, highlighted the vulnerability of highly bureaucratic, centralized systems. Meanwhile, low-income regions maintained results through crisis proof, community-based delivery models. Though causality is inferred rather than proven, the timing supports a strong link. These findings stress that adaptability, not just funding, is crucial for sustaining vaccination efforts during systemic shocks.

Part 4 - Discussion

Over the course of the analysis linking vaccination coverage trends to COVID-19, strong temporal evidence has emerged, suggesting a causal relationship rather than a coincidental one. This challenges theories of stable, linear relationships between government healthcare spending and vaccination coverages. Three key insights are identified:

Crisis-state exception: Traditional vaccination coverage models operate assume stability and predictability, yet COVID-19 expose that without dynamic frameworks addressing both normal and crisis-states, systems can collapse under acute pressure.

System resilience hierarchy: A new hierarchy of system resilience emerged, slicing through traditional income classifications. Community-based delivery systems such as the ones in Rwanda and Bangladesh (Van der Zanden & et., 2024) outperformed more institutionalized systems in wealthier nations. This reveals the vulnerability that comes with highly institutionalized systems during crisis.

Resource Mobilization Capacity: The cost spike due to supply chain disruptions underscores the need for rapid, flexible spending responses. Echoing Keynes' view, static spending-outcome models are insufficient in volatile contexts.

A core takeaway is that resilient delivery systems are key to react to sudden disruptions. The superior performance of community-based systems suggests that advanced economies should explore more decentralized, locally-controlled mechanisms to maintain healthcare standards during major events.

Moreover, the shortcomings of highly complex systems could direct policy makers to evaluate the efficiency of complex and integrated systems during crises. The varied regional responses to the pandemic era disclose poor international coordination, with each region managing responses independently. Advocating once more for more flexible, decentralized international response frameworks.

4.1 Discuss our findings

Our most significant finding is that complex, well-funded healthcare systems experienced the greatest efficiency losses during the pandemic, whereas simpler, less-funded systems proved resilience. Europe maintained >90% coverage but had dramatic cost increases from $25 to $31 per coverage point during COVID. On the other hand, African regions maintained stable child deaths per spending ratios despite having the lowest spending levels.

Traditional income classifications were deemed flawed to predict pandemic resilience. In turn, system design characteristics such as degree of centralization and institutional complexity became the main differentiator between regions' adaptability to disruptions. Community-based systems' adaptive capacity prevailed over highly institutionalized systems' tendency to create multiple failure points, requiring major resource mobilization.

The findings of this study challenge core health economics assumptions and suggests the need for dynamic models, capable to adapt to stable and unstable environments. For policy implementation, the superior performance of community-based systems drags the topic of pandemic preparedness to a more decentralized approach.

Part 5 - Reproducibility

5.1 Github repository link

Provide the link to your PUBLIC repository here: https://github.com/Quinn2861921/Vaccinations-DTP

5.2 Reference list

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