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Article

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Bounds test cointegration approach to examine factors contributing to declining maternal mortality ratio in Sudan (1969-2015)

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Abstract. Unlike other studies in the field of maternal health, the objective of this study is to examine the contribution of some socioeconomic, demographic and health care factors to the declining trend of maternal mortality ratio MMR in Sudan over the period 1969-2015. The study employs econometric techniques including the OLS, cointegration methods of Johansen and autoregressive distributed lag ARDL bounds tests and Granger causality analysis. The OLS shows that economic growth measured by GDP has significant bad affect on MRR but it has more significant good effect when measured by GDP per capita GDPP. Declining fertility rates lead to declines in MMR. Health expenditure has no effect on MMR. The ARDL bounds test shows existence of a long-run equilibrium relationship between MMR and its explanatory variables. In both the short run and long run, declines in MMR are explained by GDPP and fertility but badly affected by GDP. In contrast, health care factors have no effects on MMR. Granger causality test shows a unidirectional relationship running from economic growth measured by GDP and GDPP to MMR with no sign of feedback effect. Bidirectional relationships between MMR and fertility rate, MMR and health expenditure, as well as between MMR and the number of physicians per 100,000 people have been established. The study recommends that the government should ensure stable and inclusive economic growth. There is a need to increase resources to maternal and reproductive health with emphasis on the number of physicians per 100,000 people in order to move forward to the SDGs.
Keywords. Maternal Mortality, GDP, Fertility, Health care, Cointegration, ARDL, Sudan.
JEL. C13 C32 C51 H51 I15.

1. Introduction

Sudan is a lower middle income country on the basis of per capita income. Gross domestic product per capita (GDPP) at current US $ was estimated at 620 US$ declined to 437 in 2000, but tremendously increased to 1824 in 2010 and stands at 2415 US$ in 2015. GDP at current US$ was estimated at 12,409 billion US$ in 1990, declined to 12,257 in 2000, tremendously increase to 65634 in 2010 6 and further increased to 97,156 billion in 2015. Poverty is wide spread as 46.5% of Sudanese live under poverty line with considerable variations between and within states (Central Bureau of Statistics, 2009). Secession of South Sudan in 2011 resulted in an immediate economic downturn in Sudan in 2012, with significant decline of government revenues and soaring inflation rates, which affected the welfare of a growing number of poor people among them morbidities and mortalities are high. Total health expenditure has been the lowest amongst the countries of the Eastern Mediterranean Region Office (EMRO) of the WHO. Out of pocket health expenditure is high and increasing at a rate higher than the rate of increase of public expenditure on health and can be deemed as impoverishing and

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catastrophic. Contraceptive is use is just around 10 percent (Paul & Walque, 2012). These factors have caused Sudan to witness slow progress in achieving all health related millennium development goals (MDGs), namely reduction of maternal mortality ratio (MMR) and under-five mortality rates. In such socioeconomic and health sector situation all of the underlying causes of maternal deaths identified by the WHO are expected to prevail (Paul & Walque, 2012 and Witter, 2010). It has been well understood that factors lead to maternal death include pregnancies with abortive outcome, hypertensive disorders, obstetric hemorrhage, pregnancy-related infection, other obstetric complications, unanticipated complications of management, nonobstetric complications, unknown or undetermined and coincidental causes (Black, *et al.,* 2016).

The MDG5a supplemented by MDG5b – on universal access to contraception, targeted reduction in MMR by 75% between 1990 and 2015. Since 1990 global maternal death has been declining but with too slow rate of decline to meet that target in low income countries. On average, global MMR declined by 44 percent, from 385 maternal deaths per 100,000 live births in 1990 to 216 in 2015 (Black, *et al.*, 2016 and Alkema, *et al.,* 2015). On average, regional progress in reducing the MMR since 1990 ranged from an annual rate of reduction of 1.8% in the Caribbean to 5.0% in eastern Asia. It has also been documented that regional MMRs for 2015 ranged from 12 deaths per 100,000 live births in high-income regions to 546 in low income region of sub-Saharan Africa and that, in order to achieve the maternal health sustainable development goal (SDG) countries need to reduce their MMRs at an annual rate of at least 7.5% (Alkema, *et al.,* 2015). The simple conclusion from these estimates is that economic growth has a positive influence on MMR. For Sudan, the MMR declined from 573 per 100,000 live births in 1990 to 311 per 100,000 in 2015 (World Bank, 2017). This reduction amounts to 48% - or an annual rate of decline of 1.8% only similar to that of the Caribbean which is still far less than the target of 75% reduction; or 143 maternal deaths per 100,000 live births. This means that Sudan has a long way to go to meet the MDG5 and to move forward into achieving the maternal health SDG of reducing MMR to less than 70 per 100,000 live births by 2030. The health care factors behind such high MMR in Sudan include high percentage amounting to more than 76% of deliveries taking place at home, only 6% of deliveries attended by a physician, very low Caesarian section indicating lack of basic obstetric care, and early marriage (WHO, 2009). Skills of staff providing antenatal care have also been questionable (Witter, 2010). But these maternal health factors operate within diverse and interrelated factors of development, epidemiological and demographic factors as well as expenditure on health, availability of maternal health care including essential reproductive health services, the number of physicians, particularly obstetricians, immunization and importantly access to and use of contraception, which in Sudan is estimated just at 10 percent.

In empirical studies it has been acknowledged that MMR is one of the widely measured indicators of health status of population, with available comparable international statistics (Black, *et al.,* 2016 and Véronique, *et. al.,* 2013). But the question is what factors that drive maternal death or MMR to decline over time, or what are the determinants of MMR within and outside the health care sector? Broadly, a determinant of mortality can be defined as a variable that would change a population's mortality level if its own value was altered. Such variables encompass the proximate biological determinants of mortality (e.g., nutritional intake, exposure to disease) and the socioeconomic and cultural factors that operate indirectly through the proximate factors (Farah, & Preston, 1982). Some studies shows that availability of medical care, namely obstetric services had been the major factor behind declining maternal mortality in the United States between 1946 and 1956 (Klein, & Clahr, 1958). However, it seems that factors contribute to declining trends of MMR are multiple, complex and quite different across countries with differing implication on the best programmes targeting country-level reduction in MMR, and this indeed has something to do with the level of

development, epidemiological, demographic and health finance transitions experienced by each country, and importantly the effectiveness of spending on health care. Thus, what can be identified as explanatory factors of MMR, *inter alia*, are broadly social determinants including GDP, GDPP and household poverty, housing, education particularly years of schooling and literacy of females, public spaces; health care factors indicated by total and public health spending, number of hospital beds, number of physicians, contraceptive use, immunization coverage; population and demographic factors indicated by population growth, fertility and urbanization; environmental health factors exemplified by access to safe drinking water and access to improved sanitation facilities.

2. Objectives of the study

i. Investigate the relative contribution of economic and non-economic factors (i.e., health care policy and fertility) in explaining the declining trends of MMR in Sudan with explanation of the dynamic interplay among these factors.

ii. Draw some policy implications and recommendations for better ways of investment in maternal health.

3. Literature review

Once the major factors affecting MMR are accurately identified and measured, maternal health could be improved by investing on implementation of the best programmes and policies financed by individuals, governments or from external sources particularly in low income countries. In particular, government expenditure on health care partially determines availability of and accessibility to health care services especially by the poor among whom maternal mortality is commonly high. But, health care system services affects the status of health of population measured by MMR with complex transmission mechanisms and interplay of environmental, socioeconomic, population and demographic factors. The interplay among these non-health care factors may deem expenditure on health ineffective in contributing positively to improvement of maternal health. Thus, studying the effect of health care factors on MMR in isolation of other non-health care factors is not very helpful in designing and implementing programmes targeting improvement in maternal health particularly when the health sector is lacking resources. Therefore, effectiveness and priorities in health care matter as mortalities in low income countries have been caused mainly by communicable and infectious diseases including HIV/AIDS. Sources of reduction and effects of infectious diseases, fertility and mortality including maternal mortality have been extensively debated in the demographic community (Cutler, Deaton, & Lleras-Muney, 2006). Within this line of literature, identified factors of declining mortality include poverty and income level across countries and groups, education, nutrition, immunization, urbanization and medical treatments which fall within and outside the health care sector (Bishai, *et. al.,* 2016). However, within the health care sector, some studies find that public spending on health has been ineffective at improving health status. For example Filmer & Pritchett (1997) and (1999) argue that ineffectiveness of public health expenditure could be due to (i) lack of efficacy of the public sector in that public spending on health does not always translate into a larger supply of effective health services (ii) individual demand and market supply on which the impact of a greater supply of effective health services depends and that (iii) public money is spent on expensive, but ineffective, curative services. Furthermore, Zakir & Phanindra (1999) studying determinants of infant mortality rates (IMR) find that per capita GNP, fertility rate and female literacy significantly affect IMR and that government expenditure on health care has no role in determining IMR. Yet, (Farahani, Subramanian, & Canning 2009) used a national family health survey of India show that a 10 % increase in public spending on health decreases the average probability of death by about 2%, with effects mainly on the young, the elderly and women. They also indicate that other major factors affecting mortality are rural

residence, household poverty, and access to toilet facilities. Using a sample of 146 low and middle income countries, Véronique *et al.,* (2013) find that respectively 100% and 89% of the reductions in maternal and child mortality since 1990 were due to improvements in coverage of health determinants as approximately 50% of the mortality reductions were due to improvements in the health sector, and the other 50% were due to gains outside the health sector, including the environment, education, fertility, and women's empowerment.

It is known that fertility, child and maternal health are closely linked. It has been argued that later pregnancies among physically ill mothers result in malnourished and diseased children whose chances of survival are drastically reduced both before and after birth (Bridsall & Griffin, 1988; Hocraft, 1992 and Chowdhury, 1988). However, Chai *et al.,* (1996) suggest that there is a dual causality between infant mortality rates and fertility rates as when a woman has multiple pregnancies, the chances of her child's survival are significantly reduced, and such a woman may thus decide to bear more children. Chowdhury *et. al.,* (2013) emphasized the role of health coverage and equity in health outcomes achieved by Bangladesh despite poverty. El-Arifeen *et. al.,* (2014) state that he MMR in Bangladesh has decreased by an annual rate of 5.6%, from 322 deaths per 100,000 live births during 1998-2001 to 194 deaths per 100,000 live births during 2007-10 due to improved access to and use of health facilities as well decrease in fertility and fall in proportion of births associated with high risk to the mother, besides sharp increase in income per head, and substantial improvement of the education levels of women of reproductive age. They estimate that 52% of maternal deaths that would have occurred in 2010 compared with 2001 rates were averted because of decreases in fertility and risk of maternal death. Also, Chowdhury, *et. al.,* (2009) find that reduction in the number of maternal deaths in Bangladesh during 1979-2005 associated with fertility decline in Matlab – a rural area – was higher in government service area which has been receiving routine government health services (30%) than in the International Centre for Diarrhoeal Diseases Research (23%) receiving extensive health and family-planning services since 1978, where reduction in abortion-related mortality was 86.5% in the extensively serviced and 78.3% in the government serviced area. Other factors they identified include better access to comprehensive emergency obstetric care services, reduction in the total fertility rate, and improved education of women as all contributing to achieve MDG5. Using data from Nigeria 2008 Demographic and Health Survey Mojekwu & Ibekwe (2012) find that delivery attended by a skilled health professional and education attainment of women had more effect on MMR among the other fourteen variables including socioeconomic factors included in their study. Alvarez *et. al.,* (2009) analyze a host of health care system, education, and economic indicators and their effects on MMR in Sub-Saharan Africa between 1997-2006. They use descriptive statistical analysis in terms of Pearson/Spearman correlation and found a strong, direct relationship between the MMR and the infant mortality rate; a strong, inverse relationship with prenatal care coverage, births assisted by skilled health personnel, and access to improved water source as well as significant effect of gross national income per capita, the per-capita government expenditure on health and the out of pocket expenditure on health on MMR. Adult literacy rate, contraceptive prevalence, ratio of female rate to male rate, primary enrolment rate, primary female enrolment rate and education index are found to have significant effects on MMR. Using Pearson correlation analysis Nafiu, Aauud & Adiukwu (2016) find that GDP per capita is reversely and significantly related MMR with a coefficient of -0.37, total fertility rate is significantly and directly affects MMR with a coefficient of 0.55 and HIV prevalence also significantly affects MMR with a coefficient of 0.86 in Somalia over the period 1990-2010.

Overall, good health measured generally through decline in total mortality or conversably as increases in life expectancy has a proven positive effect on economic (Barro, 1996, 2013; and Sachs & Warner, 1997) among others. The relationship is even dynamically positive in that good health enhances economic

growth and enhanced economic growth feeds back positively to affect health, although income growth may have negative effect on health in the short run (Weil, 2005; 2013).

Sudan can be looked at as special case with respect to socioeconomic development including its health sector and health outcome indicators. Sudan has been a country with continuing civil war for decades which has caused displacement and loss of livelihoods, compounding poverty and inequality, with adverse effects on health status particularly of women. For decades, balancing spending on the military, which has been driven by the internal conflicts and growing needs for security in the war-affected areas, against spending on basic services such as education, water and sanitation as well as poverty reduction programs, continues to be a challenge that poses mounting threats to achieve the MDG5 of reducing MMR (WHO, 2015). Yet, Sudan continues to deploy efforts to expand basic services in water and sanitation, education and health, including HIV/AIDS and clearly declared commitment to improvement of women and child health (WHO, 2015 and Federal Ministry of Health, 2002). The HIV prevalence among the population aged 15-49 years was estimated at 0.2% throughout 2012-2015 and the country has been considered as at early stage of a generalized HIV/AIDS epidemic, though the national health policy and strategy give priority to the control and prevention of HIV/AIDS (WHO, 2009). Mobile and outreach HIV testing and counseling services targeting internally displaced and vulnerable populations are also being provided to increase access to HIV-related services (WHO, 2009; 2005). In general, it seems that Sudan was unable to meet the MDGs targets 2, 4, and 5 since it wasn't managed to seriously boosting the capabilities of its health facilities to combat malaria, tuberculosis and HIV/AIDS, which have been the main causes of hospital deaths (WHO, 2015). However, in response to mounting development and health challenges, the government of Sudan has developed a 25-year (2003-2027) long term strategic plan including plans for the health sector and health improvement (Federal Ministry of Health, 2002). The 25-year health sector strategy gives priority to reforming and rebuilding the health system based on fair financing, and aims to reduce the burden of diseases, develop and retain human resources, and introduce advanced technology, while assuring equity, quality and accessibility of health services especially by the poor and vulnerable populations including children, women and mothers. In order the meet such health objectives, there is a need for large increase in health spending by the government and from other sources taking into account horizontal and vertical equity dimensions as health spending in Sudan has been described as skewed towards hospital care, and primary and first-referral care levels are underfunded and lack resources, particularly in the poorer states, Witter (2010), and Paul & Walque, (2012). Underfund and unequal distribution of resources may render public spending ineffective in reducing morbidities and motilities including MMR. Total health expenditure increased from 3.2% of GDP in 2000, to 4.7% of GDP in 2005, to 5.8% in 2010 and reached 8.7% in 2015. However, government expenditure on health ranged between 0.1 as percentage of GDP in 1999 and 0.4 percentages in 2012, increased to 0.6 in 2015. Yet, out-of-pocket expenditure on health care was estimated at US$ 122 per capita and constitutes 73% of total expenditure in 2015, which can be deemed as catastrophic and impoverishing catastrophic and increasing faster than public expenditure on health.

4. Methodology and models

This study is quantitative and empirically addressing the links between economic and non-economic including health care policy and demographic factors and their relative contribution in reducing MMR in Sudan. It is unlike many other studies focusing on factors causing maternal death which are commonly medical and reproductive health factors and are well understood and repeatedly updated in various WHO reports. However, in a systematic review of published articles on maternal mortality between 2000-2004, Gil-Gomez *et. al.,* (2006) found that

reports on obstructed labour, unsafe abortion and hemorrhage are underrepresented; a finding suggests what they describe as a knowledge-base gap between the burden of the causes of maternal mortality and scientific interest in these determinants. In addition to its other contributions, our study fills some of this gap in that it investigates aggregate socioeconomic and health care factors thought to contribute to declining MMR in Sudan as a low income country. Our study covers the period from 1969 to 2015 using annual time series data for Sudan processed from the World Development Indicators (WDIs) of the World Bank (2017), analyzed with dynamic econometric models which would enable assessment of macrostructural causes of maternal health improvement. This period is chosen because over which the economy of Sudan has been witnessing remarkable changes, including liberalization and devaluation of the national currency against the US dollars in 1978 (Awad, 1992). Since then the value of the Sudanese currency been decreasing against the US$ with implications on the inflation including the prices of health care services. Since 1992, Sudan has adopted SAPs with full liberalization of prices of goods and services with federal deregulations and decentralized health care system implying major reductions in spending on social services including health and education. Since 1999 the government revenues have been increasing due to extraction and exportation of oil as well as government tax revenues, with high and stable economic growth. But since 2012 government revenues has declined as a result of losing oil revenues with the secession of South Sudan. These changes have effects on economic growth measured by the GDP which affects the willingness and ability of the government and individuals to invest in health care and health with implications on maternal and child mortality rates. Also, Sudan has been under a United Sate economic sanction since 1997 and only partially lifted in 2017, which was also blamed to have some negative effects on access to health technology and health outcomes.

4.1. Econometric models

This study builds and estimates econometric models that incorporate main socioeconomic and non-economic factors mainly health care indictors identified as important factors contributing to declining MMR over time. Empirically, this study employs the econometric techniques of the Ordinary Least Square (OLS), Augmented Dickey-Fuller (ADF) unit root test, the autoregressive distributed lag ARDL model of Pesaran & Shin (1999) and Pesaran, *et al.,* (2001), Johansen cointegration test with Granger causality (Granger, 1969). The econometric models built seek to investigate the declining trends of MMR as the dependent variable explained by economic development factors represented by GDP and GDP per capita (GDPP), and total health expenditure as percentage of GDP (THE), health care factors represented by the number of physician (PHY) and the number of hospital beds per (HP) 100,000 people. Demographic factors are represented by fertility rates (FR) defined as the ability of woman to give birth during her reproductive life. The study adopts the definition of maternal death as the death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management but not from accidental or incidental causes, or from pregnancy-related death and more broadly irrespective of the cause of death (Black, *at al.,* 2016; Alkema *et al.,* 2015) as it uses data extracted from the WHO, and the WDIs. GDP per capita (GDPP) is defined as the GDP at current prices divided by the total number of population in a year. THE stands for total health expenditure calculated as the public and private spending on health as percentage of GDP. Data on fertility rates, number of physician and number of beds per 100,000 people are sourced from the WDIs, 2017 with some processes and where some data are missing they are estimated by the author.

The general linear econometric model to be estimated is written as follows:

$$MMR = \alpha + \beta_1 GDP + \beta_2 GDPP + \beta_3 THE + \beta_4 FR + + \beta_5 PHY + \beta_6 HP + \mu \quad (1)$$

The coefficient α is the constant (intercept); $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, and\ \beta_6$ are the coefficients of GDP, GDPP, THE, FR, PHY and HP respectively, and μ is the white noise error term.

4.2. Results and discussion

4.2.1. Descriptive statistical analysis

The analysis departs from investigation of the correlation between MMR and its explanatory variables. Table 1 presents the correlation matrix.

Table 1. *Correlation Matrix*

	MMR	GDP	GDPP	THE	FR	PHY	HP
MMR	1.00						
GDP	-0.81	1.00					
GDPP	-0.73	0.98	1.00				
THE	-0.72	0.90	0.86	1.00			
FR	0.99	-0.84	-0.75	-0.74	1.00		
PHY	-0.82	0.94	0.90	0.91	-0.84	1.00	
HP	0.26	0.02	0.02	0.06	0.21	0.08	1.00

As a rule of thumb, a correlation statistic with value greater than 0.8 shows that there is a high correlation between the pair of variables. The dependent variable MMR is positively correlated with FR, while, it is negatively correlated with GDP, GDPP, THE and PHY. This is generally in conformation with Preston (1975) analysis of the relationship between mortality and economic development. As for the independent variables, GDP, GDPP and THE are positively correlated with one another. No significant correlation exists between PHY and HP which indicate deficient health care planning. However, such simple correlation coefficients indicate neither significant nor causation relationships.

4.2.2. OLS model results

The model specified in equation (1) is estimated using the actual values of the annual time series of variables data for the period 1969-2015. Table 2 and equation (2) presents the results of the OLS regression.

Table 2. *OLS Summary Results*

	Dependent Variable	MMR	Std. Error	t-Statistic	Prob.
Explanatory Variable	C	-1030.67	42.985	-23.978	0.0000**
	GDP	0.005	0.001	5.631	0.0000**
	GDPP	-145.76	28.433	-5.126	0.0000**
	THE	-3.50	3.609	-0.970	0.3380
	FR	289.14	8.406	34.394	0.0000**
	PHY	-111.19	142.218	-0.782	0.4389
	HP	41.92	22.595	1.855	0.0709*
R^2= 0.99; Adjusted R^2 = 0.99; F-Stat. = 1451.34 (P. 0.0000); DW = 1.48					

Notes: ** (*) indicates significance at 1% and 10% respectively

$$MMR = -1030.67 - 0.005GDP + 145.75GDPP - 3.50THE + 289.14FR - 111.19PHY + 41.92HP \quad (2)$$

As from table 2 and equation (2) economic growth measured by GDP has positive (bad) and highly significant effect on MMR, though with a low coefficient of only 0.005. On the other hand, GDPP has a negative (good) effect on MMR with a coefficient of 145.76 which is significant at 1% level. Total health expenditure THE has a negative (good) but insignificant effect on MMR, with a coefficient of -3.50. The relationship between MMR and fertility rate FR is positive (good) with a coefficient of 289.14 which is highly significant at 1% level, meaning that the declining trends of FR and MMR reinforce each other in the same downward direction. The number of physicians per 100,000 people PHY has a good but insignificant effect on MMR, though with high coefficient of -111.19. In this

regard, Loudon (1992) studied maternal care and maternal mortality for the period 1800–1950 remarked that, maternal mortality, unlike infant mortality, was remarkably insensitive to social and economic factors per se but remarkably sensitive to standards of obstetric care. This is also true for Egypt, where a large proportion of the women deliver in a hospital and more than half of the maternal deaths have been attributed to inappropriate management by obstetricians (Carine *et. al.,* 2008). For Sudan, it has been acknowledged that the health professional providing antenatal care service is questionable [3] which is empirically confirmed by the results of this study. Hospital beds per 100,000 people have a positive effect on MMR with a coefficient of 41.92. The coefficient of multiple regression (Adjusted R^2) is very high showing that approximately 0.99 of total variation in MMR can be explained by GDP, GDPP, THE, FR, PHY, and HP. Given the potential multicolinearity, endogenity of health status measurement and the possibility that the variables are cointegrated of the order I(1), the OLS results could be spurious and misleading. Therefore, in order to have better understanding of factors affecting MMR in Sudan, the study proceeds to more reliable econometric techniques including ARDL cointegration bounds test, Johansen cointegration test and Granger causality analysis.

4.3. Cointegration bounds test

4.3.1. Stationary and cointegration of variables

The ADF unit root test is carried out to establish stationary of variables included in the study. Stationary of time series data is required to ensure reliable and robust econometric estimations aiming at explaining a complicated behaviour of a variable as the MMR. The ADF results show that all variables are found to be nonstationary at level, with the assumption of no trend, but the first differencing makes all of them stationary as presented in table 3.

Table 3. *ADF Test Results at Level I(0) and First Difference I(1)*

Variable	ADF Test Statistic Value I(0)	5% Critical Value I(0)	P I(0)	ADF Test Statistic Value I(1)	5% Critical Value I(1)	P I(1)
MMR	0.559	-2.928	0.987	-3.484	-2.928	0.0130*
GDP	4.557	-2.927	1.000	-9.984	-2.928	0.0000*
GDPP	1.669	-2.927	1.000	-5.156	-2.928	0.0001*
THE	-0.494	-2.927	0.883	-6.352	-2.928	0.0000*
FR	-0.872	-2.937	0.787	-7.036	-2.937	0.0000*
PHY	-0.166	-2.928	0.935	-4.656	-2.928	0.0005*
HP	-1.599	-2.927	0.475	-7.697	-2.928	0.0000*

Notes: * indicates significance at 5 % level of significance

4.3.2. ARDL Estimation

The autoregressive distributed lag (ARDL) approach to cointegration proposed by Pesaran & Shin (1999) and Pesaran, *et al.,* (2001) is used in this study. This approach has several advantages over other cointegration methods including the standard Johansen cointegration method Pesaran & Shin (1999). According to Javid & Sharif (2016) the bounds test approach can be applied irrespective of whether the variables are I(0) or I(1), it captures both long term equilibrium and short term dynamics and it offers explicit tests for the existence of a unique cointegration vector. Importantly, Pesaran & Shin (1999) argued that the appropriate lag selection in ARDL methodology corrects for both serial correlation and endogeneity problems in time series data. An ARDL of equation (1) to cater for the short-run dynamics and long run equilibrium of MMR and its explanatory variables is specified as follows:

$$\Delta mmr_t = \alpha + \sum_{i=1}^{p} \beta_{1i} \Delta mmr_{t-1} + \sum_{i=0}^{p} \Delta\beta_{2i} gdp_{t-1} + \sum_{i=0}^{p} \beta_{3i} \Delta gdpp_{t-1}$$
$$+ \sum_{i=0}^{p} \beta_{4i} \Delta the_{t-i} + \sum_{i=0}^{p} \beta_5 \Delta fr_{t-i} + \sum_{i=0}^{p} \beta_6 phy_{t-i} + \sum_{i=0}^{p} \beta_7 \Delta hp_{t-i} + \beta_8 mmr_{t-1}$$
$$+ \beta_9 gdp_{t-1} + \beta_{10} gdpp_{t-1} + \beta_{11} the_{t-1} + \beta_{12} fr_{t-1} + \beta_{13} phy_{t-1} + \beta_{14} hp_{t-1} + \mu_t \quad (3)$$

Where p is the lag length. Equation (3) can be estimated through the OLS to explore the long-term relationship among the variables by performing an F-test for the joint significance of the lagged-level variables. The null hypothesis of no cointegration in Equation (3) is:

$H_0 : \beta_8 = \beta_9 = \beta_{10} = \beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = 0$, against the alternative hypothesis of existence of cointegration that: $H_1 : \beta_8 \neq \beta_9 \neq \beta_{10} \neq \beta_{11} \neq \beta_{12} \neq \beta_{13} \neq \beta_{14} \neq 0$

The decision rule for existence of cointegration in the bounds testing approach according to Pesaran & Shin (1999) is two sets of critical values for the F-statistic: the lower bound where all variables are I(0) and the upper bound where all variables are I(1). If the F-statistic lies below the lower bound value, the conclusion is no cointegration and if the F-statistic is found to be above the upper bound value, then cointegration exists. If the F-statistic falls between the upper bound and lower bound, then the test is inconclusive. Results of the estimated ARDL selected as ARDL (1, 0, 0, 0, 0, 0, 0) according to Akiake Information Criterion AIC out of 64 model evaluated are summarized and presented in table 4.

Table 4. *Summary Results of the ARDL*

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
MMR(-1)	0.282	0.1603	1.757	0.0870**
GDP	0.003	0.0010	3.088	0.0038*
GDPP	-93.381	34.125	-2.736	0.0094*
THE	-1.452	3.4848	-0.417	0.6792
FR	207.297	45.115	4.595	0.0000***
PHY	-94.575	133.08	-0.711	0.4816
HP	35.248	21.701	1.624	0.1126
C	-753.613	155.07	-4.860	0.0000***

R-squared = 0.99; Adj. R-squared = 0.99; SSE = 15.46; SSR = 9080.57; S.D. Dependent Var. = 225.59; AIC = 8.47; SC = 8.79; HQC = 8.59; F-statistic = 1363.657; D.W. = 2.16
*Note: p-values and any subsequent tests do not account for model selection.
Notes: ***, **, * indicate significance at 1%, 5% and 10% level respectively

The short run and long run cointegrating equation of the ARDL model is represented as follows:

$$\Delta MMR = 0.003\Delta GDP - 93.38\Delta GDPP - 1.42\Delta THE + 207.30\Delta FR - 94.58\Delta PHY$$
$$+ 35.25\Delta HP - 0.72MMR - 0.005GDP_{t-1} - 129.98GDPP_{t-1} - 2.02THE_{t-1}$$
$$+ 288.55FR_{t-1} + 131.65PHY_{t-1} + 49.06HP_{t-1} - 1049.00 \quad (4)$$

The estimated ARDL cointegrating short run dynamics and the long run coefficients are summarized in table 5.

Table 5: *ARDL Short Run and Cointegration Long Run Coefficients*

ARDL Short Run Dynamics Coefficients					ARDL cointegration Long Run Coefficients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.	Variable	Coefficient	Std. Error	t-Statistic	Prob.
Δ(GDP)	0.003	0.0011	3.088	0.0038*	GDP	0.005	0.0012	3.7914	0.0005*
Δ(GDPP)	-93.38	34.125	-2.737	0.0094*	GDPP	-129.98	38.7003	-3.3587	0.0018*
Δ(THE)	-1.45	3.4848	-0.417	0.6792	THE	-2.02	4.7630	-0.4245	0.6736
Δ(FR)	207.30	45.115	4.595	0.0000*	FR	288.55	11.5103	25.0691	0.0000*
Δ(PHY)	-94.58	133.08	-0.711	0.4816	PHY	-131.65	187.0544	-0.7038	0.4859
Δ(HP)	35.25	21.701	1.624	0.1126	HP	49.07	29.7099	1.6515	0.1069
ECT_{t-1}	-0.72	0.1603	-4.482	0.0001*	C	-1049.008	62.2501	-16.8515	0.0000*
Diagnostic Tests									
Normality: Jarque-Bera (4.13), P(0.1272)									
Autocorrelation: F(1.739), P(1902)									
Heteroskedasticity: F(0.52), P(0.811)									
Stability: Ramsey RESET: F(0.319), P(0.5758)									

Notes: * indicates significance at 1% level

The ARDL results show that MMR is significantly affected by economic growth and fertility and not by health care factors in terms of THE, PHY and HP in the short run. This also turns to be true in the long term, as it appears from the long run coefficients. Economic growth measured by GDP has a positive (bad) effect on MMR, while economic growth measured by GDPP has a negative (good) effect on MMR. Surprisingly, both THE and PHY have bad effect on MMR though none of them is significant. Fertility decline has high and significant good effect on MMR meaning that the two variables move on the same downward direction in both the short and long run. Collectively, the ARDL results show the ineffectiveness of health care factors in reducing MMR is Sudan in both the short run and the long run. The error correction term (ECT) of the ARDL shows that MMR adjusts to an equilibrium position by a factor of 72% each year. Applying the conventional diagnostic tests, it appears that the estimated ARDL suffers none of the conventional econometric problems of time series data as reported in table (5). The bounds test technique is applied to variables of the study and the results are summarized in table (6).

Table 6. *Summary Results of Bounds Tests on Equation (3)*

Dependent Variable	AIC Lags	F-Statistic	Prob.	Remark
F(MMR|GDP,GDPP,THE, FR, PHY,HP)	1	2.76	0.0200	No Cointegration
F(GDP|MMR, GDPP,THE, FR, PHY,HP)	1	10.01	0.0000	*Cointegration*
F(GDPP|/MMR,GDP,THE, FR, PHY,HP)	1	5.48	0.0000	*Cointegration*
F(THE|MMR,GDP,GDPP, FR, PHY,HP)	1	2.87	0.0037	No Cointegration
F(FR|MMR,GDP,GDPP,THE, PHY,HP)	1	22.54	0.0000	*Cointegration*
F(PHY|MMR,GDP,GDPP,THE, FR,HP)	1	7.67	0.0000	*Cointegration*
F(HP|MMR,GDP,GDPP,THE, FR, PHY)	1	1.80	0.1163	No Cointegration

Notes: Asymptotic critical value bounds are obtained from Table F in appendix C, Case II: intercept and no trend for K = 6 (Pesaran & Pesaran, 1997, p.478). Lower bound I(0) = 3.516 and Upper bound I(1) = 4.43 at 1% significance level, and I(0) = 2.45; I(1) = 3.61 at 5% significance level.

The bounds test shows four cointegrating forms, confirming existence of long term equilibrium relationship between MMR and its explanatory variables. In addition to the ARDL bounds test, the study also tested for cointegration using the standard Johansen (1988) cointegration test. The test shows that there are 3 cointegrated equations at lag length of 1 when using the trace statistics and 2 cointegrated equations when using the maximum Eigen value statistics as presented in table 7.

Table 7. *Cointegration Rank Test (Trace Statistic and Maximum Eigen Statistic)*

Null Hypotheses	Eigen Value	Trace Statistic	0.05 Critical Value	Prob.**	Max-Eigen Statistic	0.05 Critical Value	Prob.**
r = 0	0.680	167.563	125.615	0.0000*	51.254	46.231	0.0134*
r ≤ 1	0.600	116.309	95.754	0.0009*	41.198	40.078	0.0372*
r ≤ 2	0.480	75.112	69.819	0.0178*	29.428	33.877	0.1551
r ≤ 3	0.426	45.683	47.856	0.0789	25.019	27.584	0.1029
r ≤ 4	0.274	20.664	29.797	0.3789	14.380	21.132	0.3347
r ≤ 5	0.129	6.285	15.495	0.6619	6.238	14.265	0.5828
r ≤ 6	0.001	0.046	3.841	0.8300	0.046	3.841	0.8300

Notes: * denotes rejection of the hypothesis at the 0.05 level; **MacKinnon-Haug-Michelis (1999) p-values

The regression model is represented by cointegration equation 2 with the minimum log likelihood of -146.776 and written as follows:

$$1.0000 = 113.98GDPP + 17.10THE - 282.71FR - 1253.65PHY + 16.92HP \quad (5)$$
$$\qquad\qquad (24.38) \qquad (6.25) \qquad (12.36) \qquad (290.89) \qquad (45.86)$$

Standard errors in parentheses

Comparatively, it appears that the estimated ARDL bounds test model is more powerful in establishing the long run cointegration relationship compared with the Johansen method of cointegration for MMR and its explanatory variables.

4.3.3. Granger Causality Test

Although the ARDL cointegration approach confirms the existence or absence of a long-term relationship among the variables included in the models, it does not indicate the direction of causality. Direction of causality can be tested through Granger causality analysis (Granger, 1969). Long run Granger causality relationships of MMR and its explanatory variables are tested using a lag of 2. Granger causality test shows the existence of unidirectional casual relationship running from GDP to MMR and from GDPP to MMR as well, meaning that no feedback from maternal health to economic growth. A bidirectional causal relationship is found between total health expenditure THE and MMR. Also there is a bidirectional causal relationship between MMR and fertility rate FR as well as between MMR and the number of physicians per 100,000 people PHY. No causal relationship is established between the MMR and the number of hospital beds HP as presented in table 8.

Table 8. *Summary of Granger Causality Test*

Null Hypothesis:	Obs.	F-Statistic	Prob.	Remark	Direction of Causality
H_0: GDP does not Granger Cause MMR	45	3.83723	0.0299	Reject	*GDP* → *MMR*
H_0: MMR does not Granger Cause GDP		1.09410	0.3447	Accept	None
H_0: GDPP does not Granger Cause MMR	45	3.86597	0.0292	Reject	*GDPP* → *MMR*
H_0: MMR does not Granger Cause GDPP		1.36670	0.2666	Accept	None
H_0: THE does not Granger Cause MMR	45	3.46956	0.0408	Reject	*THE* → *MMR*
H_0: MMR does not Granger Cause THE		2.39888	0.1038	Reject	*MMR* → *THE*
H_0: FR does not Granger Cause MMR	45	5.25611	0.0094	Reject	*FR* → *MMR*
H_0: MMR does not Granger Cause FR		4.19789	0.0221	Reject	*MMR* → *FR*
H_0: PHY does not Granger Cause MMR	45	2.74086	0.0766	Reject	*PHY* → *MMR*
H_0: MMR does not Granger Cause PHY		2.66550	0.0819	Reject	*MMR* → *PHY*
H_0: HP does not Granger Cause MMR	45	1.16750	0.3215	Accept	None
H_0: MMR does not Granger Cause HP		0.64531	0.5299	Accept	None

4. Conclusion

Rather than investigating factors causing maternal death, this study has explored socioeconomic, demographic and health care factors that are thought to contribute to the declining trend of MMR in Sudan as a low income country. The study contributes to the unsettled debate on health and non-health factors contribution to improvement of maternal health using time series data from Sudan and applying

conventional dynamic econometric methods. Economic growth measured by GDP leads to increases in MMR, while it leads to decreases in MMR when measured by GDPP. Thus, more equitable distribution of income matters for health improvement. Health expenditure has no significant effect on reducing MMR in Sudan; a finding confirms previous ones in the field. Fertility is found to have major influence on MMR in Sudan, which is also consistent with findings of other studies in the demographic literature and in the field of maternal health. The relationship between MMR and its explanatory factors is of long run nature as from the findings of both the ARDL bounds test and Johnson cointegration methods which indicate the robustness and reliability of the estimated models. This means that the contribution of the included explanatory factors, namely GDP, GDPP and fertility on MMR is of long term nature, but also these factors equally captures the short run dynamics of MMR. Interestingly, GDP, GDPP and FR are found to be the main deriving factors behind the declining trend of MMR, with no significant effects of health care factors on MMR. However, from Granger causality analysis, a bidirectional causal relationship is found to run from PHY to MMR and from MMR to PHY but only significant at 10% level. In light of these findings, it can be claimed that the study advances the science of public and reproductive health in a context of a low income country in terms of highlighting causes of maternal death but importantly through dynamic empirical investigation of the relative effects of socioeconomic, demographic and health care factors leading to its decline and therefore is of significant policy implications. The study recommends that the government should ensure macroeconomic stability in terms of sustained inclusive economic growth and stable prices. There is a high need to increase resources to the health sector with emphasis on the number of and quality of physicians per 100,000 people particularly obstetricians but the effectiveness of health expenditure needs to be evidence-based. Reproductive health services contributing to declining fertility rates have strong effect on MMR and should be emphasized but needs further special investigations. Further research should be directed to the investigate (in)sufficiency and effectiveness of resources allocated to the health care of Sudan, including immunization and contraceptive use against the outcomes of maternal health in view of a achieving the unmet health MDGs and moving forward to achieve health SDGs.

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