Are childhood immunisation rates associated with per capita income? Empirical evidence from 95 countries

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Abstract

Vaccination is a relevant prevention measure as a health strategy as it improves population's health and well-being. This paper examines the relationship between trends in childhood vaccination coverage and per capita income from 2000 to 2020 and, specifically, the existence of convergence between them. We analyse data from two sources. On the one hand, we use per capita income data according to the World Bank classification (low-, lower-middle, upper-middle and high-income countries). On the other hand, we use data from the World Health Organization to analyse eight vaccines (the first dose of Bacillus Calmette–Guérin (BCG); the first and the third dose of Diphtheria-Tetanus-Pertussis (DTP1 and DTP3); the third dose of Hepatitis B (HEPB3); the first and the second dose of Measles-Containing (MCV1 and MCV2); the third dose of Polio (Pol3); and the Tetanus Toxoid (TT2)). We perform a fixed effects model to obtain the correlation between trends in coverage of the 8 vaccines mentioned and income across 95 countries during the first 20 years of the 21st century. Additionally, we follow the Barro and Sala-i-Martín approach to identify conditioned convergence. The study includes 95 countries and eight vaccines. Our findings show a positive correlation for almost all vaccines (BCG: 0.0014, p=0.0006; DTP1: 0.0012, p=0.0006; DTP3: 0.0002, p=0.0009; HepB3: 0.0037, p=0.0011; MCV1: 0.0022, p=0.0010; MCV2: -0.0062, p=0.0044; Pol3: 0.0001, p=0.0010; TT2: 0.0052, p=0.0009). Looking at conditioned convergence, the positive coefficient of the delayed dependent variable implies conditioned convergence for all vaccines (BCG: -0.1145, p=0.0073; DTP1: -0.1105, p=0.00789; DTP3: -0.1097, p=0.0070; HepB3: -0.1184, p=0.0087; MCV1: -0.1115, p=0.0075; MCV2: -0.1376, p=0.0123; Pol3: -0.1089, p=0.0070; TT2: -0.1158, p=0.0131). Hence, even if countries differ in their socioeconomic characteristics, they converge to different steady state. This paper provides new empirical evidence on both the relationship of immunisation coverage rates and per capita income. Our findings may have significant implications for health policies because socio-economic status indicators have a notable impact on immunisation rates.

Keywords: Immunisation coverage; Childhood; Per capita income; Fixed effects model

Introduction

Vaccination is one of the most relevant prevention measures as a health strategy and the different programs implemented are a matter of public choice because they are cost-effective for improving population's health and well-being. Richer countries are, on average, healthier than the poorer ones because they have more resources to improve health, invest in health infrastructure and conduct trainings to rise vaccination rates. Hence, it means that vaccination rates vary significantly across countries [1].

The Global Vaccine Action Plan (GVAP) has made some progress, but certain constraints have been identified, which have not allowed some targets set out in the Decade of Vaccines 2020 to be achieved [2]. It is necessary to improve immunisation rates for most disadvantaged groups, children being the main population at risk [3]. In other words, children who are not vaccinated are more likely to get sick, have disabilities or even die prematurely. So, their productivity can be reduced during their lives. Nevertheless, vaccination coverage is associated with family characteristics and parental attitudes, among others.

Literature on vaccination is extensive. Many health economists analyse vaccines cost-effectiveness, immunising an additional child or comparing it with savings for national health systems, among others [4-6]. In our case, we analyse the relationship between immunisation coverage and per capita income. Previous research about this topic is extensive, but most of it focuses mainly on the study of a single vaccine. Meanwhile, we focus on eight vaccines. LaMontagne et al. [7] show that countries achieve high HPV immunisation coverage rates through some strategies, but they need funding. Besides, the vaccine can reduce mortality rates in countries where there are large burdens of cervical cancer. Similarly, Bruni et al. [8] estimate the coverage of vaccinated women against HPV by region and by income level. They present burden and prevention inequalities between low- and high-income countries, finding the highest immunisation rates in upper-middle and high-income countries and higher incidence and mortality in low- and middle-income countries.

Therefore, the aim of our study is to analyse trends in childhood vaccination coverage and per capita income. We examine as many countries and vaccines as possible, considering the availability of data for the 2000-2020 period. As far as we know, this study provides the most recent evidence on the correlation between childhood vaccination, focused on eight vaccines included in the global immunisation schedules, and per capita income, considering the main 95 economies around the world. We use the Gross National Income (GNI) per capita from the World Bank and the coverage rates of eight vaccines from the World Health Organization (WHO). We follow both a linear and a dynamic econometric model and we show if there is conditioned

convergence. Our findings indicate that per capita income has positive correlation with immunisation coverage rates and the existence of conditioned convergence.

This paper is organized as follows. In the subsequent section, we describe the vaccines considered using data from both the WHO and the World Bank. In addition, we present the empirical analysis section that develops both a linear and a dynamic model to carry out our research and we show our results. Besides, we study if there is convergence between income growth rates and immunisation coverage. Discussion Section compare our findings with other articles from the most recent literature. Finally, last section summarises our findings.

Methods

Data

Based on data availability from the World Bank and the WHO, we analyse as many countries as possible as well as vaccines. We consider a period of time that covers 21 years, specifically, we analyse from 2000 to 2020. So, as we have mentioned previously, the number of observations for each vaccine has been limited by the availability of data. That is, we have eliminated from the sample those countries for which there is no data on vaccination coverage between 2000 and 2020 due to there are missing relevant data points.

On the one hand, we use per capita income data according to the classification of the World Bank. We use the most current information measured at Purchasing Power Parity (PPP) terms based on July 2021 data. Economies are divided among income groups according to 2020 GNI per capita, in U.S. dollars. The World Bank classifies countries dividing their economies into four income groups. First, low-income economies are those countries with a GNI per capita lower than $1,046. Second, lower-middle income economies are countries whose GNI per capita is between $1,046 and $4,095. Third, upper-middle income economies present a GNI per capita between $4,096 and $12,695. Last, high-income economies are those countries with a GNI per capita higher than $12,695. Therefore, our income variable can have a clear ordering of the four categories (low, low-middle, upper-middle and high). In addition, we are able to classify countries into these four categories. So, more precisely, our income variable is ordinal.

We exclude certain countries because there are missing relevant values. Therefore, our final sample consists of 95 countries: 15 low-income economies, 29 lower-middle income countries, 29 upper-middle income economies and 22 high-income countries (Table A.1).

On the other hand, we use data from the WHO's Department of Immunization, Vaccines and Biologicals, which includes childhood vaccination coverage rates of many countries. We analyse the following vaccines [9]:

The first dose of the Bacillus Calmette-Guérin (BCG) vaccine, used against tuberculosis. In terms of immunisation, coverage rates range from 75% to 90% and from 90% to 93%, in low-income and upper-middle economies, respectively, between 2000 and 2020. In the case of lower-middle income countries, this value ranges from 87% to 91%, the situation being very similar in high-income economies.

The first and the third dose of the vaccine that conveys immunity to Diphtheria, Pertussis and Tetanus (DTP1 and DTP3). The coverage rate of the first dose ranges from 87% to 94% for all countries while 81% and 91% of children get the second dose of the vaccine, in 2000 and 2020, respectively.

The third dose of the vaccine HepB3 protects from Hepatitis B. We have coverage rates for all countries, except for the low-income ones. The average coverage rate is 94% across the analysed countries in 2020, improving the situation from the previous one in 2000 (79%).

The first and the second dose of the Measles-Containing vaccine (MCV1 and MCV2), used against the measles virus. On the one hand, the coverage rate of the first dose ranges from 86% to 94% for all countries. On the other hand, for the second dose, lower-middle economies reach the greatest immunisation coverage levels (94%). So, taking into account that the higher the income the higher the vaccination coverage rates, we could expect that this vaccine would have a negative association with per capita income.

The third dose of the Polio vaccine (Pol3), used to prevent poliomyelitis. Looking at immunisation coverage rates in 2016, all countries present high values, ranging from 85% to 95%, in low- and high-income countries, respectively.

For the Tetanus Toxoid vaccine (TT2), we have coverage rates for all countries, except for the high-income ones. In 2000, around 47% infants and children get the vaccine in poorer countries, that is, low-income economies. Meanwhile, lower-middle and upper-middle economies have similar values, ranging, nearly, from 55% to 65%, in 2000 and 2020, respectively.

Table 1 shows the descriptive statistics of the vaccines considered as well as of the GNI per capita, where the number of observations corresponds to the income (US $) of the 95 countries analysed. According to the vaccines, the number of observations varies among them due to the lack of data. There are three vaccines (Pol3, DTP3 and MCV1) that have more than 2,000 observations. Besides, the TT2 vaccine has a relatively small number of observations because many high-income countries do not use it or there are missing values. Vaccines that have fewer observations may be due to the fact that these vaccines are not affordable in certain countries, or, in the case of the Measles-Containing vaccine, it should be noted that several countries have not introduced the required second dose into the national immunisation schedule, as is the case for twenty countries in sub-Saharan Africa. In addition, this vaccine has the lowest mean coverage rate. Meanwhile, the mean coverage rate is highest for the DTP1, followed by the BCG vaccine.

Table 1. Summary statistics of the eight vaccines and the GNI per capita

Variable	Obs.	Mean	Std. Dev.	Min	Max
3rd dose of Polio	2,193	88.15	13.21	12	99
1st dose of Diphtheria, Pertussis and Tetanus	1,411	91.71	11.08	14	99
3rd dose of Diphtheria, Pertussis and Tetanus	2,210	88.44	13.36	10	99
1st dose of Measles-Containing	2,040	88.18	13.44	19	99
2nd dose of Measles-Containing	442	92.67	8.45	31	99
BCG	1,785	90,16	13.32	16	99
3rd dose of Hepatitis B	816	90.65	12.49	7	99
Tetanus toxoid	629	64.2	23.08	13	99
GNI per capita (US $)	2,295	8,444.28	13,954.81	80	104,540

Note: Bacillus Calmette-Guérin, BCG. Source: authors' elaboration.

Figure 1 shows the relationship between the GNI per capita and the coverage rate of the eight vaccines considered: BCG, DTP1, DTP3, Hep3, MCV1, MCV2, Pol3 and TT2. It can be seen the grouping of most of the points in the top left corner, indicating a general pattern that vaccination rates are higher in those countries characterised by higher per capita income. Nevertheless, we find atypical data (outliers) when we focus on countries with high per capita income. Mainly, these data are in the BCG vaccine, where Sweden, which has an income above $50,000, has low vaccination rates that do not exceed 30% coverage. Likewise, in the HepB3 vaccine, Germany has values below 60% coverage in 2000 and 2020. The same happens with Belgium between 2000 and 2004, which it does not exceed 65%. Furthermore, the Republic of Korea (with an income of $ 27,600) presents outliers for the BCG, DTP1, DTP3, MCV1 and Pol3 vaccines in 2001. However, we maintain these countries in our sample after verifying that excluding them does not modify qualitatively our findings.

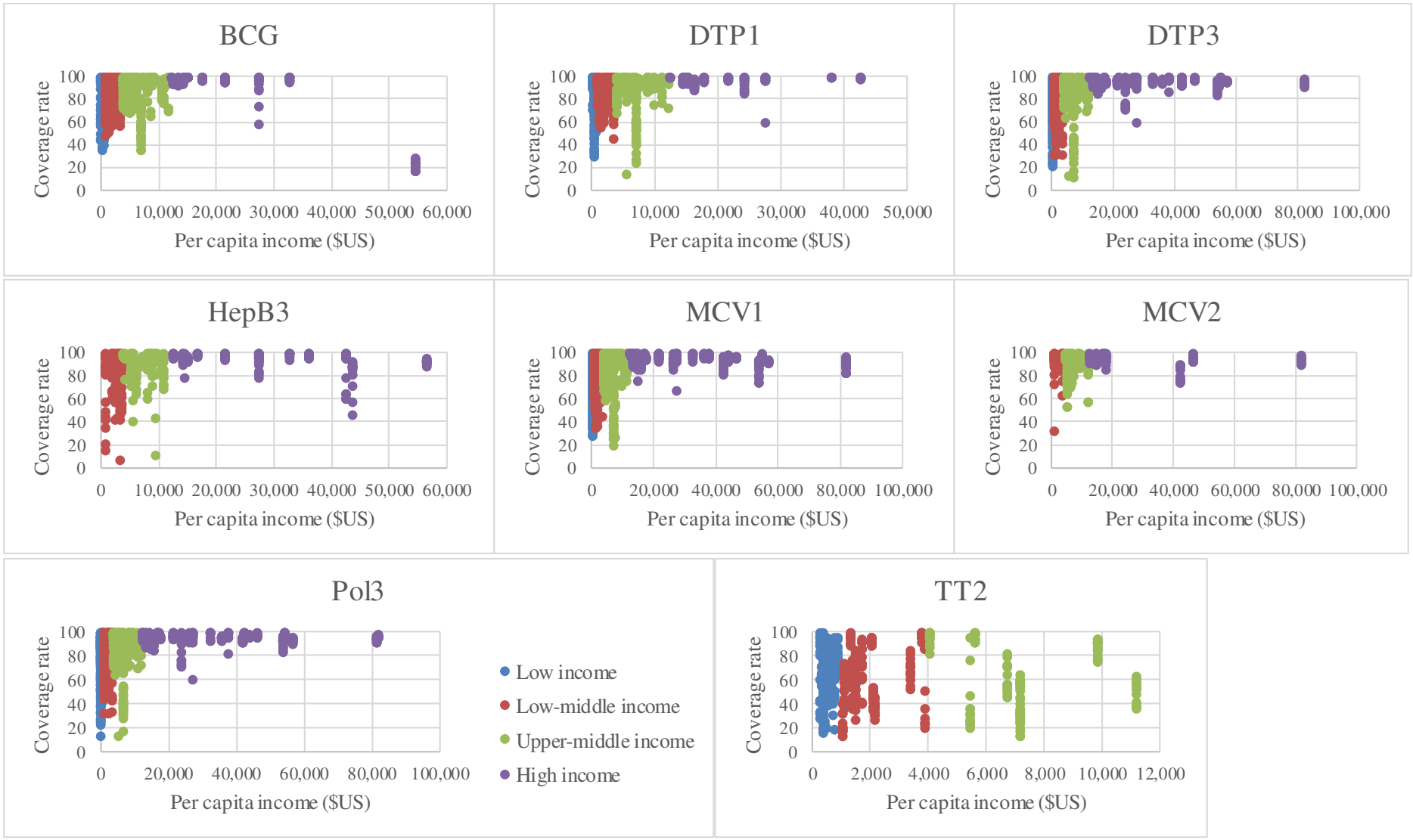

Figure 1. Per capita income and coverage vaccination rates

Note: BCG is the first dose of the vaccine against tuberculosis; DTP1 and DTP3 are the first and the third dose of the vaccine for diphtheria, pertussis and tetanus; HepB3 is the third dose of the vaccine against hepatitis B; MCV1 and MCV2 are the first and the second dose of the vaccine for Measles-Containing; Pol3 is the third dose of the polio vaccine and TT2 is the vaccine against the tetanus toxoid. Source: authors' elaboration.

Empirical analysis

In this section, we conduct an econometric model. It is expected that vaccination coverage rates have a positive correlation with per capita income. That is, we would assume that vaccination coverage rate would be higher in those countries with higher income. Therefore, in some of the most vulnerable countries., which are characterised by low-income economies, we would find a lower vaccination coverage because it is constrained by limited supply of the vaccines [10]. It must be highlighted that our principal aim is to analyse the association between trends in childhood vaccines coverage rates and per capita income. So, the models used are specified at the national level. In particular, we rely on the classification of the country, without focusing on the differences within each of the countries.

Despite the fact that Figure 1 suggests that the relationship between childhood vaccination coverage and per capita income is not linear, we want to ensure that it does just that. Hence, we estimate a regression as follows:

$$cov_{it} = \alpha_i + \mu_t + \beta_1 inc_{it} + X_{it}\delta + u_{it} \quad (1)$$

where cov_{it} is the vaccination coverage rate in the country i at year t, α_i is the country-fixed effects, μ_t is the year-fixed effects, inc_{it} represents per capita income in the country i at year t, X_{it} is a vector of control variables and u_{it} is the error term.

Moreover, the equation contains country- and year-fixed effects. On the one hand, country-fixed effects control unobservable time factors that do not vary over time for a specific country, such as historical and institutional factors. On the other hand, year-fixed effects are also important because our sample consists of an extended period. Nevertheless, these factors can be correlated with vaccination coverage rates and/or per capita income. Thus, we could have a problem from omitted variable bias if we left it in the error term.

We add control variables for each country for following reasons. Overall, we focus on sociodemographic variables that characterise each of the countries considered because our objective is to broadly examine countries according to their income level (low, low-middle, upper-middle and high). So, we use the population variable to check if a greater number of inhabitants affects to a greater or lesser extent. The same applies to population density, to observe how the average number of inhabitants in each country affects a given area. On the one hand, the percentage of population between 15 and 64 years as well as the percentage of the population over 65 years are used to check whether there is a difference between age groups. On the other hand, the percentage of female population is used to cover a basic variable such as gender. Finally, we analyse the percentage of rural population to have a variable that, as far as possible, can contain the differences within each country. As we mentioned above, we do not want to have correlation problems, so we exclude the share of male population and the urban one to prevent that problem.

Regarding the existence of some degree of correlation across the eight vaccines considered within countries, it would be logical to think that this correlation would exist across that vaccines used against the same disease. That is, DTP vaccine, considering the first and third doses; and the MCV, taking into account the first and second doses. However, we think it would be better to analyse each type of vaccine independently, without assessing all at once in the analysis. In addition, if we look at the data collected for each dose of MCV, we see that the second dose has only 442 observations compared to the first dose, which present 2,040. That is, considering the period of 21 years (2000-2020) analysed, we only have data from 29 countries. Therefore, it is not entirely clear that these doses were correlated with each other. However, it is true that we could consider it for future studies.

Our findings considering equation (1) are shown in Table 2. Each vaccine represents an estimation, so, we perform eight estimates, showing them in columns 2-9. Our dependent variable is childhood vaccination, which is based on the GNI per capita in 2020, using the most current information measured at Purchasing Power Parity (PPP) terms.

We present the standard error in our findings. So, it shows how much the value of a test statistic varies from sample to sample. Therefore, it is possible to check how disperse data are when comparing all the countries considered.

When we show the per capita income variables for the different vaccines considered, they are separately significant for most of them, except for DTP3, Pol3 and MCV2. In addition, these variables present positive coefficients, having immunisation rates a positive correlation with per capita income for all vaccines, except for MCV2. That is, for BCG estimation, the per capita income rate is 0.0014 and it is significant at the 5% level. The coefficient implies that a 1 percentage point increase in per capita income will rise immunisation coverage of BCG by 0.0014, holding other factors constant. The opposite happens for MCV2 estimation, whose per capita income is negative (-0.0062) and it is not significant. This coefficient implies that a 1 percentage point increase in the per capita income will decrease immunisation coverage of MCV2 by 0.0062, holding other factors constant.

Now, we describe our findings for control variables. In the case of population variable, they affect positively vaccination coverage, except for MCV2, although it is not relevant enough. Meanwhile, in the case of population density variable, it decreases for BCG and TT2 vaccines, being significant in most cases. Focused on the share of population between 15 and 64 years as well as older than 64, all the coefficients have a positive sign, except for HepB3 in the first variable. In terms of significance, the share of active population is significant for all vaccines, except for HepB3. Meanwhile, the second variable is significant at the 1% level for all vaccines. The share of female population variable presents negative and significant values for all vaccines. Moreover, the empirical results for the share of rural population varies among all the estimates, showing both positive and negative signs and being significant in some vaccines (DTP1, MCV2 and TT2).

Our findings for MCV2 differ from those obtained for the rest of vaccines. It is possible that MCV2 is the only vaccine that present a negative association with per capita income because of the availability of data. The sample size for this vaccine consists of 442 observations, taking into account the period of time considered (twenty-one years) and the countries (26) which implement this vaccine. Specifically, seven of the twenty-six countries correspond to low-middle income economies, ten to upper-middle income economies and the rest (9) to the high-income ones. In addition, as we mentioned previously, lower-middle economies present the greatest immunisation coverage rates for this vaccine.

Next, we also perform a dynamic panel data model to show if vaccination coverage on a certain year is conditioned by the previous one. We add the delayed dependent variable on the right-hand side of the equation (1). Our model can be described as follows:

$$cov_{it} = cov_{it-1} + \alpha_i + \mu_t + \beta_1 inc_{it} + X_{it}\delta + u_{it} \quad (2)$$

where cov_{it} is the vaccination coverage rate in the country i at year t, cov_{it-1} is the lagged vaccination coverage rate, α_i and μ_t are the country and year-effects, inc_{it} represents per capita income in the country i at year t, X_{it} is a vector of control variables and u_{it} is the error term.

Our findings for the dynamic model (2) differ from those obtained in linear model (1) (see Table 3). The estimate for each vaccine is displayed in columns 2-9. In the first row, we show the delayed vaccination coverage rate that is separately statistically significant at the 1% level and it presents positive coefficients. So, we can conclude that vaccination coverage rate on a certain year is conditioned by the previous one (anchorage effect).

Moreover, all coverage vaccines have positive correlations with per capita income, except for MCV1. For example, for this vaccine, we obtain a negative coverage rate (-0.0001), which implies that a 1 percentage point increase in per capita income will decrease immunisation coverage by 0.0001, holding other factors constant. Meanwhile, MCV2 presents a coefficient equal to 0.0012, which implies that a 1 percentage point increase in in per capita income will rise immunisation coverage by 0.0012, holding other factors constant. Additionally, HepB3 and TT2 vaccines are the only ones which show statistical significance at 5 and 1% level, respectively. Thus, we highlight that coverage variables are not relevant enough.

In the case of control variables, first, we describe the population one, which is not relevant enough although it always affects vaccination coverage rates in a positive way. The same happens with the variable related to population density, which is not significant enough (only BCG and MCV2 indicate significance at the 10% level), but it presents negative values for all vaccines, except for HepB3. On the one hand, the share of population between 15 and 64 years shows positive and significant coefficients for all vaccines. On the other hand, the share of rural population indicates positive coefficients in all vaccines, being only significant for MCV2. As happened with the population density variable, the share of population older than 64 years presents negative values,

except for TT2 vaccine and it is significant in most cases. Moreover, the share of female population variable has positive coefficients for all vaccines, except for HepB3 and TT2, and it is significant in most cases.

Table 2. Linear estimation of vaccination coverage rates and per capita income, 2000-2020

	BCG	DTP1	DTP3	HepB3	MCV1	MCV2	Pol3	TT2
Income	0.0014 **	0.0012 **	0.0002	0.0037 ***	0.0022 **	-0.0062	0.0001	0.0052 ***
	0.0006	0.0006	0.0009	0.0011	0.0010	0.0044	0.0010	0.0009
Population	0.0014	0.0040 ***	0.0023	0.0015	0.0012	-0.0335 **	0.0026	0.0130 ***
	0.0011	0.0015	0.0019	0.0018	0.0025	0.0145	0.0019	0.0031
Population density	-0.0004	0.0004	0.0015 **	0.0101 ***	0.0010 *	0.0130 **	0.0015 **	-0.0031 ***
	0.0004	0.0004	0.0007	0.0013	0.0006	0.0062	0.0007	0.0009
Share pop. 15-64 years	0.0178 ***	0.0288 ***	0.0090 *	-0.0009	0.0136 **	0.0798 ***	0.0099 *	0.0710 ***
	0.0033	0.0033	0.0054	0.0069	0.0055	0.0186	0.0055	0.0103
Share pop. >64 years	0.2328 ***	0.2064 ***	0.2809 ***	0.2568 ***	0.2815 ***	0.2514 ***	0.2856 ***	0.1298 ***
	0.0085	0.0079	0.0119	0.0141	0.0118	0.0276	0.0115	0.0416
Share female pop.	-0.3135 ***	-0.2442 ***	-0.5087 ***	-0.4428 ***	-0.5794 ***	-1.3265 ***	-0.5159 ***	-0.2083 ***
	0.0216	0.0205	0.0364	0.0476	0.0366	0.1540	0.0364	0.0489
Share rural pop.	-0.0013	0.0128 ***	-0.0009	0.0077	-0.0047	-0.0918 ***	-0.0004	0.0241 ***
	0.0024	0.0030	0.0041	0.0055	0.0042	0.0155	0.0042	0.0071
N	1785	1411	2210	816	2040	442	2193	629
Countries	105	83	130	48	120	26	129	37
R^2 within	0.4360	0.4454	0.3099	0.4904	0.3423	0.3598	0.3277	0.2246
R^2 between	0.3497	0.4809	0.4457	0.3213	0.5272	0.3732	0.4559	0.8357
R^2 overall	0.3387	0.4701	0.4299	0.3200	0.5093	0.3524	0.4404	0.7802

Note: Income is in $ 10,000. Standard errors appear in parentheses. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectively. Source: authors' elaboration.

Table 3. Dynamic estimation of vaccination coverage rates and per capita income, 2000-2020

	BCG	DTP1	DTP3	HepB3	MCV1	MCV2	Pol3	TT2
Coverage $_{t-1}$	0.9159 ***	0.9196 ***	0.9214 ***	0.9120 ***	0.9168 ***	0.9290 ***	0.9219 ***	0.7875 ***
	0.0083	0.0099	0.0069	0.0120	0.0075	0.0155	0.0070	0.0184
Income	0.0003	0.0004	0.0002	0.0010 **	-0.0001	0.0012	0.0002	0.0012 ***
	0.0002	0.0002	0.0003	0.0004	0.0003	0.0016	0.0003	0.0004
Population	0.0007 *	0.0001	0.0007	0.0006	0.0002	0.0026	0.0008	0.0010
	0.0004	0.0005	0.0006	0.0006	0.0008	0.0046	0.0007	0.0015
Population density	-0.0003 *	-0.0001	-0.0001	0.0002	-0.0002	-0.0037 *	-0.0002	-0.0003
	0.0001	0.0001	0.0002	0.0005	0.0002	0.0020	0.0002	0.0004
Share pop. 15-64 years	0.0069 ***	0.0068 ***	0.0094 ***	0.0066 ***	0.0101 ***	0.0146 **	0.0096 ***	0.0035
	0.0012	0.0013	0.0018	0.0025	0.0019	0.0064	0.0018	0.0054
Share pop. >64 years	-0.0029	-0.0016	-0.0128 ***	-0.0034	-0.0124 ***	-0.0234 **	-0.0117 ***	0.0553 ***
	0.0037	0.0037	0.0044	0.0060	0.0046	0.0100	0.0044	0.0199
Share female pop.	0.0286 ***	0.0255 ***	0.0413 ***	-0.0031	0.0371 ***	0.1670 ***	0.0409 ***	-0.0336
	0.0085	0.0084	0.0128	0.0182	0.0136	0.0554	0.0130	0.0240
Share rural pop.	0.0007	0.0019	0.0014	0.0016	0.0011	0.0095 *	0.0017	0.0023
	0.0009	0.0012	0.0014	0.0020	0.0014	0.0053	0.0014	0.0035
N	1680	1328	2080	768	1920	416	2064	592
Countries	105	83	130	48	120	26	129	37
R^2 within	0.9332	0.9283	0.9309	0.9417	0.9289	0.9374	0.9316	0.8220
R^2 between	0.9673	0.9924	0.9914	0.9813	0.9976	0.8857	0.9906	0.9905
R^2 overall	0.9625	0.9855	0.9853	0.9767	0.9912	0.8867	0.9846	0.9752

Note: Income is in $ 10,000. Standard errors appear in parentheses. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectively.

Source: authors' elaboration.

Now, following the conditional convergence framework developed by Barro and Sala-i-Martín [11] and Barro [12], we examine if there is convergence between both rates immunisation coverage and per capita GNI growth. We show how countries' economic initial conditions as well as their changes affect the speed at which poor countries reach richer ones in terms of GNI. In other words, we check whether the countries considered behave in a similar way, depending on the income group to which they belong. If the coefficient $(1 + b)$ of the lagged dependent variable (i.e., delayed vaccination coverage rate) present a positive sign, there is evidence of this type of convergence.

More specifically, there is conditioned convergence when each country converges towards its own stationary state due to its own characteristics, very different from one another. In other words, each country can have its own stationary state due to the different characteristics that exist between them and it can converge towards its own stationary state in the long term, but never towards the same.

The convergence equation can be written as follows:

$$\Delta cov_{it} = \Phi\ (a, (1 + b)(cov_{it-1}), inc_{it}, X_{it}, \dots) \quad (3)$$

where Δcov_{it} is the average growth rate of immunisation coverage. The model also includes other variables such as the lagged immunisation coverage rate, the lagged per capita income as well as variables related to population. In addition, we estimate another model using the three-year forward per capita income instead of the lagged per capita income. According to our previous models, we eliminate those variables that are not significant for each one of the vaccines.

We show the growth regressions without non-significant variables of previous models and with the lagged per capita income to each vaccine. We also run the same regressions with the three-year forward per capita income. We perform eight estimates, which correspond to each vaccine (see columns 2-9 of Table 4 and Table 5). Our dependent variable is immunisation coverage, but we transform it into the average growth rate of immunisation coverage.

In Table 4, we present the growth regressions without non-significant variables of previous models and with the delayed per capita income. The most important independent variable is the lagged immunisation coverage, which represents the relationship between starting vaccination coverage rate and its growth rate. All vaccines show a positive and significant coefficient at the 1% level, showing that there is conditioned β convergence.

In the case of control variables, both population density and the share of rural population are not significative in the vaccines considered (BCG and MCV2 in the first variable and HepB3 in the second variable). In addition, both variables are negatively related to growth rate of vaccination coverage rate. Population variable is positively associated with immunisation coverage and it is significative at the 5% level for BCG. When we focus on the share of population between 15 and 64 years old, all the growth regressions are positive and significative at the 1% level, being

understood as a result of this group is labour force. The opposite happens in the share of population older than 64 years, where we show negative coefficients and no significance in some vaccines (DTP3, MCV1 and Pol3) and another one with positive sign and significative at the 1% level (TT2). The share of female population shows positive and significative findings, except for MCV2. Per capita income variable is considered for HepB3 and TT2 and it shows similar findings. Moreover, we present the lagged per capita income. All vaccines present positive and significative results, except for TT2.

In Table 5, we show the growth regressions without non-significant variables of previous models and the three-year forward per capita income. The most important independent variable is the lagged immunisation coverage, which presents very similar results to those obtained previously, explaining that there is conditioned β convergence.

Additionally, we find similar results in some control variables such as population, population density, the share of population between 15 and 64 years old, the share of female population, and per capita income. Living in rural areas decrease immunisation coverage rates, but that variable is not relevant enough. Meanwhile, the share of population older than 64 years shows positive signs in all the vaccines considered and statistical significance in some of them (MCV1, Pol3 and TT2). Besides, the three-year forward per capita income presents positive and significative coefficients for all the vaccines, except for MCV2.

Moreover, our findings show that countries converge by groups. If we examine countries according to the World Bank classification, we find that countries that belong to the same group of income have a similar behaviour (Figure 2).

Table 4. Growth regressions without non-significant variables and with lagged vaccine rate, 2000-2020

	BCG	DTP1	DTP3	HepB3	MCV1	MCV2	Pol3	TT2
Coverage $_{t-1}$	-0.1145 ***	-0.1105 ***	-0.1097 ***	-0.1184 ***	-0.1115 ***	-0.1376 ***	-0.1089 ***	-0.1158 ***
	0.0073	0.00789	0.0070	0.0087	0.0075	0.0123	0.0070	0.0131
Population	0.0014 **							
	0.0006							
Population density	-0.0002					-0.0008		
	0.0003					0.0011		
Share pop. 15-64 years	0.0184 ***	0.01705 ***	0.0163 ***	0.0134 ***	0.0171 ***	0.0373 ***	0.0160 ***	
	0.0022	0.00220	0.0018	0.0023	0.0019	0.0046	0.0018	
Share pop. >64 years			-0.0016		-0.0030	0.0043	-0.0011	0.0406 ***
			0.0037		0.0038	0.0068	0.0035	0.0146
Share female pop.	0.0814 ***	0.07952 ***	0.0724 ***		0.0632 ***	-0.0337	0.0709 ***	
	0.0127	0.01283	0.0112		0.0117	0.0318	0.0110	
Share rural pop.						0.0017		
						0.0033		
Income				0.0011 **				0.0014 ***
				0.0005				0.0004
ln (income $_{t-1}$)	0.0007 **	0.0008 ***	0.0010 ***	0.0010 **	0.0005 *	0.0021 **	0.0008 ***	-0.0001
	0.0004	0.0004	0.0003	0.0005	0.0003	0.0009	0.0003	0.0004
N	1635	1290	2033	760	1876	411	2017	559
Countries	105	83	130	48	120	26	129	37
R^2	0.1711	0.1725	0.1669	0.2141	0.1689	0.3529	0.1705	0.1434

Note: Standard errors appear in parentheses. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectively. Source: authors' elaboration.

Table 5. Growth regressions without non-significant variables and with forward vaccine rate, 2000-2020

	BCG		DTP1		DTP3		HepB3		MCV1		MCV2		Pol3		TT2	
Coverage $_{t-1}$	-0.0830	***	-0.0744	***	-0.0791	***	-0.0699	***	-0.0859	***	-0.1097	***	-0.0806	***	-0.0878	***
	0.0086		0.0091		0.0080		0.0107		0.0086		0.0164		0.0082		0.0151	
Population	0.0020	**														
	0.0008															
Population density	0.0003										-0.0007					
	0.0003										0.0016					
Share pop. 15-64 years	0.0217	***	0.0199	***	0.0201	***	0.0150	***	0.0206	***	0.0374	***	0.0207	***		
	0.0027		0.0027		0.0023		0.0030		0.0025		0.0057		0.0023			
Share pop. >64 years					0.0087				0.0098	*	0.0097		0.0096	*	0.0621	***
					0.0053				0.0054		0.0100		0.0051		0.0216	
Share female pop.	0.0616	***	0.0626	***	0.0504	***			0.0420	***	-0.0459		0.0529	***		
	0.0148		0.0148		0.0134				0.0141		0.0381		0.0132			
Share rural pop.											-0.0052					
											0.0043					
Income							0.0013	***							0.0008	*
							0.0005								0.0004	
ln (income $_{t+3}$)	0.0023	***	0.0031	***	0.0023	***	0.0012	*	0.0023	***	0.0009		0.0018	***	0.0016	***
	0.0005		0.0005		0.0004		0.0007		0.0004		0.0015		0.0004		0.0005	
N	1680		1051		1655		618		1528		334		1642		457	
Countries	105		83		130		48		120		26		129		37	
R^2	0.1028		0.1188		0.0977		0.0862		0.1036		0.179		0.0950		0.0917	

Note: Standard errors appear in parentheses. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectively. Source: authors' elaboration.

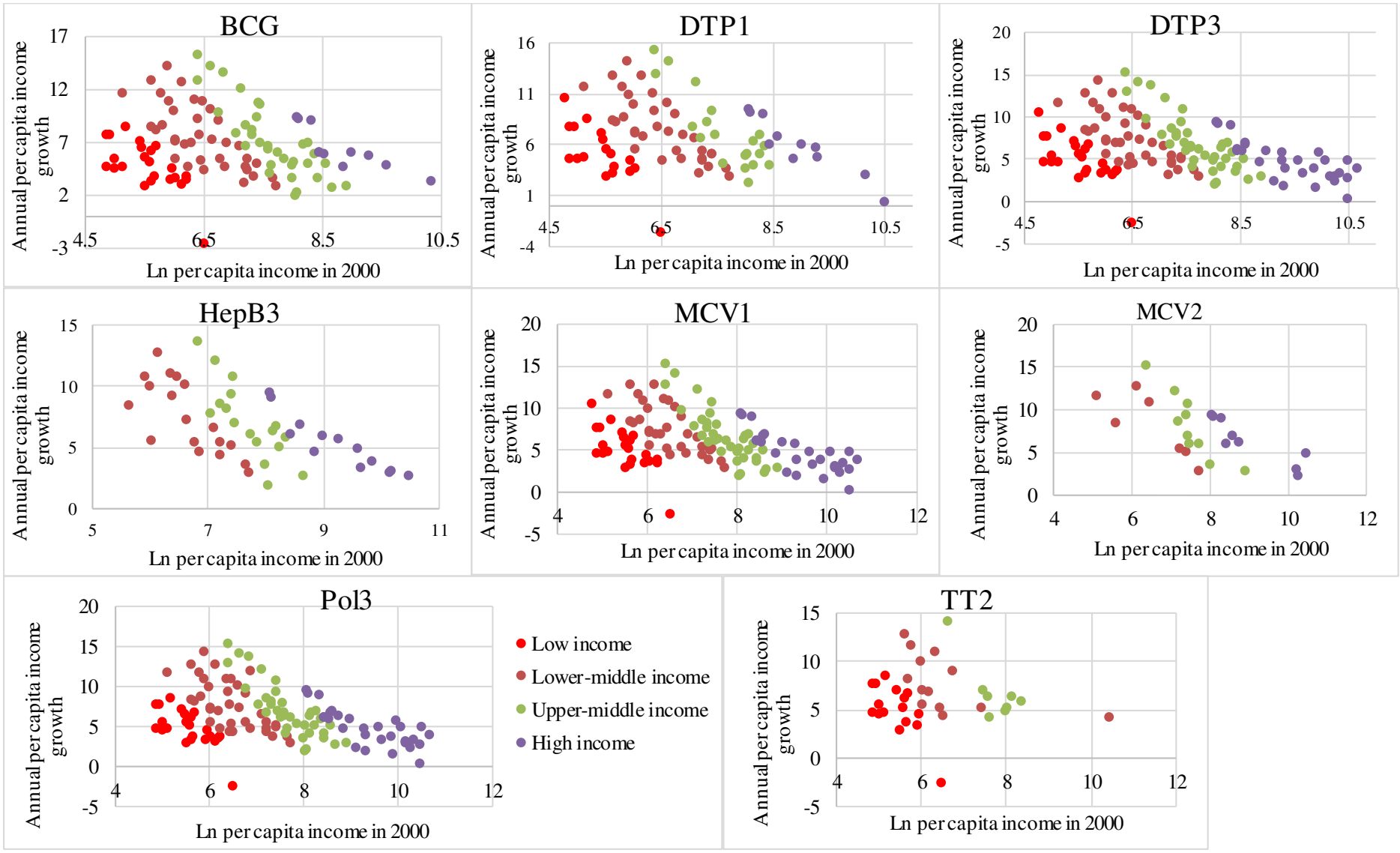

Figure 2. Conditioned convergence for all vaccines according to the World Bank classification

Source: authors' elaboration.

Discussion

Similar studies show that immunisation rates increase, but there is a time when they decrease as per capita income rises for country-level data from the WHO. Sakai [10] also demonstrates that both low- and high-income parents are less predisposed to follow the national immunisation schedule. Our findings show that the share of female population has a positive correlation with per capita income in the dynamic estimation. An interesting discussion point would be their attitudes of vaccinating children.

In the study, we mentioned that parental refusal could be a factor that decrease vaccination coverage rates. It is determined by some factors such as confidence, complacency and/or convenience of parents in most cases [13]. This situation can change if parents are provided with clear and appropriate information about vaccine efficacy and safety, side effects and/or health protection. We can consider this issue for future analysis.

For example, Szucs and Müller [14] examine determinants for influenza vaccination coverage rates across Europe, showing that city and household size as well as household income have a significant effect on vaccination coverage rate. The same happened with age and chronic illness. Meanwhile, Odusanya et al. [15] analyse the DTP vaccination coverage of rural Nigeria after the implement of a private financed vaccination project, which increase until 81%. Besides, immunisation rates are correlated with the knowledge of mothers. Similarly, Rainey et al. [16] conclude that there are factors such as gender, education level or religion related to non- and under-vaccination of children in low- and middle-income countries. In the case of Williams et al. [17], they show that an educational intervention destined to parents could improve parental attitudes about childhood vaccination. Likewise, Lukasa et al. [18] say that strategies for informing, educating and involving parents are necessary.

Analysing the determinants of childhood vaccination, we find Kusuma et al. [19]. They show that prenatal and obstetric care as well as personalized health care service in India increase the probability of childhood immunisation rates. People with lower socio-economic level reduce these rates. Hence, government must invest in education and economic development. Based on Europe, Tabacchi et al. [20] argue that there are strong predictors of negative attitudes and behaviours of parents about childhood vaccination such as low income, low education levels and non-married status. They propose to implement policies focused on increasing vaccination coverages as well as improving parental attitudes and behaviours.

On the one hand, Molina-Aguilera [21] show that introducing new vaccines is a problem to financial sustainability in developing countries because they must compete with other public health priorities. Economic characteristics should be considered due to the high cost of new vaccines. On the other hand, Phillips et al. [22] conclude that there is an increase in the demand for childhood vaccination in developing countries, although the quantitative evidence is limited. Likewise, they express that mass media campaigns can be effective.

Conclusions

This paper provides new empirical evidence on the relationship between vaccination coverage rates and per capita income. Our sample consists of 95 countries classified as low, lower-middle, upper-middle and high-income economies and eight vaccines included in the global immunisation schedules.

In view of our results, the linear estimate indicates a positive and significant relationship between coverage vaccination and to most of the vaccines (BCG: 0.0014; DTP1: 0.0012DTP3: 0.0002; HepB3: 0.0037; MCV1: 0.0022; MCV2: -0.0062; Pol3: 0.0001; TT2: 0.0052), while the dynamic estimate shows that coverage vaccination has a positive association with per capita income for all vaccines, except for MCV1 (BCG: 0.0003; DTP1: 0.0004; DTP3: 0.0002; HepB3: 0.0010; MCV1: -0.0001; MCV2: 0.0012; Pol3: 0.0002; TT2: 0.0012). In the case of control variables, most of them show a positive relation with immunisation coverage, except the share of female population and, in some vaccines, the share of rural population in the linear estimate. The same happens with the density population and the share of population older than 64 years in the dynamic estimation.

In the case of conditioned convergence, it will exist, if the coefficient of the lagged dependent variable presents a positive sign. Thus, in our study, this coefficient for all the vaccines is positive, concluding the existence of conditioned convergence (BCG: -0.1145; DTP1: -0.1105; DTP3: -0.1097; HepB3: -0.1184; MCV1: -0.1115; MCV2: -0.1376; Pol3: -0.1089; TT2: -0.1158). In addition, we add some variables to account for the different characteristics of population and they vary between the vaccines considered. Hence, when theses variables are not significant, we reject it because they cannot explain the process that leads countries to converge towards different steady states.

In short, each country has its own steady state due to the different characteristics that exist between them. Countries converge by groups according to the World Bank classification.

Our findings may have significant implications for health policies due to socioeconomic status indicators have a notable impact on immunisation rates. Improving vaccination coverage needs investments in both human and physical capital, which depend on the available resources of each country. It is necessary to develop health policies set aside for reducing income inequality and achieving uniformly high immunisation rates.

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Appendix

Table A.1. Countries classification by per capita income (2020).

LOW INCOME			
Afghanistan	Ethiopia	Mali	Sudan
Burundi	Guinea	Niger	Togo
Central African Republic	Liberia	Rwanda	Uganda
Congo, Dem. Rep.	Malawi	Sierra Leone	
LOWER-MIDDLE INCOME			
Angola	El Salvador	Lesotho	Papua New Guinea
Bangladesh	Eswatini	Mauritania	Philippines
Belize	Honduras	Mongolia	Senegal
Bolivia	Indonesia	Myanmar	Sri Lanka
Cameroon	Iran, Islamic Rep.	Nepal	Tanzania
Congo, Rep.	Kenya	Nicaragua	Tunisia
Côte d'Ivoire	Kyrgyz Republic	Pakistan	Uzbekistan
Djibouti			
UPPER-MIDDLE INCOME			
Albania	Equatorial Guinea	Kazakhstan	South Africa
Argentina	Gabon	Mexico	St. Lucia
Armenia	Georgia	Moldova	St. Vincent and the Grenadines
Azerbaijan	Guatemala	Namibia	Suriname
Brazil	Guyana	Panama	Thailand
Bulgaria	Iraq	Paraguay	Turkey
Colombia	Jamaica	Russian Federation	Tuvalu
Dominican Republic			
HIGH INCOME			
Antigua and Barbuda	Estonia	Norway	St. Kitts and Nevis
Australia	Germany	Saudi Arabia	Sweden
Bahamas, The	Ireland	Slovak Republic	Switzerland
Bahrain	Latvia	Slovenia	United Kingdom
Belgium	Lithuania	Spain	United States
Chile	Netherlands		

Source: Authors' elaboration from the World Bank (2022).