Master's Thesis of Public Health

Impact of Health Workforce Availability on Infant Vaccine Dropout Rate in Sub-Saharan African Countries

- A Panel Data Analysis –

보건의료인력 수급 현황이 사하라이남 아프리카 국가들의
영·유아 백신 접종 중도탈락률에 미치는 영향:
패널 데이터 분석

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Abstract

Impact of Health Workforce Availability on Infant Vaccine Dropout Rate in Sub-Sharan African Countries

-A Panel Analysis-

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Background: Vaccines are the most cost-effective public health intervention for preventing infectious diseases (Ehreth, 2003). Infant immunization, in particular, is an effective method to decrease morbidity and mortality caused by infectious diseases throughout one's lifetime (Brownson et, al. 2003). Timely vaccination since birth can help infants' immune systems to fight infectious diseases effectively and ultimately protect them from harmful diseases. However, despite years of global efforts to immunize children, many children in sub-Saharan African countries remain undervaccinated. Infant vaccine dropout rate, in particular, is significantly higher in sub-Saharan Africa than that of other regions So far, studies on factors related to the high infant dropout rate in sub-Saharan African countries are concentrated merely on individual socioeconomic factors and not on the countries' health systems.

Among the six WHO health system building blocks, key input components of an intervention (vaccination in this case) are 'financing' and 'health workforce'. Since most of the sub-Saharan African countries are financially supported by UNICEF and Gavi, and the essential vaccines are provided at low-cost, the study focuses on the role of 'health workforce' as it is directly related to vaccine administration and service delivery. Moreover, although it is well-known that there is a shortage of health workforce in sub-Saharan African countries, there has been no study on the effect of health workforce availability on infant vaccine dropout rate. Hence, this study aims to investigate the impact of health workforce availability on infant vaccine dropout rate in sub-Saharan African countries.

Methodology: The working definition of 'health workforce' in this paper is people who deliver and assist in the delivery of childhood vaccines. These include medical professionals who are licensed to administer vaccines such as physicians, nurses and midwives who directly assist this process. Descriptive statistics and time trend graphs were drawn to find out the general trends of all variables. Fixed-effects panel regression analysis was then conducted to examine the relationship between health workforce availability and infant vaccine dropout rates from 46 sub-Saharan African countries from 2000 to 2019. Two dependent variables: DTP1-DTP3 dropout rate and DTP1-MCV1 dropout rate were selected to represent infant vaccine dropout rate. Total number of physicians, nurses and midwives was selected to represent the total health workforce as the explanatory variable.

Results: Descriptive statistics show that over twenty years (2000-2019), number of physicians per 1,000 people has remained very low in 37 Gavi-supported countries whilst these numbers have significantly increased in 9 non-Gavi-supported countries. Similarly, fairly minimal increase in number of nurses and midwives per 1,000 people was shown in Gavi-supported countries. Number of nurses and midwives decreased over the twenty years in non-Gavi-supported countries. Both DTP1-DTP3 dropout rate and DTP1-MCV1 dropout rate showed a general decline over time. Analysis from fixed-effects panel regression analysis shows that health workforce does have a significant impact on DTP1-DTP3 dropout rate, even though its impact is minimal. However, the same statistical significance could not be seen in DTP1-MCV1 dropout rate.

Conclusion: The results of this study reveal that health workforce, and control of corruption have a moderate impact, on DTP1-DTP3 dropout rate. With a 1% increase in Health workforce, there was a 0.007% decrease in DTP1-DTP3 dropout rate. Regarding control variables, current health expenditure per capita, Gavi disbursements, and control of corruption had significant relationship with DTP1-

DTP3 dropout rate. With 1% increase in current health expenditure per capita there was a 0.045% decrease in DTP1-DTP3 dropout rate (robust standard error= 2.132, p-value<0.05) and with 1% increase in Gavi disbursements there was a 0.009% decrease in DTP1-DTP3 dropout rate (robust standard error= 0.467, p-value<0.05). Finally, with 1% increase in control of corruption there was a 0.032% decrease in DTP1-DTP3 dropout rate. This study suggests that health workforce availability is one of many factors that can foster delivery effectiveness in sub-Saharan African countries. Since DTP1-DTP3 dropout rate is considered to be a better measure of delivery effectiveness, and DTP1-MCV1 dropout rate a better measure of programme effectiveness, our results reveal that health worker availability is more directly related to delivery effectiveness. Nevertheless, there could be omitted-variable bias, meaning that it could have left out relevant factors related to both DTP1-DTP3 and DTP1-MCV1 dropout rate.

All in all, findings from this study reveal the urgent need to invest in health workforce as well as policies and strategies to maintain and scale up health workforce capacity in sub-Saharan Africa. One could suggest establishing measures such as increased salary or provision of incentives, improved working conditions as well as long-term strategies to ensure that medical personnel continue to stay in the medical field. This study is significant in that it has examined the relationship between health workforce availability and infant vaccine dropout rate in sub-Sahara African countries using panel data for the first time.

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Keywords: Health workforce, Infant vaccine, Dropout rate, Health Systems Strengthening (HSS), Sub-Saharan Africa, Panel data analysis

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List of Abbreviations

AFR	African Region
AMR	Region of the Americas
AMREF	African Medical and Research Foundation
BCG	Bacillus calmette-guérin vaccine
CDVC	Care Delivery Value Chain
CHE	Current Health Expenditure
DHS	Demographic and Health Surveys
DTP1	Diphtheria, Tetanus, Pertussis containing vaccine first-dose
DTP3	Diphtheria, Tetanus, Pertussis containing vaccine third dose
EMR	Eastern Mediterranean Region
EUR	European Region
Gavi	Global Alliance for Vaccines and Immunization
GDP	Gross Domestic Product
HepB3	Hepatitis B vaccine
Hib3	Haemophilus influenzae type b vaccine
HRH	Human Resources for Health
HSS	Health Systems Strengthening
RCV	Rubella containing vaccine
RotaC	Rotavirus vaccine
SDH	Social Determinants of Health
SDG	Sustainable Development Goals
SEAR	South-East Asian Region
LLDC	Landlocked Developing Countries
LMICs	Low- and middle-income countries
MCV1	Measles-containing vaccine first-dose
MCV2	Measles-containing vaccine second dose
MOV	Missed Opportunities for Vaccination
ODA	Official Development Assistance
OOPE	Out-of-pocket expenditure
PCV3	Pneumococcal conjugate vaccine
Pol3	Polio vaccine
PHC	Primary Health Care
UN	United Nations
UHC	Universal Health Coverage
UNICEF	United Nations Children’s Fund
WHO	World Health Organization
WPR	Western Pacific Region

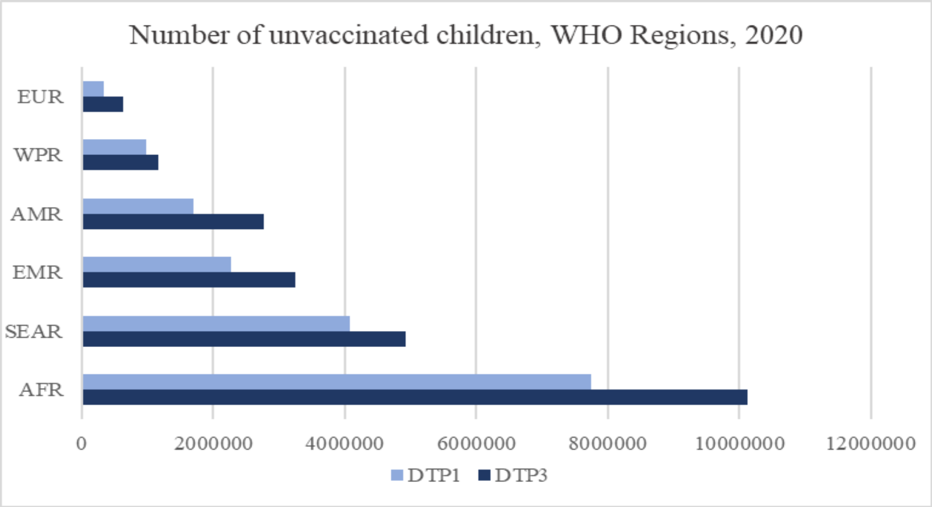
Chapter 1. Introduction

1.1. Study Background

Every year, vaccines prevent an estimated 4 to 5 million deaths in all age groups, and of those, 2.5 million are children (WHO, 2019). Needless to say, vaccines have the potential to significantly reduce infant and child mortality risks and are highly effective against main causes of childhood mortality such as malaria, pneumonia, and diarrhea (Arsenault et al. 2017). Furthermore, vaccination is known to be the most cost-effective way to save lives and protect children from various diseases. Nevertheless, a large number of children still do not receive the basic infant and childhood vaccines that have been developed many years ago (2017). Despite some progress, grave inequalities remain in vaccination coverage within and between countries, especially in Sub-Saharan Africa (Bobo et al., 2022).

As shown in Figure 1., more than 40 percent of the world's unvaccinated children are in the African Region. Moreover, the gap between children who have not had the first dose of Diphtheria Tetanus and Pertussis (DTP) vaccine and the third dose of DTP vaccine is the widest in the African Region. This gap indicates that a significant number of children in the African Region have not completed the 3-dose series of DTP.

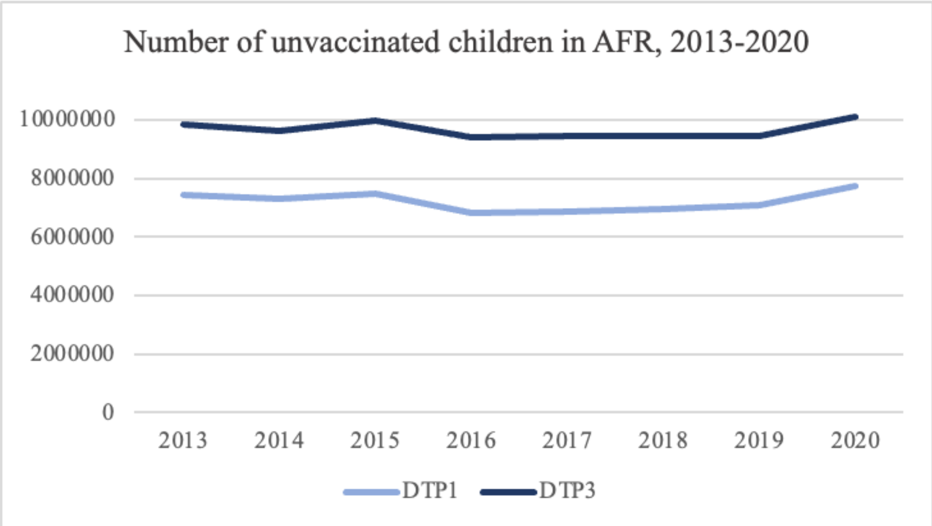
Figure 1. Number of unvaccinated children in 2020, WHO Regions



Source: original data from UNICEF Immunization dashboard, reorganized by author

UNICEF has revealed that globally, as of 2018, more than 5 million infants are not completing the entirety of their vaccine doses after starting their vaccination schedule, exposing them to a higher risk of preventable diseases (Diallo et al. 2019). Figure 2. shows the total number of unvaccinated children in the WHO African Region from years 2013 to 2020. For seven years, approximately 2.4 million children have received the first dose of DTP vaccine but not the third dose of DTP vaccine. This indicates that despite the efforts to reach 'undervaccinated' children, significant number of children still have not been fully vaccinated. The gap between the two lines shows the number of children who have had the first dose but not the third dose of DTP vaccine. Although the total number of unvaccinated children showed slight decrease in 2016, by 2020, this number has increased, presumably due to the COVID-19 pandemic. There is evidence that the pandemic dealt a serious setback to world-wide efforts to immunize children against diseases such as measles and polio (Oduwole, 2022). Consequently, there is an urgent need to monitor and evaluate current program and delivery effectiveness, as well as detect barriers to immunization and suggest potential solutions to reach undervaccinated children.

Figure 2. Number of unvaccinated children in WHO African Region from 2013 to 2020



Source: Original data from UNICEF Immunization dashboard, reorganized by author

The core reason behind numerous undervaccinated children in the African Region is due to lack of continuity within the health systems, and its ability to follow up with patients. Among various obstacles, lack of health workers in Africa has always been the crux of the matter. According to WHO, it is estimated that merely 1.3 percent of the world's trained healthcare workers are in sub-Saharan Africa despite having approximately a quarter of the world's illness burden (WHO, 2022). Yet, to have a well-functioning health system to attain Universal Health Coverage (UHC), there must be sufficient availability of trained, well-equipped, and sufficiently supported health workforce. Despite the vital role of health workers in health service delivery, they have been deprioritized historically in discussions on strengthening the health system (AMREF, 2022). Moreover, the availability of health workforce in Africa is much worse than in other regions, and these shortages are likely to be due to lack of planning, underinvestment in healthcare education and poor training institutions, unsatisfactory working conditions, and insufficient career opportunities. Adding on, professional concentration in urban areas have intensified due to labor market expansions and phenomenon such as international migration to wealthier countries, also known as 'brain drain', have accelerated (2022).

1.2. Research Objectives

The working definition of 'health workforce' in this paper is people who deliver and assist in the delivery of childhood vaccines. These include medical professionals who are licensed to administer vaccines such as physicians, nurses and those who directly assist this process such as enrolled midwives.

The main objective of this study is to examine the relationship between infant vaccine dropout rate and health workforce availability in sub-Saharan African countries. In other words, this study aims to answer the following question: Is health workforce availability associated with infant vaccine dropout rates in Sub-Saharan African countries? Assuming that health worker unavailability is the core problem to a country's weak health system, increase in health worker should show decrease in infant vaccine dropout rate.

The study employs DTP1-DTP3 and DTP1-MCV1 dropout rates to capture infant vaccine dropout rates, as DTP vaccine is one of the most universally present vaccines in all national immunization programmes. Moreover, the study employs total number of physicians per 1,000 people, and nurses and midwives per 1,000 people to capture the countries' health workforce availability.

The study aims to first identify the trend of DTP1-DTP3 and DTP1-MCV1 dropout rates, as well as the trend of total number of physicians per 1,000 people, and nurses and midwives per 1,000 people in sub-Saharan African countries over time. Then, the study aims to investigate the effect of health workforce availability on DTP1-DTP3 and DTP1-MCV1 dropout rates in sub-Saharan African countries. Findings from this study hope to contribute to policy evidence to support policy prioritization and reinstate the vital role of HRH among the health system pillars.

Chapter 2. Literature Review

2.1. Definition of Main Concepts

Childhood vaccination

The recommended childhood vaccines listed by WHO includes Bacillus calmette-Guérin vaccine (BCG) and Hepatitis B vaccine (HepB3) as soon as possible after birth, polio vaccine (Pol3), Diphtheria, Tetanus, Pertussis containing vaccine (DTP3), Haemophilus influenzae type b (Hib3), Pneumococcal Conjugate vaccine (PCV3) and Rotavirus vaccines (RotaC) at 6 weeks of age, and Measles containing vaccine (MCV) and rubella containing vaccine (RCV) at 9 months of age (WHO, 2022). Human papillomavirus (HPV) vaccine is recommended from 9 years of age for females only. These ten vaccines are recommended for all infants and children, whilst there are additional vaccines for children residing in particular regions or for children in some high-risk populations such as vaccines for yellow fever or cholera (WHO, 2022).

(View Appendix A for Summary of WHO's Recommended Routine Immunizations for Children)

Undervaccinated Children

The term undervaccinated defines children who have been vaccinated previously but have not completed the remaining required doses of specific vaccines. Terminologies such as ‘incomplete’ or ‘partial’ vaccination reflect these undervaccinated children. Meanwhile, the concept of ‘unvaccinated children’ is more straightforward, indicating children who have never been vaccinated. The term ‘zero-dose children’ is often used interchangeably with the term ‘unvaccinated’ children (Cata-Preta et al., 2021).

DTP1-DTP3 and DTP1-MCV1 Dropout

The ‘Diphtheria, Tetanus, Pertussis’ (DTP) containing vaccine is one of the few vaccines commonly present in all national vaccination schedules for infants under 1 year of age (Diallo et al., 2019). Dropout between DTP1 and DTP3 is the proportion of surviving infants that received the first dose of DTP but not the required remaining doses.

Recommended age of 1st dose of DTP vaccine is at 6weeks, and interval between 1st dose to 2nd dose and 3rd dose is between 4 to 8 weeks. Meanwhile, recommended age of 1st dose of MCV vaccine is at 9 or 12 months, and interval between 1st dose to 2nd dose of MCV is 4 weeks.

The measurement of the gap between DTP1 and DTP3 reflects continuity within a health system, including the system’s ability to follow up with patients. Meanwhile, Global Vaccine Action Plan (GVAP) used the indicator ‘DTP1 to first dose of measles-containing vaccine dropout rate’ (DTP1-MCV1). DTP1-MCV1 dropout rate is preferred over DTP1-DTP3 dropout rate, as it measures dropout over a longer time interval between doses. Moreover, according to the *Letter from GAVI CSO Constituency*, whilst DTP1-MCV1 can be a better indicator of program effectiveness, DTP1-DTP3 is thought to be a better indicator of delivery effectiveness (*Letter from GAVI CSO Constituency*, 2012).

The *Letter from GAVI CSO Constituency* further suggests that DTP1-MCV1 dropout rate is an advantageous indicator over DTP1-DTP3 as measles is the final antigen in the infant vaccination schedule of many countries. The letter also mentions that introducing a measles-related indicator to GVAP monitoring would be useful in spanning the GVAP goals of disease elimination (2012).

Although DTP1-MCV1 dropout rate can be useful as it measures dropout over a longer time interval between doses, there are few issues to take into consideration. The *Letter from GAVI CSO Constituency* suggests possible problems regarding using this indicator (2012). First, there could be more demand for measles vaccine than DTP as measles is more feared in communities. Moreover, the letter suggests that the dropout rate of DTP1-MCV1 may be artificially low since it is easier to achieve single dose compared to triple dose coverage (2012). It is also mentioned that there can be negative dropout rates because of the different service delivery strategies. Other issue has been suggested by Abhay regarding the use of DTP1-MCV1 dropout rate by GVAP (2015). Abhay mentions the possibility of taking data pertaining to measles coverage when the measles vaccine itself was unavailable.

Health Workforce

Health systems can only operate with health workers; improving health service coverage and being able to acquire the highest attainable standard of health is dependent on the "availability, accessibility, acceptability," and skill level of healthcare workers (WHO, 2022). It is well documented that health workers have a significant influence on the vaccination behavior and vaccine acceptance of their patients and the public at large (2022). However, low-income countries, especially in sub-Saharan Africa, have critical shortage of health workers (Willcox et al., 2015). Reasons behind this matter include insufficient resources to recruit and retrain, poor working environment, and migration for better jobs (2015).

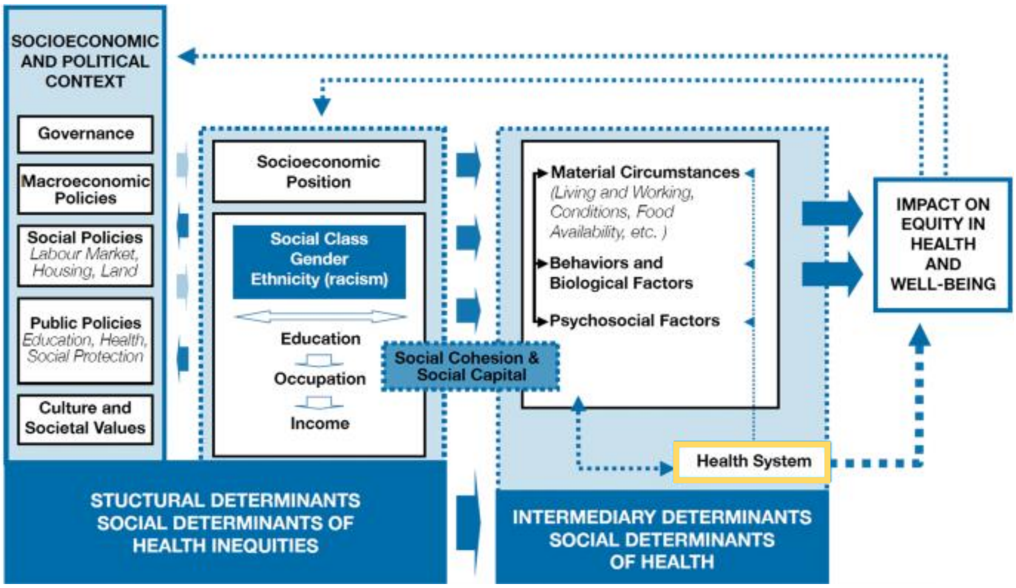
` In many African countries, it is not common for midwives to administer vaccines, but it is said that this process could be essential for many vaccines including birth dose of HepB (Okposen, 2021). Adding on, CNBC Africa mentioned that only doctors and nurses are legally permitted to administer jabs in many African countries (2022). Yet, in countries with insufficient number of physicians and nurses such as Malawi, Kenya, and Nigeria, it is likely that community health workers (CHW) and community health extension workers (CHEW) to administer vaccines (Olaniran et al., 2019).

2.2. Factors Associated with Vaccination Dropout

Even with clear recommendations for routine immunization provided by the WHO, population of low-income countries, particularly countries in sub-Saharan countries, face hardships in meeting these standards. Literature review on factors associated with childhood vaccination revealed that there are numerous country-level factors including government health spending, political stability, gender equality, and smaller land areas (Arsenault et al. 2017). Moreover, recent study on vaccination dropout rates in Democratic Republic of Congo showed that factors such as unavailability of seats, and absence of a reminder system were the predictors of high vaccination dropout rates among infants (Kayembe-Ntumba et al., 2020). Favin et al showed that the most mentioned factors associated with under-vaccination were accessibility, poor health workforce motivation and attitude (performance/competence, knowledge, ability to communicate with mothers) and cancellation of sessions due to absence of service provider (2012). These are factors which are highly related to the availability of healthcare workers.

One study employed the conceptual framework developed by the Commission on Social Determinants of Health to further depict factors associated with poor vaccination coverage (see figure 3.).

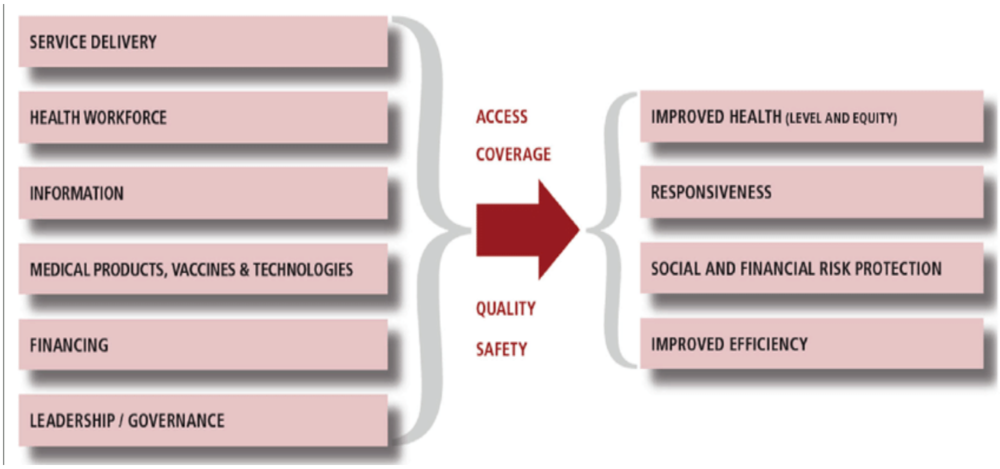
Figure 3. A Conceptual framework on Social Determinants of Health Source Commission



Source: Solar & Irwin (2006)

Previous studies on infant vaccine dropout rate have mostly focused on structural determinants rather than intermediary determinants such as the health systems of the country. For example, Wiysonge et al.'s study revealed that individual and contextual factors are associated with childhood vaccination in 24 sub-Saharan African countries (2012). Moreover, including Wiysonge et al.'s study, majority of related studies have used Demographic Health Surveys to track individual factors such as income level and education levels (Shenton et al., 2020). Although there have been few studies on this matter, the research gap lies in the fact that most of the studies have used DHS data, a cross-sectional data which cannot be used to investigate the exposure which could vary over time.

Figure 4. The WHO Systems framework



Source: WHO (2007)

Among intermediary determinants of social determinants of health lies the role of 'health system' which is vital to achieving equity in health and well-being. The WHO Systems framework shows the six vital building blocks of health systems, one of which points out to 'health workforce' (see figure 4). Overall, these six building blocks have dynamic relationships with one another (2007).

Of the six building blocks of health systems, key input components are health financing and health workforce, and immediate output components are seen as access to essential medicines and service delivery (WHO 2007). Since most of the sub-Saharan African countries are financially supported (essential vaccines provided at low-cost) by UNICEF and Gavi, the study focuses on the role of 'health workforce' in terms of actual vaccine administration and service delivery.

2.2.1. Gender and Immunization

Gender plays a large role in infant immunization in numerous ways. First, gender discrimination can lead to inequal access to vaccines for girls and boys. Accordingly, some countries may have more boys who have greater access to vaccines than girls, and vice vera. Second, gender-related barriers have indirect impact on access to vaccines, and immunization as a whole. Unequal status of women and men may reduce the changes of children being vaccinated. These include social and cultural norms, education status, economic and political status. Literature review has shown that level of maternal literacy and gender equality are important predictors of more equitable levels of infant vaccine coverage (Arsenault et al., 2017).

2.3. Global Initiatives for Immunization

Global efforts to achieve universal immunization coverage started with WHO's Expanded Programme on Immunization in 1974. Then came the Global Alliance for Vaccination and Immunization (Gavi), a public-private partnership that appeared from global recognition of the need to address inequalities in access to vaccines in 2000. Subsequent initiatives include the Global Immunization Vision and Strategy in 2006 and the Global Vaccine Action Plan (GVAP), an initiative launched in 2012. More recently, Immunization Agenda 2030 (IA2030) was adopted by WHO, setting an overarching global vision and strategy for immunization from 2021 through 2030 (WHO, 2022).

Likewise, with numerous initiatives, many aid agencies such as UNICEF, WHO, private philanthropies and development banks have made efforts to achieve optimal universal immunization coverage by funding through development assistance for health since 1990. Gavi has also functioned as the main actor in addressing inequalities in access to vaccines through resource mobilization and investing in vaccine-specific activities as well as health systems strengthening.

2.3.1. Gavi, the Vaccine Alliance

Since its inception in 2000, Gavi has helped introduce new and underused vaccines in countries in Africa and has supported routine immunization programmes to strengthen access to and delivery of Primary Health Care (Gavi, 2022). Moreover, Gavi has aimed to strengthen access and delivery of PHC as a pathway towards achieving Universal Health Coverage which has been constantly reinstated on the global agenda (2022). Eligibility for Gavi support has been and is still determined by a country's national income (Gross National Income is less than or equal to US$1,620 over the past three years). Gavi aims to support the poorest countries, and if a country passes the eligibility threshold, the country enters the 'accelerated transition phase' and is expected to phase out of Gavi's financial support (2022).

Chapter 3. Methods

3.1. Study Design

The study aimed to follow the objectives through a panel analysis, building a longitudinal dataset with observations from 46 sub-Saharan African countries. In order to examine the relationship between health workforce availability and infant vaccine dropout rate in sub-Saharan African countries, the study constructed a country-level panel dataset with observations from 46 countries from years 2000 to 2019.

Since 2000, Gavi has been an active institution which enabled many countries to implement childhood vaccination programmes through multiple dimensions such as health systems strengthening, new/underused vaccine support, and price reduction of vaccines. The study, therefore, considered this aspect for Gavi-supported countries (37) among the 46 sub-Saharan African countries that are included in this study.

Accordingly, 'Gavi countries' and 'non-Gavi countries' subgroups have been evaluated separately in this study.

3.2. Study Setting

Among 47 countries in the African Region classified by the World Health Organization, 'Algeria' has been excluded from the list as it is considered to be a part of North Africa (see Table 1.). According to the 2021-2022 World Bank's classification of income-level, 21 countries in sub-Saharan Africa are in low-income group, 18 countries are in lower-middle-income group, 6 are in the upper-middle-income group, and 1 country (Seychelles) is the only African country categorized as high-income group.

Table 1. 46 countries[1)] in the African Region classified by the WHO (categorized by World Bank's classification of income-level: 2021-2022)

Low-income (21)	Lower middle-income (18)	Upper middle-income (6)	High Income (1)
Burkina Faso*	Angola*	Botswana	Seychelles
Burundi*	Benin*	Equatorial Guinea	
Central African Republic*	Cabo Verde	Gabon	
Chad*	Cameroon*	Mauritius	
Democratic Republic of the Congo*	Comoros*	Namibia	
Eritrea*	Congo*	South Africa	
Ethiopia*	Côte d'Ivoire*		
Gambia*	Eswatini (formerly, Swaziland)		
Guinea*	Ghana*		
Guinea-Bissau*	Kenya*		
Liberia*	Lesotho*		
Madagascar*	Mauritania*		
Malawi*	Nigeria*		
Mali*	Sao Tome and Principe*		
Mozambique*	Senegal*		
Niger*	Tanzania, United Republic of*		
Rwanda*	Zambia*		
Sierra Leone*	Zimbabwe*		
South Sudan*			
Togo*			
Uganda*			

[1)] Among 47 countries in the African Region listed by the WHO, Algeria has been excluded in this study

* Gavi supported countries (total= 37)

Figure 5. Map of Africa showing countries included in the study

Source: Gavi 2022,
Map of Africa template from GeoCurrents, customized by the author.

Among 47 countries included in the study, a total of 37 countries have previously received or still receive support from Gavi. These 37 countries remain to be either low-income or lower-middle income countries according to the World Bank's classification of income level, 2021-2022. Meanwhile, 1 high-income country (Seychelles) and 6 upper middle-income countries along with 2 lower-middle income countries (Cabo Verde and Eswatini) have not received support from Gavi. Most of these countries are located in the Southern region of Africa, including South Africa, Botswana, Namibia and Eswatini. Gabon and Equilateral Guinea are located on the west coast of Africa and are known to be oil-rich countries. Cabo Verde is a country comprising of group of islands off the west coast of Africa. Similarly, Seychelles is a country comprising a group of islands in the western Indian Ocean. Many Gavi-supported countries are landlocked developing countries (LLDC), a term formed by the United Nations. (View Appendix B to see Map of Africa, countries included in the study by income group)

3.3. Measures and Data Sources

Country-level data of 46 countries were used for all the variables included in the study.

3.3.1. Dependent Variables

For the dependent variables, DTP1- DTP3 dropout rate and DTP1-MCV1 dropout rate were obtained from the WHO Immunization Data Portal. Since DTP vaccine is one of the most universally present vaccine in all national vaccine schedules, DTP1-DTP3 dropout rate is chosen to evaluate infant immunization status in general, and simultaneously to evaluate delivery effectiveness of the countries' immunization system. Measles vaccine is also one of the universally present vaccines and is thought to be a better indicator to measure program effectiveness as it measures dropout over a longer time interval between doses. Further details have been mentioned in 2.1. Definition of Main Concepts.

Each of the variables is calculated as below:

$$\text{DTP1-DTP3 dropout rate} = \frac{\text{doses of DTP1 administered} - \text{doses of DTP3 administered}}{\text{doses of DTP1 administered}} \times 100$$

$$\text{DTP1-MCV1 dropout rate} = \frac{\text{doses of DTP1 administered} - \text{doses of MCV1 administered}}{\text{doses of DTP1 administered}} \times 100$$

3.3.2. Explanatory Variable

The explanatory variable 'health workforce' is the sum of total number of physicians per 1,000 people and total number of nurses and midwives per 1,000 people. Physicians include generalist medical practitioners and specialist practitioners. Nurses and midwives include 'professional, auxiliary, and enrolled nurses', and 'professional, auxiliary, and enrolled midwives'. Although generally, the word 'health workforce' refers to all the people who help to deliver health services, in this study the term is used to specifically refer to physicians, nurses, and midwives. This is due to the direct role of which physicians and nurses have in the vaccination process. Whilst physicians have the license to practice medicine, nurses play a key role in the administration and organization of vaccines. Furthermore, healthcare personnel who are eligible to administer vaccines include registered nurses, and also enrolled nurses who work under the supervision of registered nurses. Generally, healthcare personnel who administer vaccines are expected to provide vaccination information to their patients, as well as prepare, administer, and document the vaccinations. It is vital that these personnel receive comprehensive, competency-based training on vaccine administration policies.

As aforementioned, in countries with insufficient number of physicians and nurses such as Malawi, Kenya, and Nigeria, it is likely that community health workers (CHW) and community health extension workers (CHEW) to administer vaccines (Olaniran et al., 2019). Unfortunately, due to data insufficiency, number of CHW have not been included in this study. This matter will be further discussed in the limitations section.

Meanwhile, midwives can also play a role in promoting vaccination awareness (Skirrow et al., 2020). Country-level data for number of nurses include number of midwives, and hence both nurses and midwives are included in this study.

Original source of both the number of physicians and number of nurses and midwives is WHO's Global Health Workforce Statistics, OECD, supplemented by country data. Data is reported annually, and its aggregation method is a weighted average.

3.3.3. Control Variables

A total of seven control variables were included in this study. GDP per capita (constant US$ 2015, millions) and population density (people per sq. km) were obtained from the World Bank Open Data Catalog. GDP per capita tracks the country's economy, as it measures the economic output of a nation per person.

Current health expenditure per capita (constant US$ 2015, millions) and out-of-pocket expenditure as of % of current health expenditure (percentage, %)

are obtained from the Global Health Expenditure Database. Gavi disbursements by programme year (US$) are obtained from the Gavi Transparency Portal. Higher health expenditure per capita would likely support people to access health care. Meanwhile, higher out-of-pocket expenses would likely discourage people to access healthcare.

Finally, control variables that capture the extent of conflict-affectedness; government effectiveness (percentile rank), control of corruption (percentile rank), and political stability and absence of violence (percentile rank) were obtained from the World Governance Indicators Database. Government effectiveness index includes 47 variables including quality of bureaucracy. Control of corruption encapsulates the extent to which public power is exercised for private gain. This indicator depicts different forms of corruption which can be petty or grand. Political stability and absence of violence measure the perception of likelihood of politically motivated violence. Units of all three variables are ‘percentile rank’ which indicates the country's rank among all countries covered by the aggregate indicator, with 0 being the lowest, and 100 the highest. Percentile ranks have been adjusted to correct for changes over time in the composition of the countries covered by the World Governance Indicator. Descriptions of Key variables are listed in Table 2.

Table 2. Key variables and their sources

Type	Variable	Unit	Data availability	Source
Dependent variables	DTP1-DTP3 dropout rate	percentage, %	1980-2020	Immunization Data Portal (WHO)
	DTP1-MCV1 dropout rate			
Explanatory variable	Physicians, nurses, and midwives	per 1,000 people	1990-2019	Global Health Workforce Statistics Database (WHO)
Control variables	GDP per capita	constant US$ 2015, millions	1960-2020	World Bank Open Data
	Current health expenditure per capita	constant US$ 2019, millions	2000-2019	Global Health Expenditure Database (WHO)
	Out-of-pocket expenditure as of % of current health expenditure	percentage, %		
	Gavi disbursements by programme year	US$	2001-2020	Gavi Transparency Portal
	Political stability	percentile rank (0~100, low to high)	1996-2020	Worldwide Governance Indicators
	Government effectiveness			
	Control of corruption			

3.3. Method of Analysis

This study built a longitudinal dataset with observations from 46 sub-Saharan African countries classified by WHO, from 2000 to 2019. Quantitative panel analysis has been chosen as the main study method for the following reasons. First, panel analysis is a regression analysis method which proceeds both time-series and cross-sectional analysis. Since longitudinal data covered in panel analysis provides multidimensional information and volatility, efficient estimates can be obtained. In addition, unlike cross-sectional and time-series analysis, panel analysis has the advantage of reducing model misspecification as it can estimate dynamic relationships between variables and consider unobserved heterogeneity factors of individuals. Finally, the multi-collinearity problem can be alleviated by utilizing the advantages of the linear regression model. The regression model used in this study is specified as:

$$Y_{it} = \alpha + \beta \ln(X_{it}) + u_i + e_{it}$$

Where Y = dependent variable and X = independent variable,

i = country, t = time, α = fixed effect of each country,

β = regression coefficient of independent variable,

u_i= error term of heterogeneity, e_{it}= Idiosyncratic error term

Since DTP1-DTP3 dropout rate and DTP1-MCV1 dropout rate variables contained negative values, all variables except for these dependent variables were log-transformed. All analyses were performed with StataBE 17.0.

When heteroscedasticity between individuals was tested, the null hypothesis assuming the homoscedasticity between panel entities was rejected. Therefore, robust standard error value was obtained in consideration of the heteroscedasticity existing in this analysis.

Before further statistical analysis, one anomaly identified from the DTP1-MCV1 dropout rate dataset was removed. This anomaly was a value from South Africa in the year 2009, where a value of -580.8 was detected after the value 19.2 in 2008.

Chapter 4. Results

4.1. Descriptive Statistics

Table 3. shows descriptive variables used for analysis. The mean value of the dependent variable DTP1-DTP3 dropout rate is shown as 9.507%, and the mean value of DTP1-MCV1 dropout rate is shown as 11.196%. The mean dropout rate of DTP1-MCV1 is slightly higher than DTP1-DTP3, as it measures dropout over a longer time interval between doses. Both of the dropout rates range from negative values, and this suggests that in certain years there have been more cumulative doses administered for DTP3 or MCV1 than of DTP1. The mean value of physicians, nurses, and midwives per 1,000 people is 1.120 and ranges up to 5.830 per 1,000 people.

Mean values of control variables are as follows. The mean value of GDP per capita is 2150.440 (constant 2015US$, millions), and the mean value of current health expenditure per capita is 100.717 (constant 2019US$, millions). Current health expenditure per capita ranges from 4.649 to 480.281 (constant 2019US$, millions). The mean value of out-of-pocket expenditure as percentage of current health expenditure is 40.160% and ranges from 2.993% to 84.182%. The mean value of Gavi disbursements by programme year is US$ 8,867,403, but ranges from US$0 as 9 countries are not Gavi-eligible countries, and maximum is US$ 1.73e+08. The mean value of population density is 95.328 people per sq. km of land area. The mean value of government effectiveness is 27.476 percentile rank, and the mean value of control of corruption is 32.019 percentile rank. Lastly, the mean value of political stability is 34.532 percentile rank.

Overall, between, and within variance determines the extent of heterogeneity of countries. Both DTP1-DTP3 dropout rate and DTP1-MCV1 dropout rate had greater within variance than between variance, which means that variance within the country is greater than variance between countries. For DTP1-MCV1 dropout rate, the within variance is approximately two times greater than the between variance. The explanatory variable 'physicians, nurses and midwives' showed greater between variance, meaning that variance between countries is greater than variance within the country.

Control variables including GDP per capita, current health expenditure, out-of-pocket expenditure, population density, control of corruption, government effectiveness, and political stability all had greater between variance than within variance. However, Gavi disbursements by programme year had greater within variance with the value of 1.37e+07. Government effectiveness ranges from 0 to 59.69 percentile rank, control of corruption from 0 to 63.98 percentile rank, and political stability ranges from 0 to 76.30 percentile rank.

(View Appendix C to see coefficient correlation of all variables.)

Table 3. Descriptive statistics (2000~2019)

Variables	Mean		SD	Range	No. of countries	No. of years (T/T-bar)	Obs no.
DTP1-DTP3 dropout rate *(percentage, %)*	9.507	Overall	11.681	-205.882 – 58.333	46	18.848	867
		Between	6.388	-0.458 – 28.944			
		Within	9.712	-195.918 – 53.731			
DTP1-MCV1 dropout rate *(percentage, %)*	11.196	Overall	14.128	-152.941 – 53.704	46	18.652	858
		Between	6.460	-6.832 – 22.595			
		Within	12.675	-134.913 – 48.651			
Physicians, nurses, and midwives *(per 1,000 people)*	1.120	Overall	1.219	0.001 – 5.830	45	9.467	426
		Between	0.961	0.211– 4.512			
		Within	0.695	-1.761 – 3.772			
GDP per capita *(constant 2015US$, millions)*	2150.440	Overall	2875.572	258.629 – 16438.64	46	19.544	899
		Between	2796.946	304.301 – 12725.04			
		Within	673.958	-4768.808 – 7215.795			
Current Health Expenditure per capita *(constant 2019US$, millions)*	100.717	Overall	142.388	4.649 – 840.281	46	19.413	893
		Between	131.206	14.134 – 564.732			
		Within	54.883	-179.862 – 426.221			
Out of Pocket Expenditure *(% of current health expenditure)*	40.160	Overall	20.814	2.993 – 84.182	46	19.413	893
		Between	19.510	6.009 – 73.706			
		Within	7.571	12.081 – 64.627			

Table 3 Continued

Variables	Mean		SD	Range	No. of countries	No. of years (T/T-bar)	Obs no.
Gavi Disbursements by programme year *(US$)*	8867403	Overall	1.84e+07	0.000 – 1.73e+08	46	18.196	837
		Between	1.24e+07	0.000 – 5.55e+07			
		Within	1.37e+07	-4.64e+07 – 1.35e+08			
Government effectiveness, *percentile rank (0~100, low to high)*	27.476	Overall	20.461	0.00 – 59.69	46	18.782	864
		Between	19.805	0.42 – 37.97			
		Within	6.194	-2.26 – 50.66			
Control of corruption, *percentile rank (0~100, low to high)*	32.091	Overall	22.113	0.00 – 63.98	46	18.804	865
		Between	21.285	0.97 – 58.22			
		Within	6.998	-2.98 – 50.98			
Political stability, *percentile rank (0~100, low to high)*	34.532	Overall	22.532	0.00 – 76.30	46	18.783	864
		Between	20.927	0.95 – 54.85			
		Within	9.180	-8.88 – 67.45			

4.2. General Trends of Variables

Time trend graphs of each variable have been drawn to examine the general trend amongst 37 Gavi supported countries and 9 non-Gavi countries in sub-Saharan Africa, from 2000 to 2019. Figures 6 to 7 show the time trend of dependent variables: DTP1-DTP3 dropout rate and DTP1-MCV1 dropout rate. DTP1-DTP3 dropout rate has decreased since 2000 for both Gavi supported countries and non-Gavi supported countries. Generally, the DTP1-DTP3 dropout rate is less in non-Gavi supported countries, however large fluctuations can be seen in these countries. Similar pattern can be seen in the time trend graph of DTP1-MCV1 dropout rate, yet the fluctuation is greater. The fluctuation in non-Gavi countries may be reflecting the inconsistent recording of data and may be due to the lack of sample size, as data of only 9 countries are being reflected.

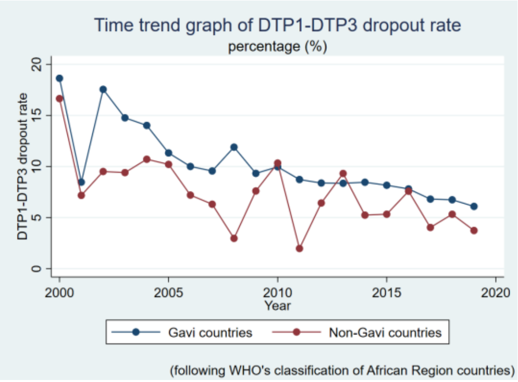
The time trend graph of the explanatory variable; health workforce is shown in figures 8 to 9. Number of physicians and number of nurses and midwives are shown separately. Generally, both the number of physicians and the number of nurses and midwives are higher in non-Gavi countries than that in Gavi countries. Number of physicians in non-Gavi countries have increased over the years, but has suddenly decreased in 2015, 2016, 2017 and drastically in 2019. Meanwhile, number of physicians in Gavi countries has remained to be approximately 0.1 per 1,000 people over the last 20 years. Interestingly, unlike the number of physicians, number of nurses and midwives has decreased since 2000, although this number has increased slightly from 2013 to 2019. The number of nurses and midwives of Gavi-countries has increased from 2000 to 2017 but has very slightly decreased in 2018 and 2019.

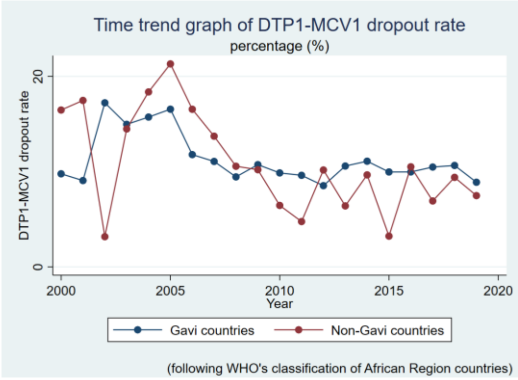
Figure 10 shows the total number of generalist medical practitioners, specialist medical practitioners, and other medical doctors that have not been further defined. The graph shows that there have been more generalists than specialists for the past two decades. However, most of the physicians have not been further defined. Similarly, figure 11 shows the total number of nurses and midwives. Number of nurses are approximately double the number of midwives in Sub-Saharan African countries.

Time trend graphs of seven control variables are shown in figures 12 to 18. Both GDP per capita and current health expenditure per capita show similar trends. Non-Gavi countries show greater values than that of Gavi countries and its increase over the past 20 years is greater. The values remain almost the same for 20 years in Gavi countries. Out-of-pocket expenditure as percentage of current health expenditure is greater in Gavi countries, but both Gavi and non-Gavi countries have decreased over the past 20 years. Gavi disbursements by programme year have constantly increased since 2001, reached their peak in 2015 and have drastically decreased in 2019. For control of corruption, government effectiveness, and political stability, the values are very low in Gavi-countries whereas it is comparably high in non-Gavi countries. Both government effectiveness and political stability, have decreased slightly over the past 20 years. Although the gap is wide, for control of corruption, both Gavi-countries and non-Gavi countries remain quite constant for 20 years. Lastly, population density has always remained higher in non-Gavi countries. Yet, population density in Gavi supported countries have increased considerably over the past 20 years.

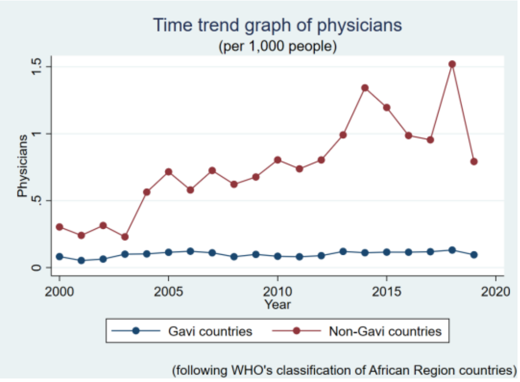
(View Appendix E to see time trend graph by income group.)

Figures 6-7 Time trend graph of dependent variables





Figures 8-9 Time trend graph of explanatory variable (physicians and nurses separated)



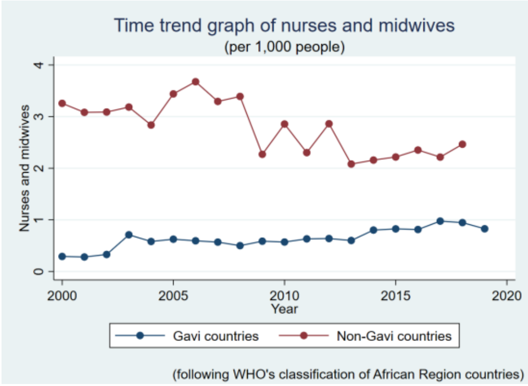
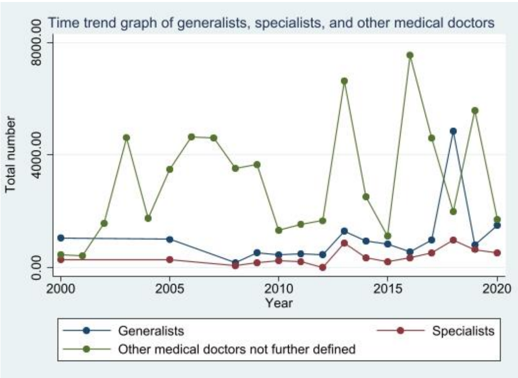
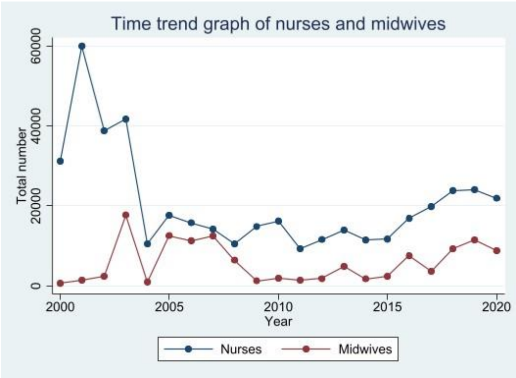
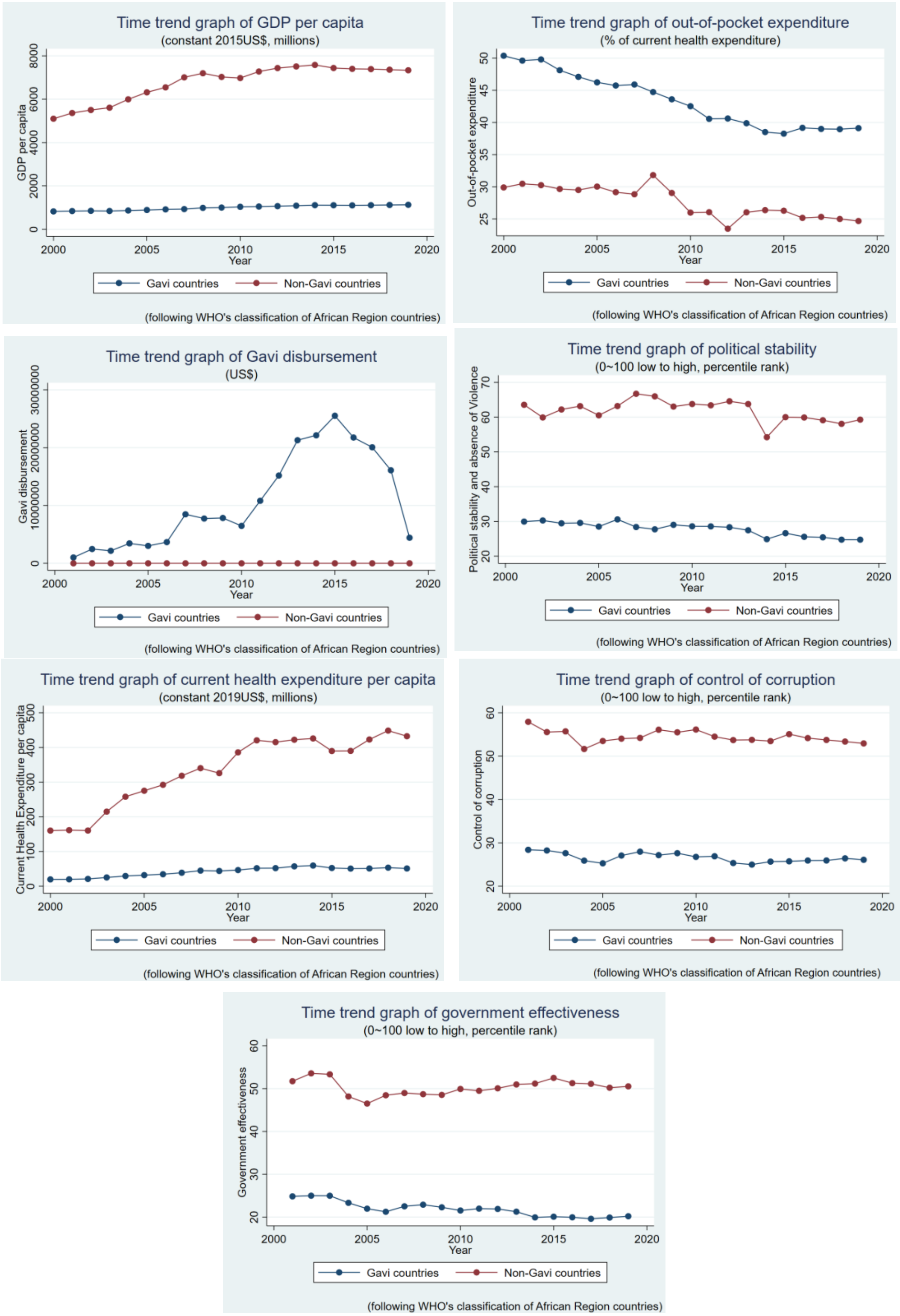


Figure 10 Time trend graph showing total number of generalists, specialists, and other medical doctors not further defined (all SSA countries); and Figure 11 Time trend graph showing total number of nurses and midwives (all SSA countries





Figures 12-18 Time trend graph of control variable



4.3. Fixed-effects Panel Regression Analysis

Relationship between DTP1-DTP3 dropout rate and health workforce shows significance in 36 sub-Saharan African countries. With 1% increase in Health workforce, there was a 0.007% decrease in DTP1-DTP3 dropout rate (robust standard error= 0.323, p-value<0.05). Regarding control variables, current health expenditure, Gavi disbursements and control of corruption had significant relationship with DTP1-DTP3 dropout rate. With 1% increase in current health expenditure per capita there was a 0.045% decrease in DTP1-DTP3 dropout rate (robust standard error= 2.132, p-value<0.05) and with 1% increase in Gavi disbursements there was a 0.009% decrease in DTP1-DTP3 dropout rate (robust standard error= 0.467, p-value<0.05). Finally, with 1% increase in control of corruption there was a 0.036% decrease in DTP1-DTP3 dropout rate (robust standard error= 1.913, p-value<0.05).

Meanwhile, relationship between DTP1-MCV1 dropout rate and health workforce does not show significance in 36 sub-Saharan African countries. Among all controlled variables, only government effectiveness showed significant relationship with DTP1-MCV1 dropout rate. With 1% increase in government effectiveness there is 0.091% decrease in DTP1-DTP3 dropout rate (robust standard error= 3.447, p-value<0.05). (View Appendix E to see scatter plot of dependent and explanatory variables by income group.)

Table 4. Fixed-effects panel regression, DTP1-DTP3 dropout rate

Number of observations:301 Number of countries: 36							
Variables	Coefficient	Standard Error	z	p-value	β	Robust SE	p-value
					(Adjusted for 36 clusters in country)		
Log [Health workforce]	-0.744	0.337	-2.21	0.028*	-0.744	0.361	0.047*
Log [GDP per capita]	-0.308	2.984	-2.10	0.918	-0.308	4.766	0.095
Log [Current health expenditure]	-4.515	1.331	-3.39	0.001**	-4.515	2.132	0.041*
Log [Out of pocket expenditure]	-1.105	1.467	-0.75	0.452	-1.105	1.913	0.567
Log [Gavi disbursement]	-0.983	0.305	-3.22	0.001**	-0.983	0.467	0.043*
Log [Government effectiveness]	-0.529	0.974	-0.54	0.587	-0.529	0.904	0.562
Log [Control of corruption]	-3.554	0.940	-0.75	0.000**	-03.554	1.913	0.041*
Log [Political stability]	-0.225	0.668	-0.34	0.737	-0.225	1.091	0.838
Number of observations	301				Sigma_u (σ u)	5.271	
Number of countries	36				Sigma_e (σ e)	4.396	
Prob> chi2	0.0000				rho	0.590	
R-sq within	0.3041						
R-sq between	0.2479						
R-sq overall	0.2518						

Statistical significance *<0.05 **<0.01

Table 5. Fixed-effects panel regression, DTP1-MCV1 dropout rate

Number of observations: 298 Number of countries: 36							
Variables	Coefficient	Standard Error	z	p-value	β (Adjusted for 36 clusters in country)	Robust SE	p-value
Log [Health workforce]	0.180	0.652	0.28	0.782	0.180	0.411	0.663
Log [GDP per capita]	-3.736	5.744	-0.65	0.516	-3.736	7.035	0.599
Log [Current health expenditure]	-2.174	2.549	-0.85	0.394	-2.174	3.289	0.513
Log [Out of pocket expenditure]	1.342	2.821	0.48	0.635	1.342	3.637	0.714
Log [Gavi disbursement]	-0.272	0.588	-0.46	0.644	-0.272	0.708	0.703
Log [Government effectiveness]	-9.134	1.877	-4.87	0.000**	-9.134	3.447	0.012
Log [Control of corruption]	1.097	1.810	0.61	0.545	1.097	1.934	0.574
Log [Political stability]	1.233	1.282	0.96	0.337	1.233	1.670	0.465
Number of observations	298				Sigma_u (σ u)	8.502	
Number of countries	36				Sigma_e (σ e)	8.404	
Prob> chi2	0.000				rho	0.506	
R-sq within	0.1447						
R-sq between	0.0456						
R-sq overall	0.0597						

Statistical significance *<0.05 **<0.01

Chapter 5. Discussion

Results of this study show that there is a significant negative relationship between health workforce availability and DTP1-DTP3 dropout rate in 36 sub-Saharan African countries. With 1% increase in Health workforce, there was a 0.007% decrease in DTP1-DTP3 dropout rate (robust standard error= 0.323, p-value<0.05). Although the magnitude of its impact seems moderate, increase in health workforce availability leads to the reduction of DTP1-DTP3 dropout rate and this suggests improvement in delivery effectiveness of the health system. Regarding control variables, Current Health Expenditure per capita, Gavi disbursements and density and control of corruption had significant relationship with DTP1-DTP3 dropout rate. The results show that these three factors can also play a role in reaching the undervaccinated children. Increased current health expenditure per capita, Gavi disbursements and control of corruption would naturally lead to increased access to healthcare services.

Meanwhile, the statistical significance of health workforce availability and DTP1-MCV1 dropout rate was not significant. The DTP1-MCV1 dropout rate indicator has several issues which could have affected the overall results (See 2.1. Definitions of Key Concepts) Alternatively, one could presume that health worker availability is more directly related to delivery effectiveness (DTP1-DPT3 dropout rate) rather than programme effectiveness (DTP1-MCV1 dropout rate). Furthermore, although health workforce is one of the most important pillars of the health system, other key factors such as vaccine availability should be considered. These pillars and functions are evidently interconnected and interdependent as health workers are only able to administer when vaccines are available, and vaccines can only be administered in the presence of physicians and nurses. In other words, there could be omitted-variable bias, meaning that it could have left out relevant factors related to both DTP1-DTP3 and DTP1-MCV1 dropout Rate.

The following text indicates future provisions to improve health workforce availability to eventually strengthen the health systems in sub-Saharan African countries.

Strategies to improve health workforce availability

Despite the vital role of health workforce in a 'functioning' health system, the number remains extremely low in the 37 Gavi-supported sub-Saharan African countries. The general trend shows slight increase in these numbers, but these numbers need to be improved considerably to meet the health needs of people in sub-Saharan African countries and to meet SDG Target 3.c which is to increase health financing and the overall recruitment, development, training, and retention of the health workforce in resource-poor settings (*SDG 3.C.1 health worker density of physicians*, 2019). Appropriate strategies to accumulate skilled health workers as well as supporting the working conditions of the health workers are needed, along with initiatives that would tackle problems such as 'brain drain'. These can include investing more in healthcare workers through increased salaries, performance-based incentives, introducing better work benefits, and training of medical personnel. Recently, Dr Keith Martin from The Consortium of Universities for Global Health has mentioned the need to "ban poaching of healthcare workers from low-income countries" (CUGH, 2022). Such advocacy to tackle the problem of brain drain can be helpful, and these words should be taken to action.

Revisiting the principles of effective global health delivery

WHO suggests four key principles in order to deliver health services effectively (2007). First is 'adapting to the local context'. 46 countries in sub-Saharan African countries are different in their economy, culture, religion, and language. These differences also exist within these countries and acknowledging the local context and adapting to this context is key to delivering health services effectively. Second is 'constructing a care delivery value chain (CDVC)'. Instead of looking at a series of discrete interventions, CDVC looks at care as an overall system, and allows a systemic analysis of value creation in a multiple number of activities during the care of a patient (Rhatigan et al., 2009). Third is 'leveraging shared delivery infrastructure'. Shared delivery infrastructure allows personnel and facilities to be used wisely which contributes to reaping economies of scale, especially in resource-poor settings (Kim et al., 2013). Fourth principle is 'improving both health delivery and economic development'. Improved health of the population eventually would enhance economic development and peace of the country. It is vital that this grand picture is seen over the entire course of strengthening the health systems in sub-Saharan African countries.

5.1. Limitation of Study

5.1.1. Constraints on research design and methodology

The main limitation of this study is data deficiency of the explanatory variable. For almost all countries included in the study, the number of physicians and number of nurses and midwives had rarely been recorded annually. Many countries have also recorded number of physicians in one year but not the number of nurses and midwives, and vice versa. This suggests that there is a lack of proper information system in these countries, and that there is a need to invest in data collection and management in order to keep track of the number of health workers in sub-Saharan African countries.

The same goes for data on CHWs and CHEWs. Due to insufficient data, CHW and CHEW were not included as ‘health workforce’ in this study which could be vital part of workforce in countries which lack in number of physicians and nurses.

Furthermore, to fully examine the role of health workforce in a country, measures of other health system building blocks such as health information system, governance/leadership and medical products, vaccines and technology are needed. Yet, such measures are either unavailable or insufficient in terms of both data quality and quantity. In order to properly track and notice infants who have or have not been vaccinated, measures to monitor and evaluate the health information system need to be in place. Similarly, measures that track number of vaccines and medical supplies would be supportive.

Other key variables include gender equality measures such as Gender Inequality Index, adult female literacy rate, and female educational attainment. These variables were omitted in this study due to lack of data. Further studies should include these variables in order to gain better understanding of their effects. However, as a means to do so, sufficient data is needed, and countries should make more effort in collecting and recording these routine data.

Another limitation is the ability to capture individual-level factors such as maternal education which has been detected as a vital factor in terms of child vaccination. Forshaw's study shows that improving maternal education plays an important role in increasing vaccination uptake and coverage (2017). Along with education level, another study showed that inequalities in wealth and geographic access can affect vaccine dropout (Ali et al., 2022). Although individual-level factors are important, this study highlights that health systems play an equally important role, and it is vital to improving health workforce availability in order to effectively resolve and target missed opportunities of vaccination (MOV).

In terms of statistical limitation, there is a probability of omitted variable bias, for it is difficult to include all factors that contribute to vaccine dropout rates. Moreover, only 36 countries were included in the final panel regression analysis. A more robust result would be gained with more countries included in the study to represent Sub-Saharan Africa.

5.1.2. Directions for future research

Future research should attempt to include those who are able and actually administer vaccines, such as CHWs and CHEWs in certain Sub-Saharan African countries. Moreover, in order to have a more solid knowledge in the role of health system, other five building blocks of health systems should be incorporated. Once again, gender equality plays a large role in vaccine coverage and yet this study failed to examine both and female literacy rate and female literacy rate due to insufficient data. It is important that sufficient amount of quality data is collected and managed in order to have reliable and meaningful results. Future research should attempt to incorporate such factors, as well as key individual-level factors that have been suggested 'important' in improving childhood immunization.

Chapter 6. Conclusion

In this study, fixed-effects panel regression analysis was conducted to examine the relationship between health workforce availability and infant vaccine dropout rates from 46 sub-Saharan African countries from 2000 to 2019. This study points out that vaccines are the most cost-effective public health intervention that can save lives, and there have been global efforts to free people from vaccine-preventable diseases. Unfortunately, there has been very little progress in terms of improving infant vaccine dropout rates in African Region countries compared to other regions classified by the WHO.

Although findings from this study reveal that health workforce show statistical significance in DTP1-DTP3 dropout rate, the same statistical significance could not be seen in DTP1-MCV1 dropout rate. Since DTP1-DTP3 dropout rate is considered to be a better measure of delivery effectiveness, and DTP1-MCV1 dropout rate a better measure of programme effectiveness, one could presume that health worker availability is more directly related to delivery effectiveness rather than programme effectiveness.

Based on the results of this study, in order to improve the dropout rate of child vaccination in sub-Saharan Africa, it is necessary to prioritize policies and strategies to maintain and scale up health workforce availability. To be specific, it is necessary to establish measures such as increased salary or provision of incentives, as well as long-term strategies to ensure that medical personnel continue to stay in the medical field. All in all, this study is significant in that it has examined the relationship between health workforce availability and infant vaccine dropout rate in sub-Sahara African countries using panel data for the first time.

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Appendix A

Table 1. Summary of WHO Position Papers- Recommended Routine Immunizations for Children (recreated by author)

Antigen		Age of 1st Dose	Doses in Primary Series	Interval Between Doses			Booster Dose	Considerations
				1st to 2nd	2nd to 3rd	3rd to 4th		
Recommendations for all children								
BCG		As soon as possible after birth	1					Birth dose and HIV; Universal vs selective vaccination; Co-administration; Vaccination of older age groups; Pregnancy
Hepatitis B	Option 1	As soon as possible after birth (<24h)	3	4 weeks (min) with DTPCV1	4 weeks (min) with DTPCV2			Premature and low birth weight Co-administration and combination vaccine Option 2 As soon as possible after birth High risk groups
	Option 2	As soon as possible after birth (<24)	4	4 weeks (min) with DTPCV1	4 weeks (min) with DTPCV2	4 weeks (min) with DTPCV3		
Polio	bOPV + IPV	bOPV 6 weeks (min) IPV 14 weeks (min)	5 (3 bOPV and 2 IPV)	bOPV 4 weeks (min) with DTPCV2	bOPV 4 weeks (min) with DTPCV3			bOPV birth dose Type of vaccine Fractional dose IPV Alternative early IPV schedule IPV / bOPV Transmission and importation risk
	IPV/ bOPV Sequential	8 weeks (IPV 1st)	1-2 IPV 2 bOPV	4-8 weeks	4-8 weeks	4-8 weeks		
	IPV	8 weeks	3	4-8 weeks	4-8 weeks			IPV booster needed for early schedule (i.e. first dose given <8 weeks)
DTP-containing vaccine		6 weeks (min)	3	4 weeks (min) – 8 weeks	4 weeks (min) – 8 weeks		3 Boosters 12-23 months (DTP containing vaccine); 4-7 years (Td/DT containing	Delayed/ interrupted schedule Combination vaccine; Maternal immunization

							vaccine), see footnotes; and 9-15 yrs (Td)	
Haemophilus influenzae type b	Option 1	6 weeks (min) 59 months (max)	3	4 weeks (min) with DTPCV2	4 weeks (min) with DTPCV3			Single dose if >12 months of age Not recommended for children > 5 yrs Delayed/ interrupted schedule Option 2 2-3 Co-administration and combination vaccine
	Option 2		2-3	8 weeks (min) if only 2 doses 4 weeks (min) if 3 doses	4 weeks (min) if 3 doses		At least 6 months (min) after last dose	
Pneumococcal (Conjugate)	Option 1 3p+0	6 weeks (min)	3	4 weeks (min)	4 weeks			Schedule options (3p+0 vs 2p+1) Vaccine options HIV+ and preterm neonate booster Vaccination in older adults
	Option 2 2p+1	6 weeks (min)	2	8 weeks (min)			9-18 months	
Rotavirus		6 weeks (min) with DTP1	2 or 3 Depending on product	4 weeks (min) with DTPCV2	For three dose series -4 week (min) with DTPCV3			Not recommended if >24 months old
Measles		9 or 12 months (6 months min, see footnote)	2	4 weeks (min) (see footnote)				Co-administration live vaccines; Combination vaccine; HIV early vaccination; Pregnancy
Rubella		9 or 12 months with measles containing vaccine	1					Achieve and sustain 80% coverage Co-administration and combination vaccine; Pregnancy
HPV		As soon as possible from 9 years of age (females only)	2	6-12months (min 5 months)				Target 9–14-year-old girls; Temporary suspension of multi-age cohort vaccination; Off-label use of extended interval of 3-5 years; Pregnancy; Older age groups > 15 years 3 doses; HIV and immunocompromised

Appendix B

Figure 1. Map of Africa, countries included in the study by income group

Source: Income group classified by the World Bank 2021-2022
Map of Africa template from GeoCurrents, customized by the author,

Appendix C

Table 2. Correlation Coefficients

	1	2	3	4	5	6	7	8	9	10	11
1. DTP1-DTP3 dropout rate	1.00										
2. DTP1-MCV1 dropout rate	-0.47*	1.00									
3. Health workforce	-0.30*	-0.12*	1.00								
4. GDP per capita	-0.04	-0.06	0.71*	1.00							
5. Current Health Expenditure	-0.21*	-0.15*	-0.64*	0.83*	1.00						
6. Out of Pocket Expenditure	0.34*	0.13*	-0.21*	-0.09*	-0.33*	1.00					
7. Gavi Disbursements	-0.06	-0.06	-0.14*	-0.19*	-0.20*	0.03	1.00				
8. Government effectiveness	-0.29*	-0.15*	0.52*	0.39*	0.57*	-0.51*	-0.08*	0.27*	1.00		
9. Control of corruption	-0.33*	-0.13*	0.45*	0.29*	0.50*	-0.55*	-0.17*	0.25*	0.85*	1.00	
10. Political stability	-0.18*	-0.04	0.49*	0.49*	0.55*	-0.40*	0.33*	0.19*	0.68*	0.72*	1.00

Statistical significance: *< 0.05

Appendix D

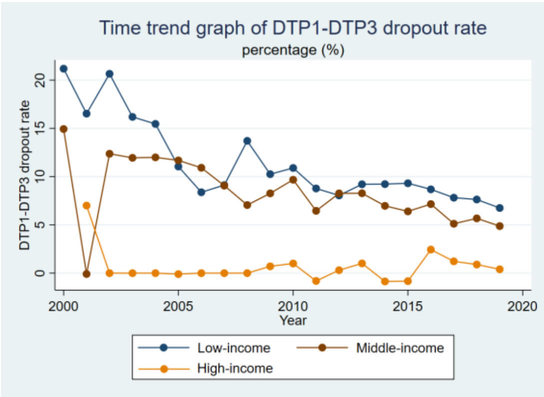
Table 3. Pooled OLS (DTP1-DTP3 dropout rate)

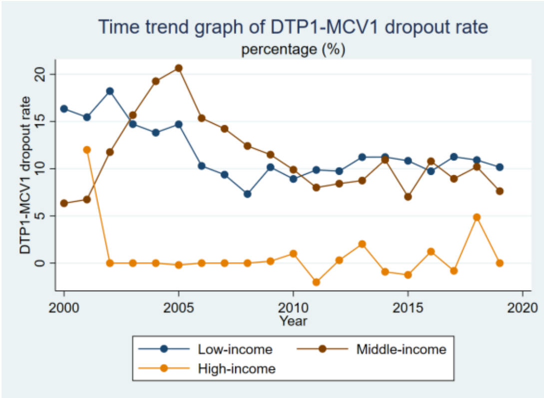
		Number of observations: 301		
Variables	Coefficient	Robust Standard Error	z	p-value
Log [Health workforce]	-1.386	0.408	-3.40	0.001**
Log [GDP per capita]	2.915	0.920	3.17	0.002**
Log [Current health expenditure]	-4.013	0.951	-4.22	0.000**
Log [Out of pocket expenditure]	0.494	0.752	0.68	0.497
Log [Gavi disbursement]	-0.935	0.332	-2.83	0.005**
Log [Government effectiveness]	-1.060	0.910	-1.16	0.245
Log [Control of corruption]	-2.523	0.762	-3.31	0.001**
Log [Political stability]	-0.562	0.613	-0.92	0.360
Number of observations	301			
Prob> chi2	0.000			

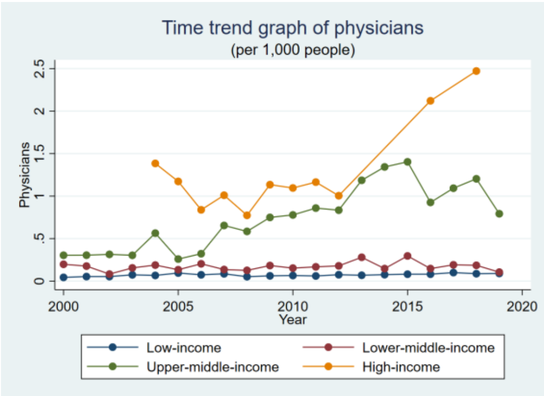
Statistical significance: *< 0.05, **<0.01

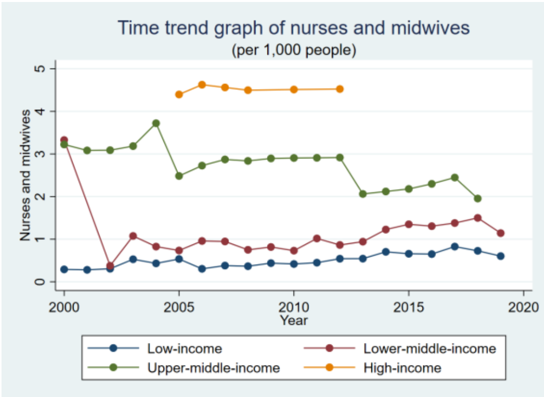
Appendix E

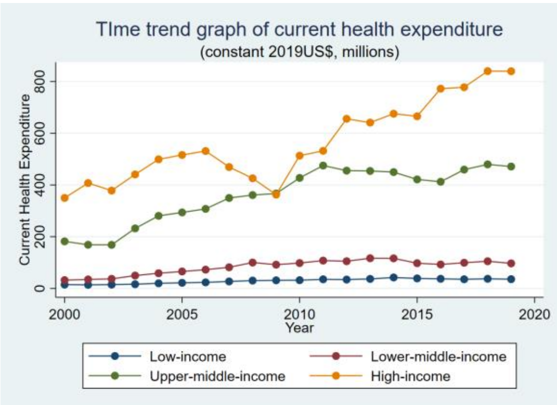
Figures 2-13. Time trend graph by income group classified by the World Bank 2021-2022[2)]

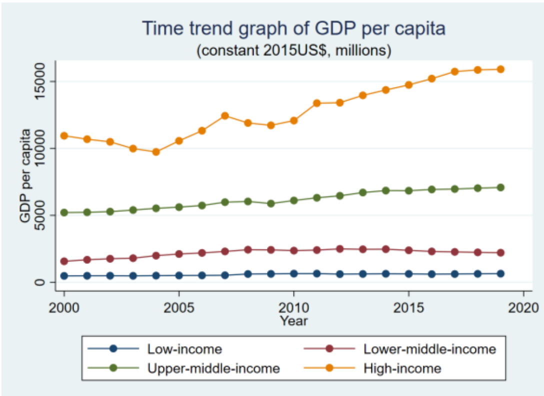




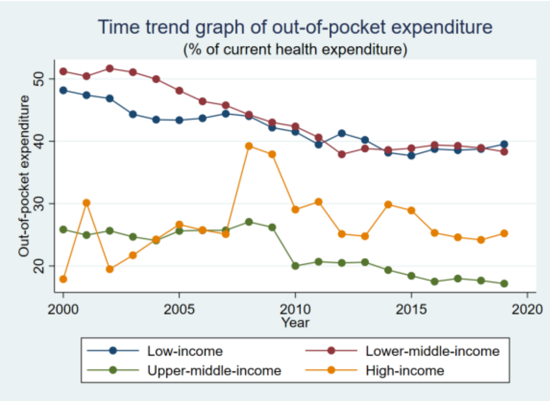


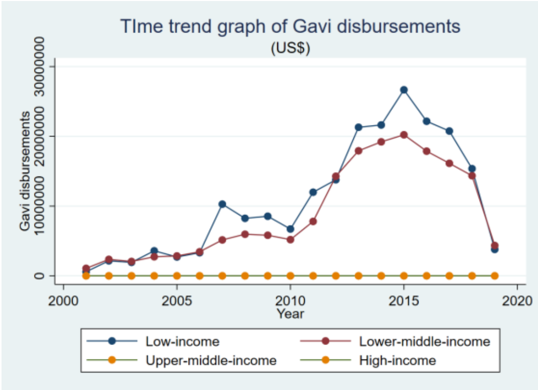


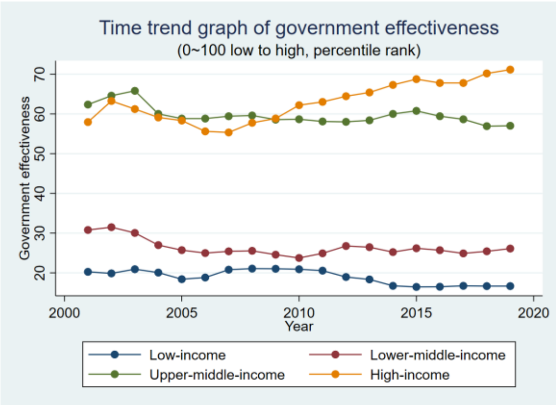


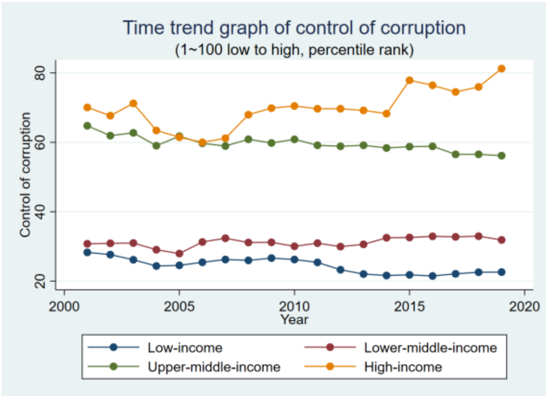


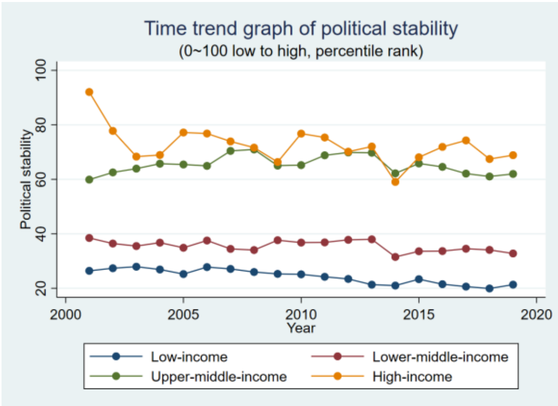
[2)] 21 countries are included in low-income countries, 18 in lower-middle-income countries, 6 in upper-middle-income countries (24 middle-income countries), and 1 country (Seychelles) is represented as high-income country


Time trend graph of out-of-pocket expenditure
(% of current health expenditure)
Out-of-pocket expenditure
20
30
40
50
2000
2005
2010
2015
2020
Year
Low-income
Lower-middle-income
Upper-middle-income
High-income


TIme trend graph of Gavi disbursements
(US$)
Gavi disbursements
0
10000000
20000000
30000000
2000
2005
2010
2015
2020
Year
Low-income
Lower-middle-income
Upper-middle-income
High-income

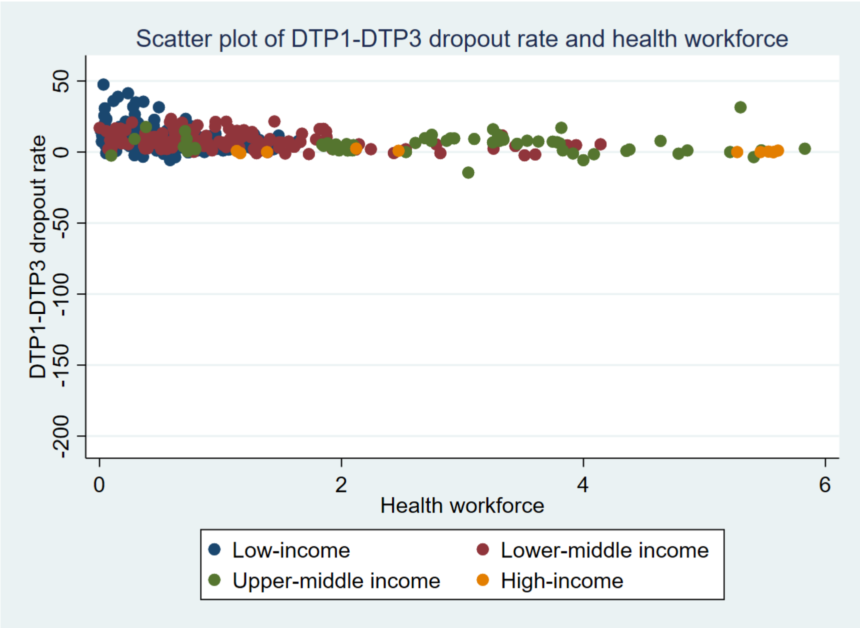

Time trend graph of government effectiveness
(0~100 low to high, percentile rank)
Government effectiveness
20
30
40
50
60
70
2000
2005
2010
2015
2020
Year
Low-income
Lower-middle-income
Upper-middle-income
High-income

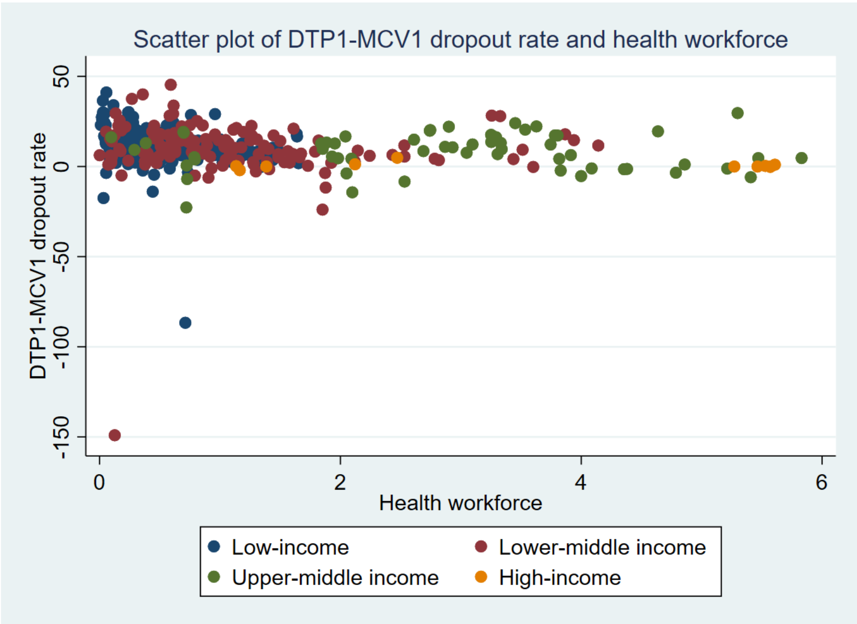

Time trend graph of control of corruption
(1~100 low to high, percentile rank)
Control of corruption
20
40
60
80
2000
2005
2010
2015
2020
Year
Low-income
Lower-middle-income
Upper-middle-income
High-income


Time trend graph of political stability
(0~100 low to high, percentile rank)
Political stability
20
40
60
80
100
2000
2005
2010
2015
2020
Year
Low-income
Lower-middle-income
Upper-middle-income
High-income

Appendix F

Figures 14-15. Scatter plot of dependent and explanatory variables by income group classified by the World Bank 2021-2022[3)]





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3) 21 countries are included in low-income countries, 18 in lower-middle-income countries, 6 in upper-middle-income countries, and 1 country (Seychelles) is represented as high-income country

Abstract in Korean

국문 초록

보건의료인력 수급 현황이 사하라이남 아프리카 국가들의 영·유아 백신 접종 중도탈락률에 미치는 영향: 패널 데이터 분석

김하영

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보건학과 보건정책관리학 전공

배경 및 목적: 감염병을 예방하는 방법 중 최소 비용으로 최대 효율을 낼 수 있는 수단은 예방접종이다 (Ehreth, 2003). 특히나 영유아 예방접종은 발생률 및 사망률을 효과적으로 감소시킬 수 있는 방법으로 알려져 있다 (Brownson et al., 2003). 예방접종을 출생 시부터 적기에 실시하는 것은 영유아의 면역을 키워 감염병을 예방하고 영유아의 기초 건강을 향상시켜 질병으로부터 안전하게 한다. 그러나, 예방접종을 위한 전 세계적인 노력에도 불구하고 사하라이남 아프리카 국가들의 많은 영유아들은 여전히 예방접종을 완료하지 못하고 있다. 특히 사하라이남 아프리카에서는 영유아 백신 접종 중도탈락률이 다른 지역보다 현저히 높게 나타나는데, 높은 중도탈락률의 요인에 대한 현재까지의 연구는 개개인의 사회경제적 요인에 많이 집중 되어있고 보건의료체계차원에서의 연구는 부족한 상황이다.

보건의료체계의 여섯 가지 구성 요소 중 예방접종이라는 의료적 개입을 위한 투입(input) 역할을 하는 것이 재정(financing)과 보건의료인력이다. 그 중 재원 조달과 대부분의 필수백신은 UNICEF 와 Gavi 의 도움으로 사하라이남 아프리카 국가들에게도 매우 낮은 비용으로 구매지원되므로 실제 백신투여에 중요한 역할을 담당하는 보건의료인력에

초점을 두어 살펴보고자 하였다. 더욱이, 사하라이남 아프리카 지역의 보건의료인력 부족은 이미 잘 알려져 있지만 보건의료인력 수급 현황이 영유아 예방접종 중도탈락률에 미치는 영향에 대한 연구는 전무하다. 따라서 본 연구는 사하라이남 아프리카 국가에서 보건의료인력 수급 현황이 영유아 백신 접종 중도탈락률에 어떠한 영향을 미치는지 조사하는 것을 목표로 하였다.

방법: 본 논문에서 정의하는 보건의료인력은 영유아 백신을 전달할 수 있는 면허 및 자격을 취득한 사람이다. 의사, 간호사 등 백신 투여 허가를 받은 의료 전문가와 이 과정을 직접적으로 보조하는 조산사 등의 전문가가 포함된다. 보건의료인력 수급 현황이 사하라이남 아프리카 국가들의 영유아 백신 접종 중도탈락률 개선에 효과가 있는지 살펴보기 위해 본 연구는 2000 년부터 2019 년까지 46 개의 사하라이남 아프리카 지역 국가들을 대상으로 국가수준의 패널데이터를 구축하여 회귀분석을 수행하였다. 영유아 백신 접종 중도탈락률 지표로는 DTP1-DTP3 과 DTP1-MCV1 중도탈락률을 살펴보았고, 보건의료인력 수급 현황은 각국의 1.000 명당 의사 수, 그리고 간호사 및 조산사 수의 합계를 이용하였다. 통제변수로는 1 인당 국내총생산, 1 인당 경상의료비, 1 인당 의료비 본인부담금, Gavi 지급액(Gavi disbursements), 정부 효과성(government effectiveness), 정치적 안정성과 무폭력(political stability and absence of violence), 부패의 통제(control of corruption)를 선택하였다.

결과: 기술 분석에 따르면 2000 년부터 2019 년까지 Gavi 지원을 받은 총 37 개국의 1,000 명당 의사 수는 크게 증가하지 않은 추세이며, 간호사 및 조산사 수는 점차 증가하는 경향이 나타나기는 했지만 전반적으로 낮은 수준에 머물러 있다. Gavi 지원을 받지 않은 9 개국의 의사 수는 20 년간 꾸준히 증가했지만 간호사 및 조산사 수는 오히려 줄고 있는 추세를 보였다.

고정효과 패널회귀분석 결과에 따르면, 보건의료인력 수급 현황이 증가할수록, DTP1-DTP3 중도탈락률은 유의하게 감소하는 것으로 나타났다.
보건의료인력 수급 현황은 DTP1-DTP3 중도탈락률, 인구 밀도, 그리고 부패 통제율에 통계적으로 유의미한 결과를 나타냈지만 효과의 크기는 미미한 것으로 확인되었다. 예를 들어, 보건의료인력 수급 현황이 1% 증가할 때 DTP1-DTP3 중도탈락률은 0.007% 감소하였다. 통제변수 1 인당 경상의료비, Gavi 지급액과 부패의 통제도 통계적으로 유의미한 영향을 미쳤지만 1 인당 경상의료비가 1% 증가할 경우 DTP1-DTP3 중도탈락률은 0.045% 감소, Gavi 지급액이 1% 증가할 경우 DTP1-DTP3 중도탈락률은 0.009% 감소하였고, 부패 통제율이 1% 증가할 경우 DTP1-DTP3 중도탈락률은 0.036% 감소했다.

결론: 보건의료인력 수급 현황이 DTP1-MCV1 중도탈락률에 미치는 영향은 통계적으로 유의미하지 않게 나타난 것은 여러 요인에 기인한 것일 수 있다. 우선 두 종속변수의 특성 차이에 기인한 것일 수 있다. 즉, DTP1-DTP3 중도탈락률은 전달 효과성(delivery effectiveness)을 측정하는 지표로 사용되고 DTP1-MCV1 중도탈락률은 프로그램 효과성(program effectiveness)을 측정하는 지표로 사용되는 것을 감안할 때, 보건의료인력 수급 현황이 전달 효과성에 더욱 직접적인 영향을 주는 것으로 추측해 볼 수 있다. 또한, 지표로서의 DTP1-DTP3 중도탈락율과 DTP1-MCV1 중도탈락률에 영향을 미치는 변수가 누락된 오류 (omitted variable bias)의 가능성에 대해서도 생각해 볼 수 있다. 본 연구는 보건의료인력 수급 현황이 보건의료체계에서, 특히 효과적인 보건 서비스 전달(service delivery)을 위한 필수 요소임을 강조하고, 의료인력 수급이 현저히 부족한 사하라이남 아프리카에서 보건의료체계 강화를 촉진할 수 있는 여러 주요 요인 중 하나임을 보여준다.

본 연구 결과로 미루어 보아 사하라이남 아프리카의 아동 예방접종 중도탈락률을 개선시키기 위해서는 보건의료인력 수급 확보방안과 근무 환경 개선을 위한 정책 대안이 필요할 것으로 보인다. 즉, 보건의료인력 수급을 위해 예산지원 등 인센티브를 부여하는 대책과 의료현장 근무 시 근무 여건 개선을 위한 장기적인 전략을 수립하는 것이 필요하다고 사료된다. 본 연구는, 이와 같은 정책적 함의 제공과 더불어 기존 연구에서 부족했던 사하라이남 아프리카의 영유아 백신 접종 중도탈락률에 대한 요인을 보건의료체계차원에서 살펴봤다는 점과, 패널자료를 이용하여 보건의료인력 수급 현황과 영유아 백신 접종 중도탈락률의 관계를 살펴본 첫 연구라는 점에서 의의를 지닌다.

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주요어: 보건의료인력, 영·유아 백신, 예방접종, 백신 접종 중도탈락률, 보건의료시스템, 사하라이남 아프리카, 패널 데이터 분석

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