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Impact of child health on economic growth: New evidence based on Granger non-causality tests

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Abstract

The paper examines the presence and the direction of causality between child health and economic growth for a sample of 175 countries from year 1990 to 2014. We use both panel data and single country approach to the Granger non-causality testing. Results show that the relationship between change of child mortality rate and GDP per capita (GDPc) growth runs in both directions, in addition to large number of cases being from child mortality to economic growth. We find evidence that the causal effects of GDPc on child health outcomes are more frequent in low- and lower-middle-income countries relative to high- and upper-middle-income countries. However, in contrast, the causal effect of child mortality on GDPc is more often found in non-low-income countries.

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1. Introduction

Reproductive, maternal, newborn and child health (RMNCH) is fundamental to social development, which is reflected in Millennium Development Goals (MDGs). MDG4 (reducing child mortality) and MDG5 (improving maternal health and achieving universal access to reproductive health) are the most important targets. It has been demonstrated that significant additional investments are needed to achieve these targets and improve women's and children's health beyond the target date of 2015[1]. Developing and presenting economic arguments that resonate with stakeholders, such as Ministries of Finance and Planning, influence their investment decisions. Stakeholders need to be convinced that spending on RMNCH should be seen as an investment, not simply a cost.

For a long time the prevailing view among economists was that the link between health and economic development ran only in one direction, from economic development to investment in health. This view was articulated in an influential background paper to the World Development Report 1993 entitled Wealthier is Healthier. It recognized that economic development leads to improved health outcomes through its impact on indirect pathways to health – such as better nutrition, water and sanitation, living environment and education – but the reverse direction of health's impact on economic development was not fully acknowledged. This paradigm began to shift 15 years ago, particularly through the work of the Commission on Macroeconomics and Health (CMH[2]). The CMH verified that the direction of relationship between income and health feedbacks and that "healthier is wealthier". Bloom and Williamson (1997) imputed 30-50% of East Asia's considerable economic growth during the period of 1965 to 1990 to declined infant and child mortality along with lower fertility rates and raised reproductive health. Nevertheless, most of the evidence presented by the CMH was related to the effects of investments in HIV/AIDS and malaria.

Two of the major objectives of the Partnership for Maternal, Newborn & Child Health (PMNCH) by WHO are (a) to address evidence gaps and (b) to contribute to raise additional funds to address MDG4 and MDG5. In 2009, PMNCH developed an investment case for RMNCH in Asia and the Pacific in collaboration with an informal network of institutions and analysts concerned with the lack of progress on MDG4 and MDG5 in the region.[3] An investment case for Africa was developed in 2010 in collaboration with Harmonization for Health in Africa.[4] Literature reviews were conducted to inform the investment cases, and it became clear that there is limited evidence on the economic benefits of investing in RMNCH.

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[1] http://www.who.int/pmnch/activities/jointactionplan/en/

[2] http://www.who.int/macrohealth/en/

[3] MNCH network for Asia and the Pacific (2009) Investing in maternal, newborn and child health – The case for Asia and the Pacific. Geneva: WHO and PMNCH.

[4] http://www.who.int/pmnch/topics/economics/20110414_investinginhealth_africa/en/

To support global, regional, and national advocacy for increasing resources, demand has been expressed by members of PMNCH and the broader RMNCH community for the synthesis, and if necessary, the generation of evidence on the economic benefits of investing in RMNCH. To achieve this, a work program has been established under the auspices of PMNCH. The work program includes a systematic literature review, an econometric study of the relationship between RMNCH outcomes and economic growth, the development of a framework/model for estimating the national economic returns of investment in RMNCH, and technical consultations.

The target of present study is to response to challenge put forth by PMNCH. We examine whether there is a relationship between child health outcomes and economic growth in countries having different income levels. To do this, we investigate with Granger non-causality tests the relationships between child mortality growth and per capita GDP growth. We use country-level panel data (175 countries) from year 1990 to 2014.

2. Data description

Five variables[5] are available on the WHO data website[6] as indicators of child health. We use under-five mortality rate *MR5* (probability of dying by age 5 per 1,000 live births) which is a commonly used indicator to measure progress on child health and is the indicator of MDG4. We focus on the growth rate of *MR5* (i.e. *DlnMR5*, yearly difference of log of *MR5*). For the reason of lack of data availability we have yearly data from 1990 to 2014. As a measure of economic growth we use yearly difference of logarithm of annual per capita GDP series (*lnGDPc*) in 2000 US prices (ERS International Macroeconomic Data Set[7]). After eliminating countries with missing data, we analyze four different panels which are built on World Bank country classification: 54 high-income countries (HIC), 47 upper-middle-income countries (UMIC), 46 lower-middle-income countries (LMIC), and 28 low-income countries (LIC), i.e. 175 countries in total. For the list of countries included in our data, see Tables 5 and 6 below.

Tables 1 and 2 give the sample summary statistics for variables *DlnMR5* and *DlnGDPc*. Surprisingly the growth rates of mortality are of same magnitude across the income groups. However the standard deviations reveal that there is large variability in *DlnMR5* especially in low income countries. In many HIV/AIDS ridden LMI and LI countries growth rate of under-five year mortality was positive for some years. In Table 2 the GDPc growth rates are smallest in the high and low income countries. However the variability of *DlnGDPc* in income groups is largest in UMI and LI countries.

[5]Infant mortality rate (probability of dying between birth and age 1 per 1000 live births), under-five mortality rate (probability of dying by age 5 per 1000 live births), the number of infant deaths (thousands), the number of under-five deaths (thousands), and measles immunization coverage among 1-year-olds (%).
[6]http://apps.who.int/ghodata/
[7]http://www.ers.usda.gov/data-products/international-macroeconomic-data-set.aspx

Table 1. Summary statics for growth of child mortality (*DlnMR5*) 1991 - 2014

Country group	Mean	Median	Standard deviation	Observations
HIC	-0.0375	-0.0357	0.0269	1296
UMIC	-0.0366	-0.0330	0.0299	1128
LMIC	-0.0333	-0.0355	0.0456	1104
LIC	-0.0357	-0.0333	0.0636	672
ALL	-0.0358	-0.0346	0.0407	4200

Table 2. Summary statics for growth of GDPc (*DlnGDPc*) 1991 - 2014

Country group	Mean	Median	Standard deviation	Observations
HIC	0.01805	0.01932	0.05341	1350
UMIC	0.02805	0.02697	0.07969	1175
LMIC	0.02134	0.02446	0.06538	1150
LIC	0.01815	0.01669	0.10130	700
ALL	0.02160	0.02197	0.07324	4375

3. Panel data approach to Granger non-causality testing

Because of having a panel with large number of cross-section units and short time dimension we use panel data approach to Granger non-causality testing proposed by Dumitrescu and Hurlin (2012), Hurlin and Venet (2001), Hurlin (2004a), Hansen and Rand (2004). In the preliminary analysis we found with panel unit root tests that *lnMR5* series were stationary around trend but the reverse was true for *lnGDPc* series. However, the differenced series were stationary. Thus the unit problems do not disturb our Granger non-causality testing results.

Moving on to the concept of Granger causality in panel data with a bi-variate setting we observe that, if the variable x_{it} is able to predict better y_{it} than all available information of y_{it}, then x_{it} is causing y_{it}, for each individual cross unit. In practice, we have a general time-stationary *VAR* system in panel for $i = 1, 2, ..., N$ cross sections

$$y_{it} = c_{1i} + \sum_{k=1}^{m} \alpha_{1ki} y_{i,t-k} + \sum_{k=1}^{m} \beta_{1ki} x_{i,t-k} + \varepsilon_{1it}, \qquad \varepsilon_{1it} \sim nid(0, \sigma^2_{\varepsilon_{1i}}),$$
$$x_{it} = c_{2i} + \sum_{k=1}^{m} \alpha_{2ki} x_{i,t-k} + \sum_{k=1}^{m} \beta_{2ki} y_{i,t-k} + \varepsilon_{2it}, \qquad \varepsilon_{2it} \sim nid(0, \sigma^2_{\varepsilon_{2i}}). \tag{1}$$

m is the number of lags, and $\varepsilon's$ are normally distributed errors, α_{vki} and β_{vki} ($v = 1,2$) are the coefficients for each country.

It is important to note two major source of heterogeneity between cross-section units which may lead to bias the coefficient estimates in the non-causality tests. Permanent cross sectional disparities is the first source of heterogeneity. Non-homogenous intercepts c_{1i} and c_{2i} may cause bias and fallacious regressions in Granger non-causality tests (Hurlin 2004a). The second and

more challengeable source of heterogeneity is the heterogeneous regression slope coefficients α_{vki} and β_{vki}.

There are two essential test procedures to be analysed in the presence of heterogeneity. The first procedure is *homogenous non-causality hypothesis* (GC-1) which concerns whether or not the coefficients of "cause" variables in the *non-panel* form are not zero, i.e. all equation specific β_{vki} 's are same for all cross sections *i*, and are simultaneously zero for all *k* lags. For example the null hypothesis of GC-1 for the first equation is

$$H_0: \beta_{1k} = 0\,, \quad \forall k \in [1,m] \quad and \quad H_1: \beta_{1k} \neq 0 \qquad (2)$$

More interesting panel approach is the heterogeneous non-causality hypothesis for each cross-section. We test the significance of all the coefficients β_{vki} to find possible causal relationships in each country separately (see Erdil and Yetkiner 2009). The null hypothesis of GC-2 is

$$H_0: \beta_{1ik} = 0 \quad \forall i \epsilon [i,N], \quad \forall k \in [1,m] \quad and \quad H_1: \beta_{1ik} \neq 0 \qquad (3)$$

If the null hypothesis is rejected for each cross units then there is a Granger causal relationship from x_{it} to y_{it} in the cross-unit of *i*.

In practice in GC-1 test we assume the existence of one large stacked data set and investigate the standard pairwise Granger non-causality test. Here, the null hypothesis treats the existence of same coefficients across all cross-sections, i.e. no panel heterogeneity is allowed in equation. A second approach adopted by Dumitrescu and Hurlin (2012) allows all coefficients to vary across cross-sections (GC-2 test) and performs the standard Granger causality equations for *each* individual cross-section. *Wbar* statistics based on the average of these test statistics, and *Zbar* statistic is the Normal standardized version of this (Eviews 2014).

4. Results of panel Granger non-causality tests in country groups

Below we present the results of panel Granger non-causality tests for our four different income country groups. Table 3 confirms that the bilateral relationship is found in five cases with the tests. For UMI and LI countries, the results of panel Granger non-causality tests are contradictory between homogenous and non-homogenous tests. This leads us to investigate Granger non-causality at the country level in details.

Table 3. Results of panel Granger causality tests for country groups HIC, UMIC, LMIC and LIC

Null hypothesis	Pairwise Granger panel non-causality tests			Pairwise Dumitrescu-Hurlin panel non-causality tests			
	F-Statistic	Prob.	Direction	W-Stat.	Zbar-Stat.	Prob.	Direction
HIC *(m =3)*							
DlnMR5 does not Granger cause *DlnGDPc*	3.132	0.024	Bilateral	5.214	3.599	0.000	Bilateral
DlnGDPc does not Granger cause *DlnMR5*	2.461	0.061		4.479	2.055	0.039	
UMIC *(m = 2)*							
DlnMR5 does not Granger cause *DlnGDPc*	8.571	0.000	Bilateral	3.434	3.088	0.002	*DlnMR5* to
DlnGDPc does not Granger cause *DlnMR5*	4.760	0.009		2.681	1.096	0.272	*DlnGDPc*
LMIC *(m = 3)*							
DlnMR5 does not Granger cause *DlnGDPc*	3.921	0.020	Bilateral	3.677	3.690	0.000	Bilateral
DlnGDPc does not Granger cause *DlnMR5*	3.661	0.026		3.918	4.322	0.000	
LIC *(m = 2)*							
DlnMR5 does not Granger cause *DlnGDPc*	2.077	0.126	*DlnGDPc* to	3.431	2.378	0.017	*DlnMR5* to
DlnGDPc does not Granger cause *DlnMR5*	3.629	0.027	*DlnMR5*	2.710	0.905	0.365	*DlnGDPc*

5. Granger non-causality testing on country level

Our results so far indicate that majority of countries have a bi-directional relationship between *DlnMR5* and economic growth. This means that changes in health outcomes and health care provisions affect economic growth, i.e. investments in health may provide returns in terms of higher GDP per capita. Note that although the growth of child mortality is *not per se* a growth factor in the short term GDP per capita growth process, it is any way a very good indicator of health conditions and level of health care provisions in every country. These have clear short run effect on GDPc growth, and the economic growth affects child mortality quite instantaneous.

As our series are also very short with 25 observations, we prefer here the concept of "instantneous Granger causality" (see Appendix for more details). This means that we allow also for lag 0 for the cause variable in the testing. The test models have now for the each country the form

$$y_t = c_1 + \sum_{k=1}^{m} \alpha_1 y_{t-k} + \sum_{k=0}^{m} \beta_1 x_{t-k} + \varepsilon_{1t}, \qquad \varepsilon_{1t} \sim iid(0, \sigma_{\varepsilon_1}^2),$$
$$x_t = c_2 + \sum_{k=1}^{m} \alpha_2 x_{t-k} + \sum_{k=0}^{m} \beta_2 y_{t-k} + \varepsilon_{2t}, \qquad \varepsilon_t \sim iid(0, \sigma_{\varepsilon_2}^2). \tag{4}$$

After some experiments with different lag lengths we based the reported test values on *m = 1*. The results (see Tables 4, 5 and 6) confirm that in the majority of countries there is a feedback (bi-directional) causal relationship of child health outcomes on GDP growth which indicates that investments in health may provide returns in terms of higher GDP growth. Table 4 gives the shares of different relationships in different country groups. In 108 (61.7%) of 175 countries we find bi-directional or *DlnMR5* → *DlnGDPc* relationship. This implies that in the majority of countries, changes of under-five mortality have an impact on economic growth. In the context of country groups, the shares of these cases are 53.7%, 48.9%, 73.9% and 78.6% for HI, UMI, LMI,

and LI countries, respectively. In 33 countries (18.8%) we find a one-way relationship from income growth to mortality change. For the remainder 34 (19%) countries, we find no significant relationships.

Table 4. The percentage of significant relationships between growth rates of MR5 and GDPc in different country groups

	Bilateral	*DlnMR5 → DlnGDPc*	*DlnGDPc → DlnMR5*	*No relationship*
HIC	25.93%	27.78%	20.37%	25.92%
UMIC	19.15%	29.79%	21.28%	29.79%
LMIC	34.78%	39.13%	13.04%	13.04%
LIC	64.29%	14.29%	21.43%	0.00%
Totality	32.57%	29.14%	18.86%	19.43%

Interestingly, we find that relationship from child health (*DlnMR*5) to economic growth is more significant in HI, UMI and LMI countries compared to LI countries. However, the bilateral relationship dominates in LI countries. This may reflect the fact that the marginal effect of health investments on health outcomes is more effective in poorer countries and income growth supports this pattern. Note also that over 90% of valid impact coefficients across the countries were negative meaning that our empirical results respond to economic theories that analyze the relationship between child mortality and GDP per capita growth (see e.g. Kalemli-Ozcan 2002).

Table 5. Granger non-causality tests between *DlnMR5* and *DlnGDPc* in HI and UMI countries

HIC	#1	#2	Direction	**UMIC**	#1	#2	Direction
Antigua & Barbuda	14.78***	1.95	MR5-GDP	Albania	74.59***	2.06	MR5-GDP
Argentina	17.87***	0.05	MR5-GDP	Algeria	0.03	3.15	No
Australia	1.75	1.17	No	Angola	1.80	0.06	No
Austria	1.18	11.97***	GDP-MR5	Azerbaijan	20.63***	7.49**	Bilateral
Bahamas	0.97	0.09	No	Belarus	2.64	81.03***	GDP-MR5
Bahrain	0.16	1.63	No	Belize	3.49	5.60*	GDP-MR5
Barbados	32.79***	8.40**	Bilateral	Bosnia Herzegovina	728.34***	5493.86***	Bilateral
Belgium	0.41	0.01	No	Botswana	4.43	177.06***	GDP-MR5
Brunei	33.48***	6.89**	Bilateral	Brazil	1.50	16.54***	GDP-MR5
Canada	0.42	11.50***	GDP-MR5	Bulgaria	15.44***	1.89	MR5-GDP
Chile	12.01***	6.45**	Bilateral	China	1.59	9.77***	GDP-MR5
Croatia	5.00*	14.20***	Bilateral	Colombia	0.66	2.37	No
Cyprus	4.44	3.95	No	Costa Rica	3.72	5.44*	MR5-GDP
Czech Republic	10.60***	2.15	MR5-GDP	Cuba	3.74	4.27	No
Denmark	0.12	14.75***	GDP-MR5	Dominica	0.47	23.03***	GDP-MR5
Estonia	30.10***	3.19	MR5-GDP	Dominican Republic	10.79***	1.57	MR5-GDP
Finland	1.97	10.78***	GDP-MR5	Ecuador	5.15*	26.71***	Bilateral
France	1.42	7.80**	GDP-MR5	Fiji	7.75**	1.68	MR5-GDP

Germany	3.02	1.49	No	Gabon	14.55***	1.50	MR5-GDP
Greece	3.10	9.05**	GDP-MR5	Grenada	11.45***	2.94	MR5-GDP
Hungary	4.57	5.31*	GDP-MR5	Iran	2.31	0.29	No
Iceland	10.03***	39.84***	Bilateral	Iraq	354.61***	5.22*	Bilateral
Ireland	2.18	7.43**	GDP-MR5	Jamaica	22.20***	0.48	MR5-GDP
Israel	26.52***	1.98	MR5-GDP	Jordan	3.60	0.30	No
Italy	7.66**	14.72***	Bilateral	Kazakhstan	3.89	4.38	No
Japan	2.12	29.20***	GDP-MR5	Lebanon	7.23**	1.53	MR5-GDP
Kuwait	114.75***	342.19***	Bilateral	Libya	3455.37***	4825.25***	Bilateral
Latvia	52.18***	0.50	MR5-GDP	Malaysia	5.67*	2.89	MR5-GDP
Lithuania	42.26***	118.75***	Bilateral	Maldives Islands	124.66***	1124.91***	Bilateral
Luxembourg	1.67	8.56**	GDP-MR5	Mauritius	3.05	4.88*	GDP-MR5
Malta & Gozo	8.27**	8.56**	Bilateral	Mexico	1.89	7.02**	GDP-MR5
Netherlands	0.90	3.89	No	Mongolia	7.81**	4.58	MR5-GDP
New Zealand	5.90*	1.88	MR5-GDP	Namibia	11.65***	10.27***	Bilateral
Norway	0.71	0.21	No	Panama	0.23	1.57	No
Oman	1.35	1.51	No	Paraguay	3.67	1.31	No
Poland	15.23***	8.33**	Bilateral	Peru	5.18*	1.51	GDP-MR5
Portugal	1.68	0.37	No	Romania	4.10	1.86	No
Russia	9.12**	22.04***	Bilateral	Serbia	24.34***	84.32***	Bilateral
Saudi Arabia	5.12*	0.51	MR5-GDP	South Africa	0.30	44.76***	GDP-MR5
Seychelles	1.21	3.99	No	St Lucia	0.81	2.16	No
Singapore	43.13***	10.00***	Bilateral	St Vincent & Grenadines	2.59	4.23	No
Slovakia	24.57***	3.53	MR5-GDP	Suriname	1.34	1.85	No
Slovenia	11.02***	21.95***	Bilateral	Thailand	15.80***	2.94	MR5-GDP
South Korea	4.63*	0.96	MR5-GDP	Tonga	1.72	1.74	No
Spain	1.33	0.06	No	Tunisia	5.37*	9.66***	Bilateral
St Kitts & Nevis	13.20***	0.21	MR5-GDP	Turkey	36.75***	2.29	MR5-GDP
Sweden	1.41	0.09	No	Turkmenistan	35.33***	3.03	MR5-GDP
Switzerland	4.99*	0.34	MR5-GDP				
Trinidad& Tobago	2.59	3.57	No				
U.A.E.	24.73***	3.70	MR5-GDP				
United Kingdom	2.14	11.33***	GDP-MR5				
United States	5.40*	0.58	MR5-GDP				
Uruguay	8.25**	0.56	MR5-GDP				
Venezuela	10.25***	152.04***	Bilateral				

H_0 #1: *DlnMR5* does not Granger cause *DlnGDPc*, H_0 #2: *DlnGDPc* does not Granger cause *DlnMR5*.
Notes: * p<0.10%, ** p<0.05% and *** p<0.01%. Lag value choice: k = 0 and 1.

Table 6. Granger non-causality tests between *DlnMR5* and *DlnGDP* in LMI and LI countries

LMIC	#1	#2	Direction	**LIC**	#1	#2	Direction
Armenia	67.61***	1.09	MR5-GDP	Afghanistan	59.61***	19.02***	Bilateral
Bangladesh	4.61*	0.38	MR5-GDP	Benin	6.81**	2.96	MR5-GDP
Bhutan	90.40***	1.20	MR5-GDP	Burkina Faso	29.41***	33.19***	Bilateral
Bolivia	1.00	2.41	No	Burundi	9.47***	1.53	MR5-GDP
Cameroon	11.56***	43.93***	Bilateral	Cambodia	7.63**	434.15***	Bilateral
Cape Verde Islands	40.47***	11.88***	Bilateral	Central African Republic	277.89***	26.83***	Bilateral
Congo (Brazzaville)	3.51	29.17***	GDP-MR5	Chad	176.49***	30.90***	Bilateral
Cote D'Ivoire	16.39***	11.47***	Bilateral	Comoros Islands	2.46	52.40***	GDP-MR5
Djibouti	5.93*	0.68	MR5-GDP	Congo (Kinshasha)	15.47***	149.39***	Bilateral
Egypt	4.96*	0.17	MR5-GDP	Equatorial Guinea	3076.68***	0.92***	Bilateral
El Salvador	9.83***	0.05	MR5-GDP	Eritrea	23.21***	44.65***	Bilateral
Georgia	21.22***	8.96**	Bilateral	Ethiopia	157.06***	6.44**	Bilateral
Ghana	4.57	1.76	No	Guinea	3.63	8.17**	GDP-MR5
Guatemala	2.95	1.95	No	Guinea Bissau	0.15	5.38*	GDP-MR5
Guyana	9.46***	2.47	MR5-GDP	Haiti	42.34***	69557.28***	Bilateral
Honduras	27.87***	213.40***	Bilateral	Liberia	376.42***	3.29	MR5-GDP
India	26.93***	1.72	MR5-GDP	Madagascar	0.18	24.71***	GDP-MR5
Indonesia	9.57***	371.32***	Bilateral	Malawi	44.92***	54.73***	Bilateral
Kenya	41.88***	8.35**	Bilateral	Mali	81.00***	76.36***	Bilateral
Kyrgyzstan	6.28**	12.03***	Bilateral	Mozambique	40.05***	73.46***	Bilateral
Laos	20.83***	0.07	MR5-GDP	Nepal	39.80***	15.50***	Bilateral
Lesotho	0.37	160.83***	GDP-MR5	Niger	22.75***	26.54***	Bilateral
Mauritania	11.93***	0.76	MR5-GDP	Rwanda	1053.11***	263933.60***	Bilateral
Micronesia	4.20	5.22*	GDP-MR5	Sierra Leone	329.42***	12.30***	Bilateral
Morocco	76.62***	0.89	MR5-GDP	Tanzania	30.44***	76.50***	Bilateral
Myanmar	23.58***	1099.05***	Bilateral	Togo	4.26	20.84***	GDP-MR5
Nicaragua	11.04***	236.76***	Bilateral	Uganda	39.34***	2.52	MR5-GDP
Nigeria	138.45***	0.39	MR5-GDP	Zimbabwe	3.69	255.49***	GDP-MR5
Pakistan	3.51	0.40	No				
Papua New Guinea	11.84***	3.53	MR5-GDP				
Philippines	5.45*	3.16	MR5-GDP				
Samoa	21.54***	3617.06***	Bilateral				
Sao Tome & Principe	26.06***	0.11	MR5-GDP				
Senegal	13.61***	2.94	MR5-GDP				
Solomon Islands	8.51**	8.78**	Bilateral				
Sri Lanka	1.44	787.87***	GDP-MR5				
Sudan	3.41	1.60	No				
Swaziland	0.58	123.98***	GDP-MR5				
Syria	40.81***	135.91***	Bilateral				
Tajikistan	25.03***	44.01***	Bilateral				

Ukraine	0.90	26.04***	GDP-MR5
Uzbekistan	13.54***	6.91**	Bilateral
Vanuatu New Hebrides	8.80**	106.25***	Bilateral
Vietnam	2.06	0.24	No
Yemen United	27.61***	3.13	MR5-GDP
Zambia	21.20***	0.17	MR5-GDP

H_0 #1: *DlnMR5* does not Granger cause *DlnGDPc*, H_0 #2: *DlnGDPc* does not Granger cause *DlnMR5*.
Notes:* p<0.10%, ** p<0.05% and *** p<0.01%. Lag value choice: k = 0 and 1.

6. Conclusions and discussion

The causal relationship between child health and economic growth is vital since it indicates potential economic and social returns on investments in growth process. The objectives of this study were to examine the relationship between changes of child mortality and GDPc growth, and to estimate the direction of any such relationships. In the analysis we used first panel data Granger non-causality test based on a bivariate model to provide some initial evidence. We found that the relationships between changes in child health outcomes and per capita GDP growth run in both directions but for UMI and LI countries the test results were contradictory with different panel tests. In the second step we conducted Grange non-causality tests allowing also for "instantaneous causality" at the country level for 175 countries. We found in general that the relationships between child health outcomes and GDPc growth run in both directions, and frequently from child health to GDPc growth. We found evidence that the causal effects between GDPc growth and child health are stronger in LI and LMI countries relative to HI and UMI countries (fore related results, see e.g. O'Hare et al. 2013 and Bhalotra 2006). This may reflect the fact that the effect of incomes on health outcomes is stronger at low GDPc levels, i.e. in countries where generally the level of health is lower.

In sum, this study supports the view that the efficiency of health investment works through two different mechanisms which are important particularly in lower income countries. Firstly, health investments will improve the health level and will reduce the gap in health inequality between the countries. Secondly, investments in health in lower income countries, which increase the efficiency of health on GDP, will in addition lead to higher GDP levels that will improve the level of health. This will reduce the health-income inequality in the world.

An important direction of future research is to investigate what factors drive the efficiency rate (impact) of maternal and child health on GDPc growth and also whether the present trends continue across the countries. One important limitation of this study is that we had to restrict the analysis to only two variables in the econometric Granger analysis, i.e. one variable of health and GDPc, without control of other potentially confounding variables, such as education, and without consideration of other aspects of health. Another limitation is the short nature of the time dimension. Thus we suggest that, following the recommendations of the Commission on

Information and Accountability for Women's and Children's Health, WHO, and other relevant organizations, in collaboration with researchers, to support countries in collecting and analyzing macro and micro-level data that can be used to further study the interaction between health and economic development. We also suggest analyzing so-called lag length effects in details, e.g. how delayed effects between health and GDPc happens in time and whether the findings make sense.

Appendix Instantaneous Granger non-causality testing

In terms of two variable *VAR* model the Granger "instantaneous non-causality", $X_t \not\to Y_t$ and $Y_t \not\to X_t$, means that error covariance matrix $\boldsymbol{\Sigma}_\mu$ of *VAR* model is diagonal, i.e. restricted (Lutkepohl 2005, Sections 2.3 ans 5.2.5). Thus, if the starting point is the *non-restricted VAR(1)* model, then

$$\begin{bmatrix} Y_t \\ X_t \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ X_{t-1} \end{bmatrix} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \end{bmatrix} = \boldsymbol{A}_1 \begin{bmatrix} Y_{t-1} \\ X_{t-1} \end{bmatrix} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \end{bmatrix},$$

and $\boldsymbol{\Sigma}_\mu$ is *non*-diagonal, i.e. $COV[\mu_{11}, \mu_{2t}] = E[\mu_{1t}\mu_{2t}^{'}] = \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{21} & \sigma_2^2 \end{bmatrix}$.

Now the question is that can we formulate also the testing for "instantaneous Granger non-causality" on the error covariance matrix $\boldsymbol{\Sigma}_\mu$ being diagonal, that is $\sigma_{12} = \sigma_{21} = 0$. This is done quite easily in following way. As $\boldsymbol{\Sigma}_\mu$ is in general setting non-diagonal and symmetric matrix, it has the following de-composition $\boldsymbol{\Sigma}_\mu = \boldsymbol{W}\boldsymbol{\Sigma}_e\boldsymbol{W}'$ where $\boldsymbol{W}$ is lower triangular matrix with unit main diagonal and $\boldsymbol{\Sigma}_\varepsilon$ is diagonal variance matrix. We obtain the *recursive model* by multiplying model above with $\boldsymbol{W}^{-1}$

$$\boldsymbol{W}^{-1}\begin{bmatrix} Y_t \\ X_t \end{bmatrix} = \boldsymbol{A}_0^* \begin{bmatrix} Y_t \\ X_t \end{bmatrix} + \boldsymbol{A}_1^* \begin{bmatrix} Y_{t-1} \\ X_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$$

where $\boldsymbol{A}_0^* = \boldsymbol{I}_2 - \boldsymbol{W}^{-1}$, $\boldsymbol{A}_1^* = \boldsymbol{W}^{-1}\boldsymbol{A}_1$ and $\boldsymbol{\varepsilon}_t = \boldsymbol{W}^{-1}\boldsymbol{\mu}_t$. In details we have a recursive model like

$$\begin{bmatrix} 1 & 0 \\ -w & 1 \end{bmatrix}\begin{bmatrix} Y_t \\ X_t \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ w & 0 \end{bmatrix}\begin{bmatrix} Y_t \\ X_t \end{bmatrix} + \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ -w\alpha_{11} + \alpha_{21} & -w\alpha_{12} + \alpha_{22} \end{bmatrix}\begin{bmatrix} Y_{t-1} \\ X_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$$

$$\Rightarrow Y_t = \alpha_{11}Y_{t-1} + \alpha_{12}X_{t-1} + \varepsilon_{1t}$$

$$\begin{aligned} X_t &= 2wY_t + (\alpha_{22} - w\alpha_{12})X_{t-1} + (\alpha_{21} - w\alpha_{11})Y_{t-1} + \varepsilon_{2t} \\ &= \alpha_0^* Y_t + \alpha_{22}^* X_{t-1} + \alpha_{21}^* Y_{t-1} + \varepsilon_{2t} \end{aligned}$$

Because $E[\varepsilon_{1t}\varepsilon_{2t}^{'}]=\begin{bmatrix}\sigma_1^2 & 0\\ 0 & \sigma_2^2\end{bmatrix}$ we can estimate these equations separately with OLS and test for "instantaneous Granger non-causality" by restriction $\alpha_0^*=0$. The standard Granger non-causality tests are the separate test for $\alpha_{12}=0$ and $\alpha_{21}^*=0$. Note that *overall* non-causality or non-predictability of X_t, i.e. $Y_{t-1} \not\to X_t$ with $Y_t \not\to X_t$, means that $\alpha_{21}^*=(\alpha_{21}-w\alpha_{11})=0$ implying that $\alpha_{21}=0$ *and* $w=\alpha_0^*=0$. However "instantaneous Granger non-causality" can happen with standard Granger causality, i.e. $w=\alpha_0^*=0$ but $\alpha_{21}^*=\alpha_{21}\neq 0$, but the opposite case ($Y_{t-1} \not\to X_t$ and $Y_t \to X_t$) is the pure correlation between X_t and Y_t without any cause and effect as long as any theory does not support it.

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