Is childhood immunization associated with competing mortality risks? A case study for Kenya.

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Abstract

Introduction Immunization coverage is insufficient in Kenya. Evidence suggests that health investments may be associated with the various health risks that an individual faces, also known as competing mortality risks (CMR). This paper aims to establish the association between CMR and the immunization coverage in Kenya.

Methods Global burden of disease data and demographic health survey data were combined to create a measure of basic vaccination status, competing mortality risks, other health risks, and controls for every child observed in the DHS data. A linear probability panel data analysis and logistic regression were performed to estimate the association.

Results The data included 16,286 children born in 2009-2014 who had lived for at least 12 months at date of interview. Between counties, mean basic vaccination rates varied from 27,1% to 86,5% and mean CMR from 118,6 to 882,7 deaths per 100,000. The linear probability model estimated that a one-unit change in competing mortality risks is associated with a decrease of -0.06% in basic vaccination status. Translating this to percentage points, a 0,1%-point increase in CMR yields a decrease of 6% in vaccination status. Panel data analysis and logistic regression estimated similar negative associations.

Discussion The results in this paper show a large negative association between CMR and vaccination status, which may yield important policy implications in Kenya. Vertical, disease-specific interventions, targeted at lowering the most severe competing mortality risks in a region may improve immunization coverage. However, the results must be interpreted with caution due to their limited extrapolation. Important limitations include a lack of data on polio and unmeasured controls that could have led to omitted variable bias.

Conclusion This paper successfully established a negative association between competing mortality risks and the immunization coverage in Kenya. As households deal with more mortality risks, children are less likely to receive all basic vaccinations.

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[2] The views, opinions, findings, and conclusions or recommendations expressed in this paper are strictly those of the author. The author has no conflict of interest to declare and received no funding support for this work. The author meets ICMJE authorship criteria.

[3] This article was written and formatted according to the Lancet, Global Health guidelines (The Lancet, 2021)

Introduction

Immunization is a vital element of preventive health care and remains one of the key components to reduce child mortality and morbidity worldwide (Plotkin & Plotkin, 2013). Both immunization and under-5 mortality play an important role in health care policy and are monitored by the Sustainable Development Goals (SDGs) (United Nations, 2020). The World Health Organization (WHO) works alongside governments, healthcare professionals, and a host of health and development partners to achieve the health-related targets laid out in the SDGs. With over 194 member states endorsing plans such as the *Global Vaccine Action Plan* (GVAP; World Health Organization, 2013) and *Immunization Agenda 2030* (IA2030; World Health Organization, 2020), the WHO is one of the key actors involved in policies regarding immunization coverage worldwide. Substantial improvements in immunization coverage have been made over the past two decades (World Health Organization, 2020). Between 2010 and 2017, the global under-5 mortality experienced a decrease of 22%, due in large part to improved immunization (The World Bank, 2019; World Health Organization, 2020). However, the most recent World Health Statistics report shows a stagnation of global immunization coverage and calls for increased efforts in order to accelerate progress and enable counties to reach their SDG goals by 2030 (World Health Organization, 2020). In addition, the WHO expresses concern for unequal immunization opportunities among children and reveals gaps in immunization coverage within countries and population subgroups (World Health Organization, 2018). Multiple strategies have been employed to stimulate childhood immunization in underprivileged countries, with varying success. The WHO calls for further research to determine the impact of policies, programs, and other factors associated with the effective delivery of child immunization (World Health Organization, 2018). This paper aims to answer this call by increasing our existing knowledge on the association between childhood immunization and competing mortality risks in Kenya.

Childhood immunization

The benefit of vaccination on global health is not easily exaggerated. With the exception of clean water, no other instrument, not even antibiotics, has had such a great impact on reducing mortality across all ages and continents in the past (Plotkin & Plotkin, 2013). This is partly due to a mechanism known as "herd immunity", which occurs when a sufficient proportion of the population is immune and prevents the transmission of infectious diseases (Jacob John & Samuel, 2000). Efficacious vaccines therefore not only protect the immunized, but significantly decrease the spread of disease in the community at large. Due to herd immunity, multiple infectious diseases have been successfully eliminated without reaching 100% immunization coverage (Andre, et al., 2007). In addition, vaccinations impact population health by preventing cancers associated with the infective agents. Persistent infections can cause chronic inflammation which is closely related to several cancers. Examples of infective agents

and their corresponding cancer are hepatitis B or C and hepatoma, human papilloma virus and cervical cancer, and helicobacter pylori and gastric cancer (Chang, 2009). Vaccinations may prevent cancers by reducing the opportunity for persistent infections and chronic inflammation. For example, both hepatitis B and human papillomavirus vaccines are known to have a prophylactic effect on the occurrence of liver and cervical cancer, respectively (Chang, 2009; Saslow, et al., 2007). Furthermore, immunization has proven to be an important tool for long-term cost saving and economic growth. Childhood vaccination has found to be associated with improved scores in IQ, language and mathematics tests in ten-year olds (Bloom, Canning, & Weston, 2005). The long-term health benefits provided through immunization appear to impact cognitive ability positively, which is associated with higher earnings in adulthood. Through boosting cognitive abilities and improving children's prospects, vaccinations provide a large return on a small investment (Bloom, Canning, & Weston, 2005). Using a full-income approach, Ozawa et al. estimated a return of investment of 44 times the costs (Ozawa, et al., 2016). In contrast to a cost-of-illness approach, a full-income approach incorporates the broader economic benefits of vaccination through quantifying the value people place on living longer and healthier lives (Ozawa, et al., 2016). With an estimated return of investment of 44 times the costs, improved immunization programs may not only increase survival, but provide an important tool for strengthening economies as well.

The association between immunization coverage and various socioeconomic, geographic and demographic factors has been well-investigated. Studies throughout Asia and Africa are consistent in their findings of the main determinants of immunization coverage (Nath, et al., 2007; Maina, Karanja, & Kombich, 2013; Bondy, Thind, Koval, & Speechley, 2009). The most prominent determinants appear to be maternal age, level of education and socioeconomic status. Though less evident; religion, birth order, and distance to health care facility were also found to be associated with immunization coverage (Nath, et al., 2007). The WHO finds similar results in a study on the determinants of immunization inequality in the top 10 priority countries worldwide (World Health Organization, 2018). These priority countries were determined by the Global Alliance for Vaccines and Immunization (GAVI). They require further assistance and funding to increase their immunization coverage and consist of: Afghanistan, Chad, Democratic Republic of Congo, Ethiopia, India, Indonesia, Kenya, Nigeria, Pakistan, and Uganda (GAVI, 2020).

The benefits of vaccination and the determinants of immunization coverage have been well established in the available literature. However, research has yet to analyze the relationship between childhood immunization and *competing mortality risks*: "the various causes of death competing to the end of one's life" (Chiang, 1991). This forces households to consider whether they should invest in lowering the mortality risk of one disease, when the risk of dying from another disease may seem equally or more pressing. Rossi et al. (2020) analyzed households' behavioral responses to a public intervention that

lowered the risk of malaria in Senegal. They found that subsidizing anti-malaria interventions and thereby lowering competing mortality risks, increased households' expenses to prevent other diseases (Rossi & Villar, 2020). In light of this evidence, it seems plausible that the competition of health risks within a country may be associated with the immunization coverage as well. Organizations such as the WHO and GAVI have been struggling to decrease under-5 mortality for the past few decades through programs like GVAP and IA2030 (GVAP; World Health Organization, 2013, IA2030; World Health Organization, 2020). An association between competing mortality risks and the immunization coverage may have important policy implications for priority countries. Horizontal (health system-wide) interventions are generally preferred over vertical (disease-specific) interventions, as it is often argued that targeting one specific disease may impact other diseases negatively by drawing limited resources, such as funding, away (Rossi & Villar, 2020). However, as Rossi et al. (2020) show, the decrease in risk for a single disease may positively impact health seeking behavior towards other diseases. If this association extends itself towards vaccinations, it may be useful to consider regional competing mortality risks with respect to policies aimed at increasing immunization coverage. This paper intends to investigate whether the degree of child immunization is indeed associated with competing health risks in Kenya.

Kenya experienced a significant decrease in under-5 mortality from 89,9 to 43,2 deaths per 1,000 from 2000 to 2019 (The World Bank, 2019). Nevertheless, the country has a long way to go before reaching the SDG of 25 deaths per 1,000 (World Health Organization, 2020). Signatory to the WHO's GVAP, the Kenyan government committed to fully vaccinating 90% of all children by 2020, with a minimum of 80% in all administrative counties (World Health Organization, 2013). Progress is being made as Kenya's Diphteria-Pertussis-Tetanus (DPT3) coverage—a metric commonly used to gauge immunization coverage—was estimated by the WHO to have increased 10% from 2000 to 2019 (World Health Organization, 2020). Although immunization services are offered free-of-charge in public facilities and substantial improvements have been made at the national level, large differences between population subgroups persist (World Health Organization, 2018). Of all children in Kenya aged 12-23 months, 79% were reported as having received all basic vaccinations (Kenya National Bureau of Statistics , 2014). However, this proportion varies from 55,6% in the North Eastern Province to 93,3% in the Central Province. Studies performed in the slums of Nairobi reported similar inequalities, with an immunization coverage of 44% in the slums compared to 73% for the whole of Nairobi (Magadi, 2004). As a result of insufficient coverage, GAVI classified Kenya as a Tier 1 Priority Country in receiving targeted assistance and funding for improving immunization coverage (GAVI, 2020).

Competing mortality risks

The term "competing mortality risks" (CMR) embodies all different health risks exercising competing forces on life (Dow, 1999). It forces households to weigh the benefit of a specific health investment, as it may seem less appealing considering all other possible health risks. On the other hand, a price reduction in one specific health investment may lead to an increase in other health investments, a phenomenon known as "the spillover effect" (Chiang, 1991). In this way, health investments for seemingly unrelated diseases are connected through competing mortality risks.

A model of health investments under competing mortality risks imposes complementarities between disease-specific investments. As recently demonstrated by Rossi et al. (2020), public and private health investments were found to be complements (Rossi & Villar, 2020). Public investments in malaria treatment and prevention incentivized parents to make other, private investments in their child's health. This idea of disease-specific complementarities reverberates through the theoretical literature on health investment decisions. In a deterministic setting, the notion of complementarities has been explained via a Leontief production function of overall lifetime under competing risks (Dow, 1999). This implies non-substitutable input factors, used in fixed proportions, through which a consumer will act towards equalization of competing risks. A consumer will only be incentivized to invest in disease X when the risk of dying from disease Y is equalized. Considering the theoretical framework of competing mortality risks, the degree of immunization coverage may be connected to other, unrelated diseases in a region. When households are faced with numerous, more prevalent and pressing mortality risks, immunizing a child may seem unprofitable. Analyzing the association between vaccination coverage and competing mortality risks may improve our understanding of immunization and bear important policy implications.

Methods

Data collection

In estimating the association between CMR and immunization, individual household data in Kenya was complemented with subnational county-level data on mortality risks. Two databases were merged to conduct this secondary data analysis. Data concerning child immunization status and family characteristics was collected from The Demographic and Health Surveys (DHS) Program. The 2014 DHS-Vll Children's Recode includes one record for every child per interviewed woman, born within five years preceding the date of interview. The survey contains maternal and child information regarding pregnancy, postnatal care, immunization, and health for children born between 2009 and 2014. Using DHS data on childhood immunization, a child's basic vaccination status was determined. Besides immunization, DHS data on maternal, socioeconomic, demographic and geographic factors was included. The Global Health Data Exchange database (GHDx*)* 2019*,* created by the Institute for Health

Metrics and Evaluation (IHME), was consulted for data on regional disease burdens in Kenya in order to compute a metric for competing mortality risks. The GHDx is one of the most extensive, publicly available global health databases and provides annual data from 1990 to 2019 for 195 countries and 297 diseases. Data provided detailed information on regional disease burdens for children aged 1-4 for various categories of diseases from 2009 to 2014 and was available for all 47 Kenyan counties separately. This made it possible to calculate regional competing mortality risks for children in the immunization age.

Measurement of immunization and competing health risks

The DHS follows the guidelines developed by the WHO and states "basic vaccinations" as: 1 dose of TBC (tuberculosis), 3 doses of DPT (diphtheria, pertussis, tetanus, hepatitis b, haemophilus influenza type b), 3 doses of polio vaccine, and 1 dose of measles vaccine, which conforms to Kenya's national policy (Croft, Marshall, & Allen, 2018; Kenya Ministry of Health, 2013). Furthermore, basic vaccinations must be provided within the first 12 months of life. For empirical reasons, children born within 12 months of interview date were therefore excluded. Basic vaccination status was valued "1" if children had received all necessary vaccinations and "0" if this was not the case.

Total death rates for children aged 1-4 were provided by the GHDx data and reported as the number of deaths per 100,000. Each region and year were assigned a total death rate, representing *all mortality risks* (e.g Nairobi was allocated a death for children aged 1-4 for the years 2009-2014). Alongside these total rates*, vaccine-preventable death rates* were calculated for DPT, TBC, and measles. DPT's disease burden was a combination of the death rates for diphtheria, pertussis, tetanus, and hepatitis b. It was not possible to determine death rates for polio as the GHDx did not provide sufficient data. Competing mortality risks, defined in this paper as *all health mortality besides vaccine-preventable mortality*, were computed by subtracting vaccine-preventable risks from all mortality risks in a certain region and year. Subsequently, DHS and GHDx data were merged and all children were assigned total-, vaccine-preventable-, and competing mortality risks, in accordance with their county of residence and year of birth. Because this analysis focusses on children aged 1-4, all competing mortality risks occurring before the age of 1 were disregarded. Therefore, children that had died before reaching te age of 1 were excluded from analysis.

Statistical analysis

In order to model the probability of being vaccinated in the presence of competing mortality risks, multiple statistical models were employed. First, a linear probability model (LPM) was conducted using "basic vaccination status" as the dependent variable and "competing mortality risks" as the main

independent variable of interest. (Aldrich & Nelson, 1984). Other independent variables incorporated in the linear probability analysis included the death risks of vaccine-preventable diseases (DPT, TBC, measles). Maternal controls included in the analysis were: age at birth of child, years of education, ethnicity and religion. Family and child-level controls included wealth score, distance to nearest health care facility, and birth order. DHS data reported wealth scores as a proxy for household's long-term standard of living, consistent with expenditure and income measures (Kenya National Bureau of Statistics, 2015).

Secondly, a fixed effects panel data analysis was used to estimate the effect of changing competing mortality risks over time for mothers with ≥ 2 children. All controls were time-invariant in the DHS data and could therefore not be included in the fixed effect analysis. Lastly, to illustrate robustness of results, a logistic regression reporting marginal effects was included. Results are presented as coefficients with clustered standard errors and 95% confidence intervals. The threshold for statistical significance was set at $p<0.05$. Data were analyzes using Stata version 16 (StataCorp LLC, 2020).

Results

The data included 16,286 children born in 2009-2014 that had lived for a minimum of 12 months at date of interview (table 1). Competing mortality risks were computed for 2009-2013, since no children born in 2014 aged ≥12 months at date of interview. 66,5% of all children in the study cohort received all basic vaccinations. Complete TBC vaccinations were most frequently received (94,1%), followed by measles (86,2%), DPT (86%) and polio (76,8%). Both total, vaccine-preventable and competing mortality risks decline on a national level throughout the study period. 23 ethnicities and 5 religious categories were included in analysis. Between counties, mean basic vaccination rates varied from 27,1% to 86,5% Mean competing mortality risks varied from 118,6 to 882,7 deaths per 100,000. An overview of county-level descriptive statistics is provided in Appendix A (table 1B).

Table 1: Summary statistics study cohort

Variable	Mean	Std. Dev.	Min	Max
Vaccination status				
All basic vaccinations	.665	.472	0	1
Full TBC vaccine	.941	.235	0	1
Full measles vaccine	.862	.345	0	1
Full DPT vaccine	.86	.347	0	1
Full polio vaccine	.768	.422	0	1
Year of birth[1]				
2009	.086	.28	0	1
2010	.252	.434	0	1
2011	.258	.437	0	1
2012	.244	.43	0	1
2013	.16	.367	0	1
2014	0	0	0	0
Competing mortality risks[2]				
2009	404.734	245.124	137.616	1036.386
2010	377.797	223.751	127.503	959.272
2011	345.828	199.768	120.625	882.673

2013	323.51	186.523	105.901	812.456
2014	315.415	178.454	103.557	779.827
Mortality rate TBC[3]				
tbc09	5.391	5.119	.15	19.868
tbc10	5.748	5.306	.18	20.242
tbc11	5.787	5.187	.187	19.69
tbc12	5.358	4.741	.175	18.114
tbc13	5.178	4.553	.179	18.237
tbc14	4.761	4.132	.165	17.238
Mortality rate DPT[3]				
dpt09	11.003	7.775	1.087	36.919
dpt10	12.619	8.764	1.243	41.797
dpt11	12.41	8.637	1.219	41.139
dpt12	11.416	8.073	1.02	38.528
dpt13	11.401	8.457	.954	43.262
dpt14	11.349	8.357	.97	42.406
Mortality rate measles[3]				
Meas09	32.689	18.454	7.535	78.528
Meas10	21.116	11.72	5.239	51.134
Meas11	23.813	12.928	6.037	57.232
Meas12	36.128	19.689	8.298	87.145
Meas13	22.21	12.533	5.106	57.136
Meas14	21.588	12.526	4.797	59.164
Maternal/ household characteristics				
Mother's age at birth of child	26.64	6.423	12.667	47.417
Wealth index factor score	-20930.202	99130.169	-250248	361848
Education in single years	6.496	4.357	0	19
Distance to health facility				
Big problem	.154	.361	0	1
Not a big problem	.327	.469	0	1
Ethnicity				
Embu	.008	.09	0	1
Kalenjin	.153	.36	0	1
Kamba	.077	.267	0	1
Kikuya	.116	.32	0	1
Kisii	.049	.217	0	1
Luhya	.119	.324	0	1
Luo	.103	.304	0	1
Maasai	.033	.178	0	1
Meru	.037	.189	0	1
swahili Mijikenda	.058	.233	0	1
Somali	.083	.276	0	1
taita taveta	.01	.1	0	1
Turkana	.034	.18	0	1
Sambura	.031	.172	0	1
Pokomo	.013	.113	0	1
Iteso	.009	.096	0	1
Boran	.017	.13	0	1
Gabbra	.007	.083	0	1
Kuria	.008	.09	0	1
Orma	.004	.065	0	1
Mbere	.005	.073	0	1
Rendille	.004	.062	0	1
Other ethnicity	.022	.146	0	1
Roman Catholic	.184	.388	0	1
Protestant and other Christian	.618	.486	0	1
Muslim	.167	.373	0	1
No religion	.025	.158	0	1
Other religion	.003	.055	0	1

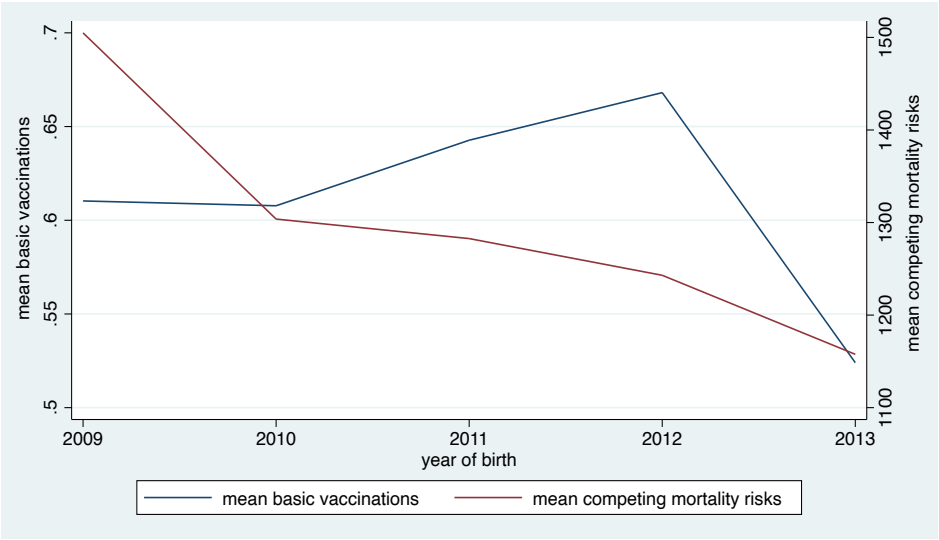
Abbreviations: TBC, tuberculosis; DPT, diphtheria-pertussis-tetanus.

[1] *Year of birth of child*

[2] *Competing mortality risk calculated as deaths per 100,000 for children aged 1-4 in Kenya for all causes except vaccine-preventable diseases (dpt, tbc, measles).*

[3] *Mortality rates for dpt, tbc, and measles calculated as deaths per 100,000 for children aged 1-4 in Kenya for dpt, tbc, and measles respectively.*

Graph 1: mean basic vaccinations and mean competing mortality risks over time



Mean competing mortality risks were calculated as the mean deaths per 100,000 for children aged 1-4 in Kenya in 2009-2013 for all causes except vaccine-preventable diseases (dpt, tbc, measles). Mean basic vaccinations were calculated as the mean amount of children aged >12 months to have received all basic vaccinations (tbc, dpt, measles, polio) in Kenya in 2009- 2013.

Graph 1 shows the correlation between mean competing mortality risks and mean basic vaccination rates for all children born in Kenya between 2009-2013. Without controlling for any other variables, graph 1 shows a negative correlation between CMR and basic vaccinations between 2009-2012.
This negative correlation seemingly disappears in 2013. One potential explanation for this may be a disproportional exclusion of children born in 2013 throughout the various counties. This could have taken place when excluding all children born within 12 months of interview date. However, as seen in Appendix B, this does not seem to be the case. The percentages of children excluded based on age at date of interview are evenly distributed among counties. However, the amount of observations in 2013, which was lower than in previous years (see Table 1), may provide an explanation for the converging lines due to a difference in means. The graphs included in Appendix C plot mean basic vaccinations and mean competing mortality risks for the first, second, and third birth order. Similar negative correlations are observed.

The results of the cross-sectional linear probability model are shown in Table 2. Both the adjusted and the unadjusted model report similar negative coefficients (-0.0005, P<0.01 and -0.0006, P<0.01), indicating a negative association between CMR and basic vaccination status. One-unit change in competing mortality risks is associated with a decrease of -0.06% in basic vaccination status. Translating this to percentage points, a 0,1%-point change in CMR yields a coefficient of -0,06 or a decrease of 6% in vaccination status per 0,1%-point CMR. Important to note here is the scope of variation within CMR. Appendix A reports a maximum difference of 764,2 in mean competing mortality risks between counties (mix 118,5, max 882,7), indicating a maximum range of 0,76% in

CMR variation, which limits the extrapolation range of the association. As reported by the coefficients and p-values, the DPT death rate (-0,0169, P<0.01), TBC death rate (0.0306, P<0.01), and education (0.009, P<0.01) were significantly associated with basic vaccination status. The same was true for birth order and religion, reporting a significant positive and negative association respectively (Appendix D, table 2B). The negative association between CMR and basic vaccinations increases by 20% when controls are added (-0,0005 to -0,0006).

Table 2: cross-sectional linear probability model

	(1) Basic vaccinations	[95% Conf Interval]	(2) Basic vaccinations	[95% Conf Interval]
Competing mortality risks[1]	-.0005***	[-0.0008, -0.0002]	-.0006***	[-0.001, -0.0002]
	(.0002)		(.0002)	
Death rate DPT[2]	-.0169***	[-0.0232, -0.0105]	-.014***	[-0.0204, -0.0076]
	(.0031)		(.0032)	
Death rate TBC[2]	.0306***	[0.0175, 0.0436]	.0257***	[0.0078, 0.0435]
	(.0065)		(.0089)	
Death rate measles[2]	-.0012	[-0.0033, 0.0009]	.0007	[-0.0006, 0.0021]
	(.001)		(.0007)	
Mother's age[3]			.0001	[-0.0013, 0.0014]
			(.0007)	
Wealth score			0	[-1.343e-07, 1.946e-07
			(0)	
Education in single years			.009***	[0.0049, 0.0132]
			(.0021)	
Distance to health facility: big problem			.0098	[-0.0266, 0.0461]
			(.0181)	
Distance to health facility: not a big problem			.0016	[-0.0171, 00203]
			(.0093)	
_cons	.9011***	[0.8291, 0.9730]	1.0364***	[0.3535, 1.7193]
	(.0358)		(.3393)	
Observations	16286		16286	
R-squared	.053		.081	
Ethnicity dummies	NO		YES	
Religion dummies	NO		YES	
Birthorder dummies	NO		YES	

Clustered standard errors are in parentheses
*** p<.01, ** p<.05, * p<.1*
Abbreviations: TBC, tuberculosis; DPT, diphtheria-pertussis-tetanus.
[1] *Competing mortality risk calculated as deaths per 100,000 for children aged 1-4 in Kenya for all causes except vaccine-preventable diseases (dpt, tbc, measles).*
[2] *Mortality rates for dpt, tbc, and measles calculated as deaths per 100,000 for children aged 1-4 in Kenya for dpt, tbc, and measles respectively.*
[3] *Mother's age at birth of child*

Table 3 reports the results from panel data analysis with fixed effects. After excluding mothers with only one birth between 2009-2014, 8280 mothers remained. Birth order of children per mother constituted the time variable, with a maximum of 4 births. The employment of panel data may control for unmeasured and unobserved time-invariant maternal—and therefore also household—characteristics. Though similarly negative, the CMR coefficient has increased by 20% compared to the adjusted linear probability model (-0.0007, P<0,01). A one-unit change in competing mortality risks is associated with a decrease of -0.07% in basic vaccination status. All controls included in the LPM were time-invariant and therefore excluded from panel data analysis.

Table 3: panel data analysis with fixed effects

	(1) Basic vaccinations	[95% Conf Interval]
Competing mortality risks [1]	-.0007***	[-0.0009, -0.0004]
	(.0002)	
Death rate DPT	-.0114**	[-0.0218, -0.001]
	(.0053)	
Death rate TBC	.0194***	[0.0047, 0.0434]
	(.0123)	
Death rate measles	.0002	[-0.0014, 0.0019]
	(.0008)	
_cons	.8863***	[0.7062, 1.0663]
	(.0918)	
Observations	8280	
R-squared	.0106	

Clustered standard errors are in parentheses
**** p<.01, ** p<.05, * p<.1*
Abbreviations: TBC, tuberculosis; DPT, diphtheria-pertussis-tetanus.
[1] *Competing mortality risk calculated as deaths per 100,000 for children aged 1-4 in Kenya for all causes except vaccine-preventable diseases (dpt, tbc, measles).*
[2] *Mortality rates for dpt, tbc, and measles calculated as deaths per 100,000 for children aged 1-4 in Kenya for dpt, tbc, and measles respectively.*
[3] *Mother's age at birth of child*

In order to test robustness of results, a logistic regression was conducted of which the results are reported in Appendix E (table 4A). Coefficients reported similar negative and positive associations as those seen in LPM and panel data. A slight change in the CMR coefficient was observed after adding controls. Average marginal effects for variables that presented significant associations are reported in table 4. Based on logistic regression, one-unit change in competing mortality risks is associated with a decrease of -0.06% in basic vaccination status. This is equivalent to the effect reported by unadjusted LPM.

Table 4B: Average marginal effects from logistic regression

	dy/dx	Std.Err.	Z	P>z	[95% Conf Interval]
Competing mortality risks	-0.0006	0.0002	-3.0700	0.0020	[-0.0009, -0.0002]
Death rate DPT	-0.0132	0.0030	-4.4500	0.0000	[-0.0190, 0.0074]
Death rate TBC	0.0242	0.0084	2.87	0.0040	[0.0077, 0.0408]
Education	0.0091	0.0020	4.65	0.0000	[0.0053, 0.0129]

Abbreviations: TBC, tuberculosis; DPT, diphtheria-pertussis-tetanus.

Discussion

The results reported in this paper indicate a negative association between competing mortality risks and the immunization coverage in Kenya. All analyses indicated a negative association, illustrating robustness of results. As the amount of competing mortality risks in a county increase, we see a negative trend in immunization coverage. In line with Dow's theory on disease-specific complementarities, immunization may be connected to all other unrelated health risks in a certain region (Dow, 1999). Parents might only be incentivized to invest in immunization when the risk of dying from other diseases is lowered. This supports earlier findings by Rossi et al. (2020), who reported an increase in private health investments as competing mortality risks decreased (Rossi & Villar, 2020). Though basic

vaccinations are free-of-charge in Kenya, immunization may be seen as a private health investment since it requires personal effort, time, and resources (e.g. transportation).

Besides CMR, this paper also reports significant associations of immunization with the death rate for DPT, death rate for TBC and education. In line with previous findings, education is the most significant control variable associated with vaccination status (Nath, et al., 2007; Maina, Karanja, & Kombich, 2013; Bondy, Thind, Koval, & Speechley, 2009). This supports global immunization policy focused on knowledge building and education. In terms of death rates for vaccine preventable diseases, one would expect a positive association with basic vaccination status, following the logic that an increased mortality risk incentivized parents to immunize their children. Though the association between the death rate for TBC is positive, the death rate for DPT reports a negative coefficient. A potential explanation for this may be found in the differences in administration for these vaccines. While a TBC vaccine is given directly at birth, the DPT vaccine must be given at 6, 10, and 14 weeks of age and therefore has a more complicated administration. The TBC vaccine is often directly offered by the health care professional present at birth, whereas the DPT vaccine administration requires more effort, discipline, and active planning by parents. A more complicated vaccine administration may impact basic vaccination status by lowering the likelihood of full DPT immunization. For the same reasons, it may impact the death rate for DPT. Therefore, the administration of the DPT vaccine may bias the correlation between basic vaccination status and the death rate for DPT, as it affects them both directly.

When interpreting the results, it is important to consider the scope of variation within CMR. An association of 6% change in vaccination status per 0,1%-points is substantial. However, as discussed in the results, the maximum range within which mean CMR differs is 0,76%. Still, CMR may be associated with large differences in vaccination status and yield important policy implications. Plans such as the Immunization Agenda 2030 report horizontal, health-system wide goals targeting the health workforce, surveillance systems, and supply chain and logistics (World Health Organization, 2020). However, the results reported in this paper support the statement by Rossi et al. (2020) that vertical, disease-specific interventions, may be effective through "the spillover effect" (Rossi & Villar, 2020; Chiang, 1991). This paper is the first to show that previous knowledge on competing mortality risks is applicable to childhood immunization as well. Decreasing the burden of a disease that imposes severe competing mortality risks in a region may incentivize parents to make other, private health investments. This may provide an implication for more regionally focused health policies that target the most prevalent mortality risks in a county. Not only would this decrease the burden of predominant diseases in an area, it may also affect the immunization coverage positively through the framework of competing mortality risks.

However, the results bear some important limitations as well. Due to a lack of data, it was impossible to compute a death rate for polio. Thus, not all relevant health risks were included in the analysis. Furthermore, it is beyond the scope of this study to draw a causal conclusion on the effect of CMR on immunization coverage. While all relevant and available DHS variables were included, it is plausible that unmeasured controls could affects the results through omitted variable bias. Though panel data analysis solved part of this problem by controlling for unobserved characteristics within a household, variables such as county GDP, amount and quality of health facilities, and provision of immunization information would have ideally been included. In addition, the generalizability of the results remains limited as the study sample, though quite large, was restricted to Kenya. It is difficult to say if a country with different maternal, demographic, socioeconomic characteristics and trends would yield similar results.

Though this paper reports promising results that are in line with recent evidence, further research is still needed to establish a direct causal effect of competing mortality risks on immunization. In doing so, countries with different predominant diseases, health systems, socioeconomic, and demographic factors should be taken into consideration. Additionally, future papers might consider Disability Adjusted Life Years (DALYs) to compute a measure for CMR since it incorporates both morbidity and mortality. In terms of Kenya, it may be interesting to develop a more comprehensive understanding of the variation in CMR per county. This may lead to more detailed conclusions about the associations between CMR and immunization coverage.

Conclusion

This paper successfully established a negative association between competing mortality risks and the immunization coverage in Kenya. As households deal with more mortality risks, children are less likely to have received all basic vaccinations. This supports the notion of disease-specific complementarities, imposed by Dow (1999) and Rossi et al. (2020), and provides important policy implications for Kenya. Accelerated efforts are required if Kenya is to reach the SGD goals regarding immunization. The evidence presented in this paper suggests that vertical, disease-specific, interventions may be able to boost the immunization coverage. However, causal effects must be confirmed by further research, for which this paper provides a good foundation.

Contributors

Raf van Gestel, assistant professor at Erasmus University, supervised the initiation of the study, provided critical evaluation and revision throughout the process, and reviewed and edited drafts of the paper.

Data sharing

No primary data were collected for this study. GHDx data is publicly available at http://ghdx.healthdata.org/gbd-2019, DHS data is available after registration at https://dhsprogram.com/data/new-user-registration.cfm.

Declarations of interests

We report no declarations of interest.

Acknowledgments

We are grateful for the Erasmus University of Rotterdam, The Institute for Health Metrics and Evaluation, and The Demographic and Health Surveys (DHS) Program for having provided the resources for this research.

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Appendices

Appendix A

Table 1B: Summary statistics per county

	All basic vaccinations	Full TBC[1]	Full DPT[1]	Full measles[1]	Full polio	CMR[2]	Mother's age[3]	Education[4]	Wealth score	Distanc: problem	Distance: no problem
Baringo	.695	.976	.893	.934	.78	118.639	25.639	10.212	133032.52	.051	.439
Bomet	.747	1	.865	.935	.849	174.594	27.717	8.816	18475.073	.135	.31
Bungoma	.722	.987	.919	.923	.812	197.904	27.156	9.799	70663.15	.094	.389
Busia	.619	.984	.974	.952	.651	313.99	27.342	8.545	31019.894	.058	.439
Elgeyo Marak	.733	.986	.937	.977	.747	183.702	27.388	8.738	24167.738	.081	.385
Embu	.733	.988	.967	.947	.774	178.043	27.356	10.292	100993.03	.029	.44
Garissa	.661	.984	.859	.919	.734	291.827	26.385	8.097	104312.66	.085	.403
Homa Bay	.794	.971	.904	.91	.878	250.098	27.069	4.366	-53046.436	.105	.392
Isiolo	.712	.953	.91	.882	.847	351.592	27.094	4.844	-38253.741	.158	.302
Kajiado	.665	.944	.851	.808	.812	460.951	27.062	3.538	-98478.556	.23	.212
Kakamega	.62	.957	.749	.853	.842	368.083	27.093	5.287	-7263.405	.143	.344
Kericho	.78	.973	.942	.91	.87	298.115	28.363	8.193	21499.821	.152	.336
Kiambu	.656	.933	.848	.825	.813	352.362	25.408	1.519	-118816.47	.207	.286
Kilifi	.741	.944	.893	.878	.832	668.489	26.417	3.324	-58937.993	.085	.376
Kirinyaga	.785	.972	.939	.927	.838	348.672	26.482	7.943	18574.964	.113	.393
Kisii	.855	.99	.942	.976	.874	259.492	28.246	7.401	-12231.657	.208	.275
Kisumu	.833	.986	.943	.914	.924	234.71	26.669	8.667	26370.905	.124	.367
Kitui	.744	.988	.903	.934	.809	261.773	27.447	7.103	-46034.797	.3	.188
Kwale	.848	.993	.976	.962	.883	174.962	26.681	8.772	17250.872	.183	.303
Laikipia	.839	.991	.947	.972	.892	197.823	27.075	8.229	-11878.582	.223	.269
Lamu	.51	.806	.82	.767	.694	170.234	27.55	.789	-78576.347	.248	.255
Machakos	.361	.793	.652	.676	.467	296.021	27.403	1.112	-103454.87	.255	.173
Makueni	.271	.673	.495	.606	.364	463.739	27.69	.684	-91833.854	.322	.194
Mandera	.631	.957	.897	.866	.689	761.863	25.749	8.163	-1835.8	.066	.351
Marsabit	.701	.966	.864	.907	.78	447.356	25.775	8.562	17504.853	.218	.257
Meru	.357	.811	.783	.797	.544	852.875	25.394	6.98	-33485.641	.128	.345
Migori	.553	.921	.773	.841	.676	882.696	25.156	8	-16689.163	.15	.338
Mombasa	.775	.986	.934	.893	.876	181.384	26.201	8.997	-3209.723	.069	.393
Muranga	.865	.986	.972	.965	.91	130.402	25.841	9.664	-1733.744	.066	.422
Nairobi	.529	.895	.749	.744	.649	437.364	27.667	1.393	-138725.7	.218	.268
Nakuru	.365	.773	.697	.646	.582	456.877	27.462	4.365	-76520.039	.227	.283
Nandi	.621	.93	.844	.786	.763	326.489	25.77	2.177	-105128.01	.202	.312
Narok	.603	.962	.802	.854	.743	324.615	26.91	7.962	10173.653	.12	.35

Nyamira	.729	.985	.909	.897	.817	501.789	26.244	6.897	-51328.448	.248	.215
Nyandarua	.681	.952	.896	.89	.743	196.663	26.462	9.081	33811.427	.081	.421
Nyeri	.842	.981	.935	.916	.882	130.83	26.926	8.888	-17704.643	.04	.457
Samburu	.902	.987	.979	.955	.95	137.614	26.27	8.54	-594.934	.095	.389
Siaya	.765	.984	.919	.899	.853	173.043	27.532	6.309	-21810.713	.088	.368
Taita Taveta	.764	.975	.917	.892	.864	231.817	26.749	8.628	45235.361	.097	.378
Tana river	.623	.956	.822	.816	.764	134.435	26.253	5.709	-48816.423	.144	.324
Tharaka	.496	.976	.724	.824	.619	177.913	26.312	5.745	-2756.003	.113	.365
Trans-Nzoia	.667	.973	.882	.879	.794	236.572	25.945	8.755	-20696.31	.375	.153
Turkana	.845	.992	.952	.915	.909	125.457	25.532	8.275	-31299.968	.037	.451
Uasin Gishu	.629	.956	.869	.857	.733	653.808	26.141	7.767	3053.607	.172	.328
Vihiga	.848	.971	.949	.94	.876	473.167	27.358	8.222	-4673.419	.143	.352
Wajir	.691	.975	.868	.857	.814	472.452	27.045	8.093	-10677.659	.232	.259
West Pokot	.689	.989	.881	.879	.813	482.79	25.888	6.58	-16155.953	.084	.414

Abbreviations: TBC, tuberculosis; DPT, diphtheria-pertussis-tetanus, CRM, competing mortality risks.
[1] Child received all necessary vaccinations for respective disease.
[2] Competing mortality risk calculated as deaths per 100,000 for children aged 1-4 in Kenya for all causes except vaccine-preventable diseases (dpt, tbc, measles).
[3] Mother's age at birth of child
[4] In single years

Appendix B

Table 1c: number of children excluded per county [1]

county of residence - as in the sample file	Freq.	Percent	Cum.
Nairobi	97	2.41	2.41
Nyandarua	49	1.22	3.62
Nyeri	43	1.07	4.69
Kirinyaga	37	0.92	5.61
Muranga	48	1.19	6.80
Kiambu	62	1.54	8.33
Mombasa	61	1.51	9.85
Kwale	104	2.58	12.43
Kilifi	120	2.98	15.40
Tana river	130	3.22	18.63
Lamu	70	1.74	20.36
Taita taveta	58	1.44	21.80
Marsabit	95	2.36	24.16
Isiolo	85	2.11	26.26
Meru	62	1.54	27.80
Tharaka	41	1.02	28.82
Embu	55	1.36	30.18
Kitui	87	2.16	32.34
Machakos	90	2.23	34.57
Makueni	67	1.66	36.24
Garissa	112	2.78	39.01
Wajir	116	2.88	41.89
Mandera	71	1.76	43.65
Siaya	76	1.88	45.54
Kisumu	82	2.03	47.57
Migori	120	2.98	50.55
Homa bay	111	2.75	53.30
Kisii	79	1.96	55.26
Nyamira	59	1.46	56.72

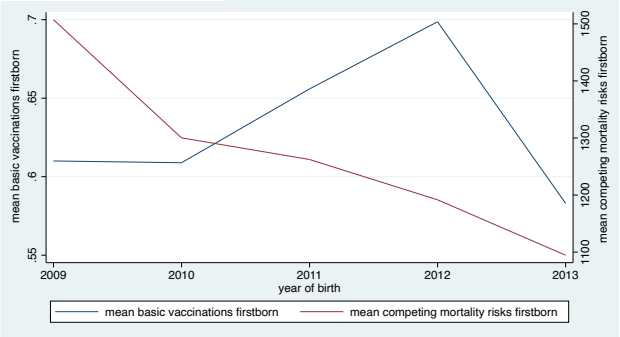
Turkana	110	2.73	59.45
West pokot	116	2.88	62.33
Samburu	120	2.98	65.30
Trans-nzoia	104	2.58	67.88
Baringo	86	2.13	70.01
Uasin gishu	77	1.91	71.92
Elgeyo marak	85	2.11	74.03
Nandi	88	2.18	76.22
Laikipia	74	1.84	78.05
Nakuru	86	2.13	80.18
Narok	136	3.37	83.56
Kajiado	103	2.55	86.11
Kericho	85	2.11	88.22
Bomet	104	2.58	90.80
Kakamega	85	2.11	92.91
Vihiga	64	1.59	94.49
Bungoma	113	2.80	97.30
Busia	109	2.70	100.00
Total	4032	100.00	

[1] Children excluded because the time between date of interview and date of birth was less than 12 months.

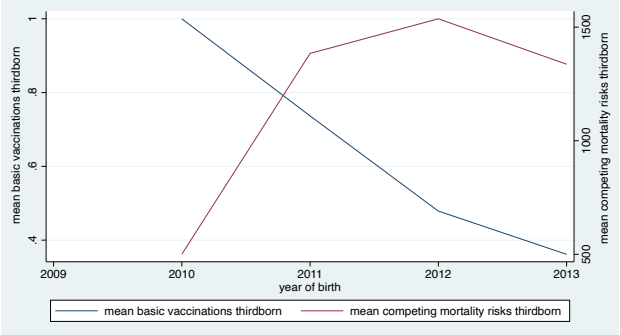
Appendix C

Graph 1a, 1b, 1c: mean basic vaccinations and mean competing mortality risks over time and birth order

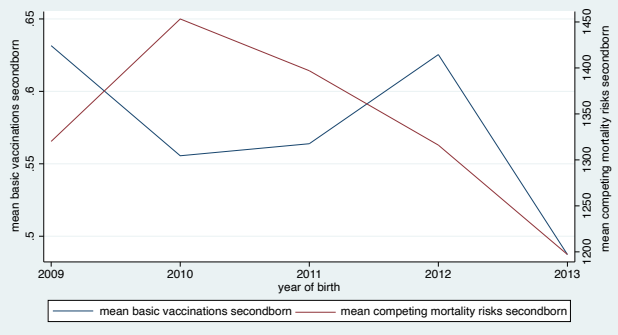
1a



1b



1c



Mean competing mortality risks were calculated as the mean deaths per 100,000 for firstborn (a), second born (b), and third born (c) children aged 1-4 in Kenya in 2009-2013 for all causes except vaccine-preventable diseases (dpt, tbc, measles). Mean basic vaccinations were calculated as the mean amount of firstborn (a), second born (b), and third born (c) children aged >12 months to have received all basic vaccinations (tbc, dpt, measles, polio) in Kenya in 2009- 2013.

Appendix D

Table 2B: cross-sectional linear probability model (extended)

	(1) Basic vaccinations	(2) Basic vaccinations
Competing mortality risks (CMR) [1]	-.0005***	-.0006***
	(.0002)	(.0002)
Death rate DPT[2]	-.0169***	-.014***
	(.0031)	(.0032)
Death rate TBC[2]	.0306***	.0257***
	(.0065)	(.0089)
Death rate measles[2]	-.0012	.0007
	(.001)	(.0007)
Mother's age[3]		.0001
		(.0007)
Wealth score		0
		(0)
Education[4]		.009***
		(.0021)
Distance to health facility: big problem		.0098
		(.0181)
Distance to health facility: not a big problem		.0016
		(.0093)
First born		-.0503
		(.1975)
Second born		-.062
		(.1948)
Third born		-.112
		(.199)
Forth born		
Fifth born		
Embu		-.1484
		(.2756)
Kalenjin		-.2412
		(.2755)
Kamba		-.1455
		(.2691)
Kikuya		-.2044
		(.2686)
Kisii		-.164
		(.2716)
Luhya		-.1497
		(.2584)
Luo		-.1704
		(.262)

Maasai		-.3135
		(.2698)
Meru		-.0858
		(.2681)
Swahili_Mijikenda		-.0908
		(.268)
Somali		-.2736
		(.271)
Taita_Taveta		-.0869
		(.2668)
Turkana		-.1924
		(.2733)
Sambura		-.2344
		(.2687)
Pokomo		-.1322
		(.268)
Iteso		-.1046
		(.2687)
Boran		-.1644
		(.2723)
Gabbra		-.128
		(.2708)
Kuria		-.1993
		(.2711)
Orma		-.0239
		(.2735)
Mbere		-.2048
		(.2832)
Rendille		-.0246
		(.2681)
Other ethnicity		-.1363
		(.2712)
Roman_Catholic		.0246
		(.0803)
Protestant and other Christian		.0222
		(.0777)
Muslim		-.0102
		(.0815)
No religion		-.0451
		(.0904)
Other religion		-.189
		(.1262)
_cons	.9011***	1.0364***
	(.0358)	(.3393)
Observations	16286	16286
R-squared	.053	.081

Clustered standard errors are in parentheses
*** p<.01, ** p<.05, * p<.1*
Abbreviations: TBC, tuberculosis; DPT, diphtheria-pertussis-tetanus, CRM, competing mortality risks.
[1] Competing mortality risk calculated as deaths per 100,000 for children aged 1-4 in Kenya for all causes except vaccine-preventable diseases (dpt, tbc, measles).
[2] Mortality rates for dpt, tbc, and measles calculated as deaths per 100,000 for children aged 1-4 in Kenya for dpt, tbc, and measles respectively.
[3] Mother's age at birth of child
[4] In single years

Appendix E

Table 4A: Logistic regression

	(1) Basic vaccinations	[95% Conf Interval]	(2) Basic vaccinations	[95% Conf Interval]
Competing mortality risks (CMR) [1]	-.0022***	[-0.0036, -0.0009]	-.0027***	[-0.0045, 0.0009]
	(.0007)		(.0009)	
Death rate DPT	-.0742***	[-0.1015, -0.0469]	-.0645***	[0.0943, -0.0356]
	(.0139)		(.0148)	
Death rate TBC	.1359***	[0.0768, 0.1951]	.1183***	[0.036, 0.2006]
	(.0302)		(.042)	
Death rate measles	-.0056	[-0.0148, 0.0035]	.0033	[-0.0028, 0.0094]

	(.0047)		(.0031)	
Mother's age			.0005	[-0.006, 0.0069]
			(.0033)	
Wealth score			0	[-6.480e-07, 9.289e-07]
			(0)	
Education			.0443***	[0.026, 0.0627]
			(.0094)	
Distance to health facility: big problem			.0432	[-0.124, 0.2103]
			(.0853)	[-0.0828, 0.0966]
Distance to health facility: not a big problem			.0069	
			(.0458)	
_cons	1.7702***	[1.416, 2.1240]	2.4731	
	(.1805)		(1.8016)	
Observations	16286		16286	
Pseudo R^2	.0408		.0633	
Ethnicity	NO		YES	
Religion	NO		YES	
Birthorder	NO		YES	

Clustered standard errors are in parentheses
*** p<.01, ** p<.05, * p<.1*
[1] *Competing mortality risk calculated as deaths per 100,000 for children aged 1-4 in Kenya for all causes except vaccine-preventable diseases (dpt, tbc, measles).*
[2] *Mortality rates for dpt, tbc, and measles calculated as deaths per 100,000 for children aged 1-4 in Kenya for dpt, tbc, and measles respectively.*
[3] *Mother's age at birth of child*

Appendix F

List of abbreviations

CMR	Competing mortality risks
DHS	Demographic Health Survey
DPT	Diphtheria-Pertussis-Tetanus
GVAP	Global Vaccine Action Plan
GHDx	Global Health Data Exchange
IA2030	Immunization Agenda 2030
IHME	Institute for Health Metrics and Evaluation
SDGs	Sustainable development goals
WHO	World Health Organization