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Impact of Vaccine Availability on the Number of Children Vaccinated and Under-Five Mortality in Tanzania

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Capstone in Public Administration

Impact of Vaccine Availability on the Number of Children Vaccinated and Under-Five Mortality in Tanzania

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TABLE OF CONTENTS

ABSTRACT

Stockouts have previously been reported to interrupt immunization services in low-and-middle income countries. However, there has been little research to understand the direct impact of stockouts on the number of children immunized and no research to understand the impact on under-five mortality. Using panel data from Tanzania's Vaccine Information Management System training program, a regression model with fixed and random effects is used to analyze the effect of stockouts on the number of children immunized. The Lives Saved Tool® is used to estimate the effect of stockouts on under-five mortality. The results suggest that stockouts have a statistically significant impact on the number of children immunized for most vaccines in the current month and for several months after the stockout. No impact was found on under-five mortality. However, due to limitations in this analysis, this relationship should be further explored.

EXECUTIVE SUMMARY

Stakeholders of immunization supply chains and programs in low-and-middle income countries have a goal to increase immunization coverage and improve patient health outcomes through their services. This includes ensuring vaccine availability through maintaining adequate stock levels. Stockouts are a typical indicator collected by immunization supply chain managers to measure vaccine availability. A stockout is usually defined as an entity reporting zero stock of a vaccine or supply in stock. However, little research has been done to understand the effect stockouts have on the number of children immunized. Additionally, no research has been done to understand the effect stockouts have on patient health outcomes, such as mortality.

The first focus of this paper is to measure the number of children immunized over time as a result of increased stockouts reported by health facilities in mainland Tanzania. This is done by

2

using a panel data regression model of data from Tanzania's Vaccine Information Management System training program. The second focus of this paper is to estimate the impact on under-five mortality as a result of increased stockouts reported by health facilities. This estimate is done using the Lives Saved Tool®.

The findings of this analysis indicated that stockouts have an influence on the number of children immunized not only in the current month of the stockout, but also for several months after. The findings also indicated that stockouts did not influence under-five mortality. However, this is probably due to Tanzania's high immunization rates. With high immunization rates it would be difficult to detect a difference in under-five mortality on the national level. In conclusion, vaccine availability influences the number of children immunized in mainland Tanzania, but further research is needed to understand the influence on under-five mortality because of limitations in this analysis.

INTRODUCTION

Evidence has shown that immunizations are one of the most cost-effective global public health interventions, saving an estimated two to three million lives every year.[1] Since the introduction of the Expanded Programme on Immunization by the World Health Organization in 1974, global immunization coverage to prevent tuberculosis, diphtheria, tetanus, pertussis, poliomyelitis, and measles has grown from less than 5% to 86%.[2] These programs have continued to expand, and the World Health Organization now recommends vaccines against

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[1] 2018 Assessment report of the Global Vaccine Action Plan. Geneva: World Health Organization, 2018.
[2] Peck, Megan. "Global Routine Vaccination Coverage, 2018." *MMWR. Morbidity and Mortality Weekly Report* 68 (2019).

eleven diseases for infants; tuberculosis, hepatitis B, polio, diphtheria, tetanus, pertussis, Haemophilus influenzae type b, pneumococcus, rotavirus, measles, and rubella.[3]

Despite this expansion, Gavi's 2018 Annual Report indicates that coverage for certain immunizations in low- and middle-income countries (LMICs) has slightly declined or plateaued in recent years. While third-dose pentavalent vaccine coverage which protects against diphtheria, tetanus, pertussis, hepatitis B, and Haemophilus influenzae type b increased from 80% to 82% between 2015 and 2017, there was a decline to 81% in 2018.[4] Four countries that once transitioned to the high coverage threshold of >80% fell below this mark. Additionally, the first-dose measles vaccine has plateaued at 81% and second-dose coverage is at just 54% in Gavi-eligible countries.[5] Gavi, The Vaccine Alliance is an alliance of global partners aimed at increasing immunization coverage in LMICs. Countries are eligible for Gavi support based on their gross national income.

Demand influencing factors such as wealth, educational status of the mother, and geographical distance to the health center have been reported to impact immunization coverage in LMICs.[6] Factors influencing supply of vaccines, such as cost, have also been shown to impact immunization coverage as well, especially in middle-income countries never eligible for Gavi support. Adoption of new vaccines in these countries is slower due to higher procurement costs. Middle-income countries never eligible for Gavi support were responsible for 17% of the

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[3] Feikin, Daniel R., Brendan Flannery, Mary J. Hamel, Meghan Stack, and Peter M. Hansen. "Vaccines for Children in Low- and Middle-Income Countries." In *Reproductive, Maternal, Newborn, and Child Health: Disease Control Priorities, Third Edition (Volume 2)*, edited by Robert E. Black, Ramanan Laxminarayan, Marleen Temmerman, and Neff Walker. Washington (DC): The International Bank for Reconstruction and Development / The World Bank, 2016.
[4] 2018 Annual Progress Report, *Gavi, The Vaccine Alliance,* pp 13.
[5] 2018 Annual Progress Report. *Gavi, The Vaccine Alliance*, pp 16.
[6] Global Vaccine Action Plan 2011-2020. *World Health Organization*, pp. 19.

world's under-immunized children in 2017.[7] Cost does not seem to be an influencing factor in

Gavi-supported LMICs because of funding support from Gavi and similar stakeholders.

Stock related issues within immunization supply chains have also influenced the supply

of vaccines as well as immunization services. In the 2018 Assessment Report of the Global

Vaccine Action Plan, 70 countries experienced stockouts in 2017 and 69 experienced sub-

national stockouts. A stockout was defined as a facility reporting zero vaccines in-stock. Sub-

national stockouts were responsible for the interruption of immunization services in 78% of the

cases. Among LMICs, causes of stockouts identified in the report included stock management

issues, vaccine quality issues, procurement delays, global vaccine shortages, funding delays, and

other non-specified issues.[8]

With supply chain logistic issues resulting in stockouts and interruption of immunization

services, it is important to understand the impact vaccine availability has on the number of

children immunized and under-five mortality. There have been several studies that evaluate the

impact of supply chain interventions and redesign on improving vaccine availability and

immunization coverage. However, most of these studies do not directly link improved vaccine

availability to increased immunization coverage, nor do they consider the impact on population

health such as under-five mortality. Vaccines are a unique life-saving intervention, in that they

provide protection beyond the person immunized through preventing the spread of disease within

a population.[9] Analyzing how vaccine availability impacts the number of children immunized

and under-five mortality will provide stakeholders with a better understanding of how their

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[7] Silverman, Rachel & Glassman, Amanda. "New Gavi Modalities for a Changing World." *Global Immunization and Gavi: Five Priorities for the Next Five Years* (2019). pp 20.

[8] 2018 Assessment report of the Global Vaccine Action Plan. *WHO*. pp 6

[9] Orenstein, Walter A., and Rafi Ahmed. "Simply Put: Vaccination Saves Lives." *Proceedings of the National Academy of Sciences* 114, no. 16 (April 18, 2017): 4031.

services affect the populations they serve. This may have been difficult to analyze in the past because logistic management information systems and health information systems are often separate. Thanks to a novel electronic logistic management information system implemented in the United Republic of Tanzania and the Lives Saved Tool®, this type of analysis can now be performed.

The United Republic of Tanzania is an appropriate country to use for this analysis because its immunization trends reflect those outlined in Gavi's 2018 Annual Report. According to Tanzania's 2010-2015 multi-year plan submitted to Gavi, antigen coverage was reported to be 98.4% for BCG (Bacille Calmette-Guerin vaccine), 94.7% for DTP3 (third dose diphtheria, tetanus, pertussis, Haemophilus influenzae B, and hepatitis B vaccine), and 84.4% for measles. While immunization coverage is high, there is significant regional variation. Additionally, the proportion of districts with DTP3 coverage less than 80% increased from 9.4% in 2004 to 21% in 2010.[10] Tanzania has 26 regions and 131 districts.

The United Republic of Tanzania is made up of mainland Tanzania and Zanzibar. Mainland Tanzania and Zanzibar have separate governing bodies for health with the Ministry of Health, Community, Development, Gender, Elderly, and Children overseeing services of Tanzania's mainland and the Ministry of Health overseeing Zanzibar.[11] Immunization services are provided throughout the country and are free in both public and private health facilities. The distribution of vaccines and supervision of immunization services is managed at the district level.[12] Currently, the World Health Organization recommends vaccination against 14 different

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[10] The United Republic of Tanzania: Ministry of Health and Social Welfare-Tanzania Mainland. Expanded Programme on Immunzation 2010 - 2015 Comprehensive Multi Year Plan (2011). pp 5.
[11] The United Republic of Tanzania: Ministry of Health and Social Welfare-Tanzania Mainland. Expanded Programme on Immunzation 2010 - 2015 Comprehensive Multi Year Plan (2011). pp 1.
[12] The United Republic of Tanzania: Ministry of Health and Social Welfare-Tanzania Mainland. Expanded Programme on Immunzation 2010 - 2015 Comprehensive Multi Year Plan (2011). pp 2.

antigens in Tanzania.[13] Immunizations that target children under five years can be seen in Table 1 below.

Table 1: United Republic of Tanzania Immunization Schedule for Children <5 years

Antigen	Description	Schedule
BCG	Bacille Calmette-Guerin vaccine	Birth
DTP-Hib-HepB	Diphtheria and Tetanus and Pertussis and Haemophilus influenzae B and Hepatitis B vaccine	6, 10, 14 weeks
IPV	Inactivated polio vaccine	14 weeks
MR	Measles and rubella vaccine	9, 18 months
OPV	Oral polio vaccine	Birth; 6, 10, 14 weeks
PCV-13	Pneumococcal conjugate vaccine	6, 10, 14 weeks
Rotavirus	Rotavirus vaccine	6, 14 weeks

LITERATURE REVIEW

As mentioned previously, several published studies demonstrate interventions on immunization supply chains increase the availability of vaccines and reduce the number of stockouts in LMICs. Some of the research indicates an increase in immunization coverage during the same time period, but this was not directly linked to increased vaccine availability. Under-five mortality is an important population health outcome collected by stakeholders and is important to consider since immunization schedules target this vulnerable age group. However, none of the studies were able to evaluate the impact of vaccine availability on under-five mortality.

One tool that has been proposed for vaccine management is an electronic logistic management information system (eLMIS). A study evaluating the effectiveness of an eLMIS for

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[13] World Health Organization. WHO vaccine-preventable diseases: monitoring system. 2019 global summary (10 December 2019).

vaccine management in India found the number of zero-stock events dramatically reduced after adoption of the system.[14] Zero-stock events were defined as the number of transactions, per month, in which the closing balance of materials was zero. The zero-stock event was classified as a stockout if the amount remained zero at the start of the following session day. While the overall number of zero-stock events reduced, suggesting an improvement in stock management, the proportion of stockouts did not change.

Redesigning delivery systems has also influenced stockouts and immunization coverage. Sarley, *et al*. (2017), evaluated complete immunization supply chain redesign in Nigeria, which included improving data visibility and cold chain equipment, transforming the delivery system to an informed push model, and strengthening organizational leadership and performance culture.[15] The authors found a dramatic decrease in the number of health facilities reporting stockouts, from 43% to 0%, in a pilot district after the push delivery system was implemented. The push delivery system consisted of direct to facility customized delivery schedules. Immunization coverage in these facilities increased from 57% to 88% as well during the same time period.

A second study analyzed supply chain redesign on the state level in Kano, Nigeria. Aina, *et al*. (2017), also evaluated the effect of the push delivery system and found a decrease in stockout rates, from 41% to 10%, after the first delivery cycle.[16] Immunization coverage for most vaccines also improved during the review period. DTP3, OPV (oral polio vaccine), BCG, and yellow fever all showed significant upward trends. The measles vaccines also displayed an

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[14] Gilbert, Sarah Skye, Neeraj Thakare, Arun Ramanujapuram, and Anup Akkihal. "Assessing Stability and Performance of a Digitally Enabled Supply Chain: Retrospective of a Pilot in Uttar Pradesh, India." *Vaccine*, Building Next Generation Immunization Supply Chains, 35, no. 17 (April 19, 2017): 2203–8.

[15] Sarley, David, Mustafa Mahmud, Jide Idris, Modele Osunkiyesi, Onome Dibosa-Osadolor, Peter Okebukola, and Owens Wiwa. "Transforming Vaccines Supply Chains in Nigeria." *Vaccine* 35, no. 17 (April 2017): 2167–74.

[16] Aina, Muyi, Uchenna Igbokwe, Leke Jegede, Rabiu Fagge, Adam Thompson, and Nasir Mahmoud. "Preliminary Results from Direct-to-Facility Vaccine Deliveries in Kano, Nigeria." *Vaccine*, Building Next Generation Immunization Supply Chains, 35, no. 17 (April 19, 2017): 2175–82.

upward trend, but this was not statistically significant. The hepatitis B vaccine displayed a statistically significant downward trend.

Similarly, a report of immunization supply chain redesign in Mozambique analyzed the impact of their strategies on vaccine management. These strategies included using a modeling system, improving data visibility and cold chain equipment, partnering with the private sector for delivery systems, and leadership engagement.[17] The authors of this report found a decrease in the number of health facilities reporting stockouts after supply chain redesign. Stockouts decreased from an average of 36% in 2010 to 5% in 2015. This report defined stockouts as "the percentage of visited health centers during a distribution period that reported a stockout of a specific antigen at the time of delivery (and before restocking by distribution team)."

To this author's knowledge there is only one published study directly evaluating the impact of vaccine availability on immunization coverage and none that evaluate the impact of vaccine availability on under-five mortality. A recently published study using data from Nigeria analyzed the effect of vaccine availability on immunization coverage as well as supply and demand factors that affect this relationship.[18] The authors found vaccine stockouts significantly decreased the number of children immunized with effects lasting several months after a stockout occurred. Some of this demand was recovered as a result of children "catching-up" with their immunization regimens, however the author's concluded that about half of the demand was permanently lost. The authors of this study suggested the lasting loss in demand was a result of "learning effects" from vaccine stockouts. These learning effects included loss of trust in the

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[17] Prosser, W., Sampath, V., West, M., Burey, J., & Bancroft, E. Lessons Learned in Reaching the Final 20: Building a Next-Generation Immunization Supply Chain in Mozambique. *VillageReach* (2016).
[18] Gooding, Emily, Eirini Spiliotopoulou, and Prashant Yadav. "Impact of Vaccine Stockouts on Immunization Coverage in Nigeria." *Vaccine* 37, no. 35 (August 14, 2019): 5104–10.

healthcare system by the child's mother which would prevent the mother from returning for future immunizations, as well as parents informing neighbors of a stocked-out facility which would discourage others from taking their children to the facility for immunizations. This study is limited in its external validity, however, as the structure of immunization supply chains varies among LMICs.

Additional studies are needed to confirm the impact of vaccine availability on immunization coverage. A majority of previously published studies do not directly analyze the effect of vaccine availability on the number of children immunized. It is important for stakeholders to know if stockouts are indeed influencing immunization coverage over time. This could indicate children are being lost to follow-up because of trust in the health care system which would put children at risk for contracting and spreading deadly diseases. Further research may be needed to understand when, and if, children eventually catch up with their immunization regimens. Additionally, this could indicate the need for campaign outreach after significant regional or national stockouts. Lastly, studies involving vaccine availability have not been able to measure population health outcomes such as under-five mortality. Understanding the impact vaccine availability has on under-five mortality will provide stakeholders additional insight into how their immunization supply chain services affect the populations they serve.

OBJECTIVE AND HYPOTHESIS

The objective of this capstone is to answer the following two research questions: 1) What is the effect of vaccine availability on the number of children immunized in Tanzania? and 2) What is the effect of vaccine availability on under-five mortality in Tanzania? In this analysis, the outcome measures of interest are the number of children immunized and under-five mortality estimated as a result of stockout events. Stockout events serve as a measure of vaccine

availability. A stockout is defined as a health facility reporting zero stock of a vaccine or supply in each month. Given previous findings on stockouts and immunization coverage, I hypothesize that an increase in the number of stockout events will result in a decrease in the number of children immunized and that this trend will last for several months following the stockout event. Additionally, I hypothesize that under-five mortality will increase as a result of the increase in number of stockout events.

RESEARCH DESIGN

The first aim of this study is to analyze the effect of stockouts on the number of children immunized in Tanzania using a regression of panel data with fixed and random effects. Reporting standards for Tanzania's Vaccine Information Management System (VIMS) was rolled out in phases over time to different areas of the country. Data from VIMS training program, the data source for this analysis, reflects this phenomenon. It could be expected that as more health facilities adopt VIMS over time, the absolute number of children immunized would increase as health facility workers receive additional training and partake in better data collection. A concern of using this model is omitted variable bias. Using the Hausman test for each regression model, there is no evidence that region-specific omitted variables correlate with observed explanatory variables.

The second aim of this study is to estimate the effect of vaccine availability on under-five mortality in Tanzania using the Lives Saved Tool®. This tool provides an estimate on mortality rates from the scale-up of certain health interventions, such as the scale-up of immunizations.

COUNTRY SELECTION AND DATA SOURCES

The United Republic of Tanzania was chosen for this analysis because of reasons stated in the introduction of this paper and because of recent implementation of VIMS. VIMS is a semi-autonomous module of Tanzania's electronic logistic management information system and was implemented in mainland Tanzania under the leadership of the Ministry of Health, Community, Development, Gender, Elderly, and Children and in partnership with US Agency for International Development, the Bill and Melinda Gates Foundation, and Gavi with the Clinton Access Initiative, John Snow, Inc., PATH, and VillageReach. VIMS combines data from three different systems that were once operating in silos: the District Vaccine Data Management Tool, the Stock Management Tool, and the Cold Chain Equipment Inventory Tool. Essentially, VIMS allows stock to be tracked as it moves along the supply chain all the way until stock is used. Health facilities are expected to count stock on hand at the end of each month and enter this information into VIMS along with other key performance indicators. This includes submitting information on the number of children vaccinated according to records in the electronic immunization registry. This information can then immediately be transmitted to district level supply chain managers. VIMS became the national reporting standard for vaccine stock management in January 2019.

It had been intended to use data from January 2019 through December 2019 for this analysis, however the author was unable to access the actual data collected in VIMS. Instead the data source for this analysis is the VIMS training program. The VIMS training program was designed to train health facility workers and program managers on how to input information into the system and generate reports. The training program does not contain real data. While data from the training program is not real data collected, it mirrors actual trends observed across

mainland Tanzania and will serve the purpose of this paper. Data obtained from the training program includes the number of health facilities that reported a stockout and the number of children immunized for the following four vaccines per region per month: Measles and rubella (MR), rotavirus (RV), pneumonococcal conjugate (PCV-13), and diphtheria, tetanus, pertussis, Haemophilus influenzae type b and hepatitis B (DTP-Hib-HepB). Additional data obtained from the training site includes total target population as well as the number of health facilities expected to report into VIMS each month. Data is also obtained from Tanzania's 2015-2016 Demographic and Health Survey and Malaria Indicator Survey. This includes information on wealth and education status of females.[19] Data is aggregated at the regional level for all 26 regions in mainland Tanzania. The research protocol was approved by the University of Kentucky Institutional Review Board.

POPULATION AND OUTCOME MEASURES

The target population is children five-years and younger living in mainland Tanzania between the time period January 1, 2018 through December 31, 2018. The outcome measures of interest are the number of children immunized for each of the following four vaccines: MR, RV, PCV-13, and DTP-Hib-HepB. This is measured as the absolute number of children immunized for each vaccine.

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[19] Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC) [Tanzania Mainland], Ministry of Health (MoH) [Zanzibar], National Bureau of Statistics (NBS), Office of the Chief Government Statistician (OCGS), and ICF. "Tanzania Demographic and Health Survey and Malaria Indicator Survey (TDHS-MIS) 2015-16." Dar es Salaam, Tanzania, and Rockville, Maryland, USA: MoHCDGEC, MoH, NBS, OCGS, and ICF. (2016). pp 35 & 42.

13

EXPLANATORY VARIABLES

The explanatory variable of direct interest is vaccine availability. Vaccine availability is defined as the number of health facilities that reported a stockout per region per month. Other variables that have been shown to influence the number of children immunized in LMICs include wealth, education status of the mother, and size of target population. Therefore, these variables are included in the model. Wealth is defined as the Gini coefficient reported for each region, education status of the mother as the median years of schooling completed by females in each region, and target population as the number of children under five-years in each region. The number of health facilities expected to report into VIMS per region per month is also included as an explanatory variable. A table of explanatory variables along with their definition and source can be seen below in Table 2.

Table 2: Description of Explanatory Variables

Variable Name	Definition	Source
stockoutMR	The number of health facilities reporting zero stock of MR vaccine each month	VIMS training program
stockoutRota	The number of health facilities reporting zero stock of rotavirus vaccine each month	VIMS training program
stockoutPCV13	The number of health facilities reporting zero stock of PCV-13 vaccine each month	VIMS training program
stockoutDTP	The number of health facilities reporting zero stock of DTP-Hib-HepB vaccine each month	VIMS training program
healthfac	The number of health facilities expected to submit reports into VIMS each month	VIMS training program
targetpop	The number of children under five years in each region	VIMS training program
motheredu	Median years of schooling completed by females in each region	2015-2016 DHS-MIS
ginicof	Gini coefficient in each region	2015-2016-MIS

STATISTICAL ANALYSIS

The equation for the panel data regression model is shown below:

$$Number\ of\ Children\ Immunized_{it}$$
$$= \beta_0 + \beta_1(stockout)_{it} + \beta_2(healthfac)_{it} + \beta_3(targetpop)_{it}$$
$$+ \beta_4(motheredu)_{it} + \beta_5(ginicof)_{it} + \alpha_i + u_{it}$$

The above model will be used to run separate regressions for each of the four vaccines

included in this analysis and will be lagged to prevent analysis of a definitional relationship

between the amount of vaccines available and the rate of immunization. All statistical analyses are performed using Stata v16.1.

LIVES SAVED TOOL

Using the outputs from the above panel data regression model for each vaccine and the Lives Saved Tool®, the effect of vaccine availability on under-five mortality can be estimated. The Lives Saved Tool®, developed by Johns Hopkins Bloomberg School of Public Health and funded by the Bill and Melinda Gates Foundation, is a mathematical linear model for LMICs that estimates population health outcomes from the scale-up of certain health interventions.[20] The methodology of the tool is described elsewhere.[21] The tool is regularly updated with evidence from the latest scientific literature and demographic household surveys and includes data for all four vaccines included in this analysis. A complete look of data included in the model can be visualized at listvisualizer.org.

A baseline projection for the year 2018 will first be computed to serve as the counterfactual for the second part of this analysis. A second projection will then be computed using the outputs from the four regression models with a one-month lag. The impact on under-five mortality from vaccine availability can then be estimated by comparing this second projection to the counterfactual.

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[20] "About — The Lives Saved Tool."
[21] Walker, Neff, Yvonne Tam, and Ingrid K Friberg. "Overview of the Lives Saved Tool (LiST)." *BMC Public Health* 13, no. Suppl 3 (September 17, 2013)

RESULTS

Not surprising, the analysis found that stockouts have a statistically significant influence on the number of children immunized for most vaccines in the current month of the stockout. However, results suggest that this influence lasts several months following the month of stockout. This finding was significant for all vaccines. The second part of this analysis did not find that stockouts have an influence on under-five mortality.

SUMMARY STATISTICS

Summary statistics for each of the 26 regions in mainland Tanzania over the year 2018 can be seen in Table 3 below. There was a total of 228 observations for regions reporting the number of vaccines given and the number of stockouts in each month. Missing observations reflect when VIMS was not operational in certain regions at a point in time; therefore, there was no data to observe. Missing observations were dropped from the analysis. The number of children immunized varied greatly between vaccine type and region, with the minimum number of children immunized being equal to 0 (MR vaccine) and the maximum number of children immunized equal to 953,056 (Rotavirus vaccine). Target population, education of the mother, and Gini coefficient also varied for each region. The mean target population was equal to 346,620 children, mean education of the mother equal to 4.172 years, and mean Gini coefficient equal to 0.4696. The number of health facilities reporting a stockout of a vaccine in each month varied depending on vaccine type. On average the number of health facilities reporting a stockout in each region per month was greatest for the DTP-Hib-HepB vaccine (21.8). This was followed by the MR vaccine (19.2), PCV-13 vaccine (15.7), and rotavirus vaccine (13.5).

Table 3: Summary Statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
DTP Vaccine	228	94,337	82,474.28	118	426,237
MR Vaccine	228	56,304	50,183.07	0	237,364
PCV-13 Vaccine	228	93,679.36	81,861.02	195	414,205
Rotavirus Vaccine	228	67,242.54	80,973.14	126	953,056
Target Population	312	346,620	215,121.8	23,850	958,784
Mother's Education (years)	300	4.172	1.493	1.8	6.6
Gini Coefficient	300	0.4696	0.1340	0.08	0.7
No. of Health Facilities	312	166	120.27	0	346
No. of Health Facilities Reporting DTP Vaccine Stockout	228	21.8	18.2	0	97
No. of Health Facilities Reporting MR Vaccine Stockout	228	19.2	16.3	0	89
No. of Health Facilities Reporting PCV-13 Vaccine Stockout	228	15.7	14.5	0	72
No. of Health Facilities Reporting Rotavirus Vaccine Stockout	228	13.5	13.0	0	68

EFFECT OF VACCINE STOCKOUTS ON NUMBER OF CHILDREN IMMUNIZED

The number of health facilities reporting a stockout had a statistically significant impact on the number of children immunized for most vaccines in the current month. The exception for this was the impact of stockouts on the number of children immunized with the DTP-Hib-HepB vaccine ($p=0.063$). When analyzing the effect of the number of health facilities reporting a stockout in the previous month on the number of children immunized, the effect was statistically significant for all vaccines. This effect was statistically significant for a one-, two-, and three-month lag for all vaccines. These results can be seen below in Table 4. The number in parentheses is the standard error for each coefficient. The asterisk indicates the level of statistical significance.

18

Table 4: Effect of Stockouts on Number of Children Immunized

	DTP Vaccine	MR Vaccine	PCV-13 Vaccine	Rotavirus Vaccine
Current Month	-755.6 (406.1)	-969.7* (267.2)	-1,967.9* (490.4)	-1,380.0* (504.4)
One-Month Lag	-943.6* (406.3)	-899.0* (262.3)	-1,949.9* (484.8)	-1,304.4* (506.2)
Two-Month Lag	-1,053.2* (395.1)	-821.2* (259.4)	-1,765.1* (476.8)	-1,432.1* (533.6)
Three-Month Lag	-996.2* (384.7)	-667.6* (254.7)	-1,654.4* (456.5)	-1,447.9* (587.1)

$*p<0.05$

EFFECT OF VACCINE STOCKOUTS ON UNDER-FIVE MORTALITY ESTIMATE

A baseline projection estimated the mortality rate to be 54.0 deaths per 1,000 live births in the year 2018. After accounting for the number of children who missed immunizations as a result of the number of health facilities reporting a stockout in the previous month, the projection estimated the mortality rate to stay constant at 54.0 deaths per 1,000 live births. These results can be seen below in Table 5.

Table 5: Projection of Under-Five Mortality Estimate in 2018

Projection	Under-Five Mortality Estimate (deaths per 1,000 live births)
Baseline	54.0
Final	54.0

DISCUSSION

The above results suggest that stockouts have an influence on the number of children immunized each month. The results of this analysis also suggest this impact stays constant for several months following the reported stockout event. These results support those found in Gooding, *et al*. (2019), further confirming the impact that stockouts have on the number of children immunized. These findings suggest that children may be lost to follow-up after being denied a vaccination due to a stockout. However, because of the structure of this analysis and

available data, the model used may not accurately reflect the significance of stockouts on the number of immunizations given. Gooding, *et al*. (2019), determined that children "catch-up" on their immunizations through campaign outreach. The effect of campaign outreach could not be determined in this analysis based on available data. It is probable that campaign outreach could influence the number of children immunized, showing an increase in the number of children immunized over time. This would lessen the impact of stockouts on the number of immunizations given over time. Also, education of the mother (motheredu) and Gini coefficient (ginicof) are nearly perfectly collinear with other included variables. Therefore, the influence of these two variables on the number of children immunized could not be estimated based on available data. Distance to health facility has also been reported to influence immunization, but this could not be controlled based on available data. These lack of control variables may overestimate the influence stockouts have on the number of children immunized.

This analysis found stockouts did not influence under-five mortality in Tanzania. This is likely a result of Tanzania's high immunization rates and should not downplay the significance of vaccines. It is likely that the decrease in immunizations given would have an impact on increasing under-five morality estimate. However, since the Lives Saved Tool® measures this estimate at the national level, this result was not large enough to show an impact on mortality. It is possible an impact on under-five mortality could have been estimated if the first part of this analysis was done at the national level instead of at the regional level.

LIMITATIONS

This analysis has several limitations that must be mentioned. First, it must be noted that this is not an analysis of real data, but data used for training from the VIMS training program. While the data from the training program reflects real trends of immunizations and stockout

events, it is not real data. Therefore, the results should not be used to guide decisions until an analysis can be completed with actual data collected in VIMS. Secondly, it is a limitation that there are missing observations in the data set. It is possible the true impact of stockouts on the number of children immunized was not measured because not all months for each region could be accounted for based on when the regions were expected to start using VIMS. This could also be the case because not all variables that could potentially affect the number of children immunized could be included, as mentioned above. The variable used as a wealth indicator, the Gini coefficient, may not be the best indicator of wealth either, but this was the best measure given available data. Lastly, the results of this analysis are limited in their external validity and cannot be generalized to other low-and-middle income countries. This is due to differences in immunization program and supply chain structure among low-and-middle income countries.

CONCLUSION AND RECOMMENDATIONS

In conclusion, the number of health facilities reporting a stockout in the previous month(s) had a statistically significant impact on the number of children immunized for each of the following four vaccines: DTP-Hib-HepB, MR, PCV-13, and rotavirus vaccine. The reported stockouts resulted in a decrease in the number of children immunized. This analysis did not find the number of health facilities reporting a stockout to have an impact on under-five mortality estimate. The following recommendations are stated based off this analysis:

Recommendation One:

- Perform analysis with actual data collected in VIMS. This will allow the true impact of stockouts on the number of children immunized to be measured and can be used for the basis of decision making.

21

Recommendation Two:

- Consider collecting the number of children reached through immunization campaigns in VIMS. As of now, health facilities report the total number of immunizations given per month into VIMS. It would be beneficial for decision makers to understand how many of these immunizations are given through campaign outreach in order to decide where to allocate funds. This would also allow decision makers to understand the influence campaigns have on the number of children immunized after a reported stockout.

Recommendation Three:

- Consider performing this analysis at the national level. Performing this analysis at the regional level does not provide insight into how stockouts effect under-five mortality estimate with current available tools. The impact on this estimate could be determined by analyzing stockouts and the number of children immunized at the national level.

Recommendation Four:

- Encourage timely and accurate reporting at the facility level. Timely and accurate reporting in VIMS will not only improve vaccine management through ensuring adequate supply but will also provide insight for decision makers on where improvements can be made.

Recommendation Five:

- Continue to support funding of VIMS in Tanzania and implementation of VIMS in other low-and-middle income countries. VIMS is a novel information system combining logistic data and health information. This electronic logistic management information system allows stakeholders to measure the impact of their services and provides insight for better decision making.

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