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When more is less: Do information and communication technologies (ICTs) improve health outcomes? An empirical investigation in a non-linear framework

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A B S T R A C T

The purpose of our research is to investigate the influence of information and communication technology (ICT) on the physical health outcomes of nations. The covered countries are 185 (54 high-income and 131 low-income countries, also analysed on subsamples) and the period of the analysis is 2005–2018. We use parametric regression analysis of unbalanced panel data and our quadratic models validate the influence of ICT upon life expectancies, mortality rates and measles immunisation rates, controlling for economic prosperity, cultural dimensions and environmental performances. Our results are original within the specialized literature, shedding new light on the ICT infrastructure - health status nexus as they support the inverted U-shaped relationship between internet users and mobile cellular subscriptions as ICTs proxies on the one hand and population health outcomes proxies on the other. We also validate a multiplier effect of ICT proxies upon mortality rates from high-income countries to low-income countries, as follows: the negative effect of Internet access and online information usage is 3.34 times stronger in low-income countries compared to high-income countries. These findings are robust to various estimation techniques, alternative measures of ICT or health and various added controls. The drawbacks are major: in a world in which healthcare programs and policies consider digital inclusion, the limits of using technologies for the benefit of one's health have to be firmly determined. From regular individuals to top policymakers, one should consider when more ICT infrastructure becomes actually less for people's health status.

1. Introduction

In the last decades, many human activities have been increasingly influenced by information and communication technologies (ICT).

ICT comprise tools that ease communication and the processing and transmission of information and the distribution of knowledge by electronic means [1]. These high-level technologies have led to transformations in the basic relationships in both the economic and the social field [2]. Such technological innovations have the role of accelerating the degree of automatization through artificial intelligence, they decrease the potential complications of various works, reduce the existing information gaps among participants, reduce spatial barriers, reduce time consumption and facilitate the spread of knowledge, reduce governmental tasks, improve transparency in most decision-making processes and others [3]. The ICT help individuals to share information and live experiences to the entire community regarding health problems, being also an effective tool in terms of costs and benefits [4]. Moreover, with the development of ICT, the individuals better interact with the personnel in healthcare services for taking advice and decisions on how to manage their diseases and other educational issues [5–7]. In addition, more than ever, the periods of crisis such as the COVID-19 pandemic show the importance of the digital resilience in times of crisis and consider to have demonstrated how essential digital technologies have become "by monitoring the spread of the virus, or accelerating the search for cures and vaccines" [8].

Countries such as Finland, Sweden, the Netherlands and Denmark have the most active internet users, while Romania, Bulgaria and Italy are the least active in the European Union [9]. In the same time, using World Bank data [10], we may note that people from Finland, Sweden, the Netherlands and Denmark are among the longest-living people in the

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European Union with an average life expectancy of around 81–83 years. Conversely, people from Bulgaria and Romania live the shortest among European Union countries, about 74–75 years on average. However, people from Italy have a low level of internet services but their life expectancy is among the highest (about 83 years) from the European countries. Starting from these results, we intend to investigate the relationship between ICT and various physical health outcomes. In order to accomplish our research targets, we run a panel regression for 185 worldwide countries for the 2005–2018 time span, in which we examine the influence of ICT upon health outcomes, controlling for some variables such as per capita gross domestic product (GDP), culture and environmental performance. To the best of our knowledge, this is the first paper that validates a non-linear effect of ICTs upon health outcomes, relationship that is stable for various ICT proxies and physical health indicators, and additions of various control variables. Nonetheless, the separate testing of the influence of ICTs upon the health outcomes over the two subsamples of high-income and low-income countries is another important component that adds a valuable benefit to our investigation. In this view, we obtain useful results for the validation of a differentiated effect of ICT upon the health outcomes in developing countries compared to developed countries: their effect is up to four times stronger in the analysed low-income countries. Important policy drawbacks are further sketched, as the inflexion points of our parametric approaches are computed, further establishing thresholds for the positive effects of ICTs upon the health outcomes of nations. Once these determined thresholds are exceeded, more technology usage imprints negative effects upon the health of people, these computed levels being a strong contribution of our paper to the research field.

The structure of the paper is set up in the following way: section 2 reflects the literature review in order to state the analysed Hypothesis, section 3 presents our data and the used methods, section 4 contains our obtained results, also discussing the main empirical findings and validating the robustness of our estimations. The final section 5 presents the conclusions, includes a summary of the main findings and a brief discussion of policy implications, limitations and avenues for future research.

2. Literature review

A large strand of studies find a positive relationship between ICT and health outcomes [1,7,11–16]. ICT facilitates an improved bidirectional patient - health care system communication [11], easing the access to the most important health care information and also to international collaboration [17]. Thus a large strand of literature validates that increases in technology lead towards enhanced health outcomes and human development. For instance Ref. [13], based on the review of several studies in this field, conclude that the accelerated application of Web technologies such as Web 2.0 and Web 3.0 for healthcare provides helpful solutions for the overwhelming system-wide challenges faced by healthcare providers. In addition, the study of [15] conducted on 184 countries over the 1990–2014 period finds a positive and significant effect of ICTs upon the life expectancies at birth and infant mortality rates of nations, when the ICT infrastructure is measured through the number of internet users, mobile cellular subscriptions and fixed telephone subscriptions. Similarly [14], using a panel database for 67 countries and covering the 2000–2014 period, find that ICT exposure positively boosts the level of well-being and progress. In Uganda, the study of [18] finds that improving communication among traditional birth attendants through radio technology significantly reduces the maternal mortality rate. For poor countries [1], find that ICT significantly reduce child mortality and improve maternal health for data from the 1990–2007 period. For instance, among the thirteen transition countries considered in this study, the highest decrease of mortality rates below the age of 1 per 1000 live births is found in Malawi, from 124 to 71. Similarly, for a number of 30 Asian countries over the 2000–2016 period [7], find a significant and a positive long-run impact of ICT upon health outcomes. For measuring purposes [7], use an ICT index while health outcomes are expressed through the Infant Mortality Rate. For Sub-Saharan Africa [12], finds that women who received mobile telephone support were more prone to follow the antenatal recommendations than those who did not receive any support. In this way, ICT facilitate the communication with health providers, significantly improving the antenatal services. They find that hospital delivery was of 80.1% for the group of women with mobile telephones, compared to only 44%, if no ICT support was provided. In this view [19], consider that, for the particular case of rare diseases, the World Wide Web available information lacks in terms of quality, so the authors compensate this by generating a set of quality criteria specific to rare diseases [19]. ultimately conclude that a balance between the high standard of quality criteria for health information websites in general and the limited provision of information about some rare diseases is required in order to be able to describe useful quality criteria for websites about rare diseases. Similarly [16], find that construction of smart cities improves the health status of residents by reducing the use of outpatient services and increasing the utilization of inpatient services.

However there is another strand of studies which questions a positive relationship between ICT and health outcomes [20–25]. There are studies [15,26] that highlight the fact that poor countries are often focused on providing basic healthcare services and the electric system and water supply infrastructure rather than an ICT coverage. Therefore, in these countries, on the background of a chaotic and corrupt healthcare system, technological fixes provide far less than they should [15]. To be efficient on the long-term, the investments in ICT need associated elements like technical engineers, assuring long term expenses for maintenance [15] or the ability of governments to provide adequate funding [1]. Similarly [27], validate the importance of knowledge management in the productiveness of IT investments. In this view [27], find disparities in IT performances between high-income and low-income countries which can be related to the fact that “developed countries have already made complementary investments in infrastructure, human capital, and information-oriented business process”. This idea is followed by Ref. [11] who question the simplicity of a positive linear effect of ICT investments on development (when development is measured by the standard of living - GDP per capita and health as infant mortality rate and/or life expectancy at birth)). In their study that covers 51 states from 1994 to 2003, they highlight that the effect of ICT investments on developmental dimensions is allowed to be even negative or completely absent and not only positive, under certain conditions (related to the relative outcome of ICT components, it varies according to the groups of countries: *High, Medium,* or *Low* categories). These justify the apparent inconsistency of the previous results [20,23] for the relationship between ICT investments and development. In addition, internet use is negatively associated with well-being [24]. Thus, within a study conducted on a large representative sample of over 6300 children in England over 2012–2017 [24], validate the negative effect of internet usage upon the psychological wellbeing of children aged 10–15, measured through their perception about various life aspects. The authors suggest parents should limit internet and social media use especially during childhood, in order to boost the emotional health of their children.

Also regarding the emotional state, the study of [25] offers interesting results for the position of elderly people regarding the new healthcare system enabled by machine intelligence. The authors investigate the effect of trust required for elderly people to accept autonomous homecare systems based on machine autonomy instead of human support. This study reveals that elderly people urge for independence related to maintaining their previous standard of life and they can be motivated to develop trust in these healthcare machines. Concluding, based on the aforementioned studies regarding the relationship between ICT and health outcomes, this relationship is not fully understood [11,27], the research literature offering opposed results. With our research, we intend to replenish such a gap in literature, with the purpose of modelling the exact relationship between ICT and health outcomes, in order to further be able to sketch international policy recommendations. In an original manner, asking ourselves whether the impact of ICTs upon health is positive or not necessarily direct, our paper wants to test the following working Hypothesis:

Hypothesis. Higher levels of information and communication technologies (ICT) improve health outcomes.

In addition, from the previous results we find that there are discussions around the fact that poor countries are just as interested in investing in technology as developed countries, as long as they would have previously managed to cover many basic needs (health services, electricity) rather than ICT. Thus, one may assume that the impact of technology is not the same for all countries, but it may actually depend on the level of economic development [11,27,28]. Thus, we are questioning ourselves whether income may count in the relation between ICT and health outcomes. Furthermore, we are determined to empirically validate the answer to the following research question:

Research question: How do the results of testing our *Hypothesis* differ among high-income and low-income countries?

3. Data and methods

3.1. Data

The dependent variables consist of health outcomes. According to the literature, we measure health outcomes through the following indicators: *Life expectancy at birth* [11,15,29,30], *Mortality rate, under the age of 5* (per 1000 live births) [7,11,15,29,30], and *Measles immunisation rate of children* [30]. Health has always been a multifaceted concept, and one of the most frequently quoted indicators for the health status of the population is people's life expectancy, in itself even an indicator of the economic development of nations and of their life quality. Then, we also consider the children mortality rate as another physical health state proxy. Different types of immunisation (DPT-diphtheria, pertussis or whooping cough, and tetanus-immunisation and Measles immunisation) are also considered good proxies for health outcome [30]. Some specialists even approach composite indicators for reflecting health and healthcare [31,32].

The independent variables consist of *Information and communication technologies (ICT)* indicators. Following studies, we measure ITCs through *the weight of the people using the Internet within the total population* [7,14,28] and *the number of mobile cellular telephone subscriptions* per *100 people* [7,14,15,28]. Following the latest research papers, we use several cultural and economic control variables previously appealed by the specialized literature: *the level of economic development* [11,15,27,29,30, 33,34], *culture* [29,30,35] and *environmental performances* [15].

On a sample of Latin American and Caribbean states [33] find that the more wealth there is, the better the health outcomes are, but the exact amount of improved health depends on the particular distribution of wealth. Moreover, using an extended literature review of this domain [34], concludes that "people with lower incomes report poorer health and have a higher risk of disease". So, our paper uses the Gross Domestic Product (GDP) per capita given by World Development indicators [10] as a proxy for the level of economic development. Highly developed countries have powerful healthcare systems and invest large amounts of capital for supporting population health, while a lower economic development of countries indicates a poor healthcare system and modest investments for promoting health [33,34].

With respect to the cultural dimensions, Lancet Commission has documented itself rather early on the large effects held by the cultural systems upon the health outcomes of nations, within and across cultures [36]. Culture actually determines changes in the attitudes and comportments of humans and that's why their *life expectancy* can be influenced [35]. In this view, the empirical study of [29] finds that individualism, indulgence, uncertainty avoidance and masculinity have different influences upon population health. In our paper, culture relies on the multidimensional cultural model of Hofstede [37] summing up the following: Power distance (PD), Individualism versus collectivism (IDV), Masculinity versus Femininity (MAS), Uncertainty avoidance (UAI), Long-term orientation (LTO) and the latest added dimension, Indulgence versus restraint (IND). The cultural dynamics of states is easier understood through the studies of Hofstede [38].

Pollution brings along negative effects upon the health status of people, spreading even up to future generations. As environmental concerns have gained more and more importance in the last decades, the metric tons of CO_2 emissions have previously been used as an indicator of environmental state [14,15]. The latest Environmental Performance Index [39] framework organizes 32 indicators into 11 issue categories and two policy objectives, with well-established weights, incorporating CO_2 emissions and it has previously been used as a proxy for the environment.

The present research further classifies its cross-sectional 185 countries by their level of economic development, splitting the entire sample into a subsample of high-income countries and a subsample of low-income countries. This delimitation is performed according to the data given through the World Bank report on 'Country and Lending Groups' [40] that classifies nations into high income, upper middle income, lower middle income and low income countries. We have used the World Bank [10] distribution of countries into low-income countries (the low and middle income economies) and high-income countries (the high-income countries), detailed within Appendix 2. Our subsamples include 54 high-income and 131 low-income countries, analysed throughout the 2005–2018 time interval and forming an unbalanced panel. At first, the Pooled OLS method for panel data has been used, through the simple regression modelling technique, further moving on to a parametric approach, both for the entire sample of 185 countries as well as for the two subsamples of high-income and low-income countries. A sequential search method with the forward estimation approach has been applied, aiming to find the best regression estimates for our quadratic models. Further on, the multiple models have been analysed through the fixed effects model (FEM) and the random effects model (REM) techniques, in order to capture the best estimation technique. All our models have been interpreted in detail.

A synthetic review of our variables and their proxies is found within Appendix 1. Then Table 1 contains the descriptive statistics of these variables for the full sample of states (_all) and for the split samples of high-income states (_HI) and low-income states (_LI).

3.2. Methodology

To begin with, in order to test the relationship between ICT and health outcomes, we graphically represent them against each other (Fig. 1). From Fig. 1 one may clearly observe that the correlation between the proxies of ICT infrastructure and the ones for the health outcomes has an inverted U-shape.

Following the statistical clouds presented in Fig. 1, we set the econometric presentation of the inverted U-shape representing the relationship between health outcomes and ICT, given by:

$$\text{Health\_outcome}_{it} = \beta_0 + \beta_1 \text{ICT}_{it} + \beta_2 \text{ICT}_{it}^2 + \beta_3 \text{Development}_{it} + \beta_4 \text{Culture}_i + \beta_5 \text{Environment}_{it} + \varepsilon_{it} \quad (1)$$

where:

$\text{Health\_outcome}_{it}$ – proxy for the health status of the population of country i in year t (*Life expectancy, Under 5 mortality rate, Measles immunisation of children*);

β_1 - linear effect parameter;
β_2 - quadratic effect parameter;
ICT_{it} – proxy for the information and communication technology infrastructure of country i in year t; it includes:

Table 1
Summary statistics for the variables.

Variable	Mean	Std. Dev.	Min	Max	Total observations
LE_all	70.34306	8.842978	42.518	84.93414	N = 2562
LE_HI	78.50187	4.548564	54.449	84.93414	N = 742
LE_LI	67.01677	7.965219	42.518	80.095	N = 1820
MORTchild_all	37.30091	38.49383	1.7	208.6	N = 2520
MORTchild_HI	8.267429	14.86195	1.7	134.4	N = 700
MORTchild_LI	48.46764	38.96116	2.5	208.6	N = 1820
Measles_all	87.02228	13.89687	21	99	N = 2513
Measles_HI	93.17429	8.472183	27	99	N = 700
Measles_LI	84.64699	14.82477	21	99	N = 1813
Internet_all	36.67133	29.46103	0	100	N = 2431
Internet_HI	68.93424	20.3776	1.14979	100	N = 728
Internet_LI	22.87955	20.64663	0	89.44303	N = 1703
Mobile_all	88.24557	46.41033	0	345.3245	N = 2541
Mobile_HI	121.677	36.45406	12.92802	345.3245	N = 742
Mobile_LI	74.45673	42.93778	0	207.7518	N = 1799
GDP_all	13235.51	18931.49	151.6815	118823.6	N = 2525
GDP_HI	36192.65	21151.23	5226.938	118823.6	N = 742
GDP_LI	3681.838	3291.368	151.6815	16433.94	N = 1783
PD_all	63.91919	20.78806	11	100	N = 1386
PD_HI	51.59524	22.46063	11	100	N = 588
PD_LI	73	13.59386	35	100	N = 798
IDV_all	39.47475	21.9082	6	91	N = 1386
IDV_HI	54.11905	21.97992	16	91	N = 588
IDV_LI	28.68421	14.26371	6	80	N = 798
MAS_all	47.66667	18.65282	5	100	N = 1386
MAS_HI	46.2381	22.54727	5	100	N = 588
MAS_LI	48.7193	15.08558	10	88	N = 798
UAI_all	64.0202	21.36469	8	100	N = 1386
UAI_HI	66.07143	22.85049	8	100	N = 588
UAI_LI	62.50877	20.081	13	99	N = 798
LTO_all	41.75294	22.77172	4	100	N = 1190
LTO_HI	52.475	21.84724	13	100	N = 560
LTO_LI	32.22222	19.04479	4	87	N = 630
IND_all	48.21795	22.77041	4	100	N = 1092
IND_HI	48.92308	19.63664	13	80	N = 546
IND_LI	47.51282	25.52137	4	100	N = 546
EPI_all	52.30193	16.96467	14.68	90.68	N = 1920
EPI_HI	69.71303	11.20177	40.37	90.68	N = 561
EPI_LI	45.11457	13.34241	14.68	84.6	N = 1359
MORTinfant_all	26.99714	24.61035	1.4	128	N = 2520
MORTinfant_HI	6.707571	10.66978	1.4	93.8	N = 700
MORTinfant_LI	34.80082	23.99267	2.3	128	N = 1820
Telephone_all	17.48852	16.86015	0	69.71523	N = 2526
Telephone_HI	36.33228	15.30505	0.8287401	69.71523	N = 740
Telephone_LI	9.68092	9.845444	0	48.10332	N = 1786
Urban_all	57.18743	22.98558	9.375	100	N = 2555
Urban_HI	78.71945	14.64904	31.147	100	N = 742
Urban_LI	48.3751	19.73267	9.375	91.87	N = 1813
Unempl_all	7.72052	5.822517	0.11	37.25	N = 2506
Unempl_HI	7.012195	4.215795	0.11	27.466	N = 742
Unempl_LI	8.018466	6.356097	0.317	37.25	N = 1764
Alcohol_all	6.250396	4.216636	0	17.9	N = 2148
Alcohol_HI	9.038	4.065896	0	15.8	N = 600
Alcohol_LI	5.172481	3.75254	0	17.9	N = 1548
Protestant_all	11.90909	20.43662	0	97.8	N = 2464
Protestant_HI	18.48302	28.3459	0	97.8	N = 742
Protestant_LI	9.076423	15.00368	0	64.2	N = 1722
Catholic_all	30.82079	35.64585	0	97.3	N = 2492
Catholic_HI	35.92222	36.53112	0.1	97.3	N = 756
Catholic_LI	28.59919	35.0325	0	96.6	N = 1736
Muslim_all	24.23	36.25961	0	99.9	N = 2492
Muslim_HI	13.26741	30.65317	0	98.9	N = 756
Muslim_LI	29.00403	37.46456	0	99.9	N = 1736
Other_all	33.05659	32.42391	0	100	N = 2464
Other_HI	32.90868	31.92305	0.9	98.5	N = 742
Other_LI	33.12033	32.64634	0	100	N = 1722

$Internet_{it}$ – the percentage of the total population of country i in year t that use the Internet *and*

$Mobile_{it}$ – the number of cellular telephone subscriptions per 100 people in country i in year t;

$Development_{it}$ – per capita gross domestic product of country *i*, year *t*;

$Culture_i$ - the cultural dimensions of country *i*, year *t* from the cultural model provided by Hofstede [37];

$Environment_{it}$ – the environmental performance index of country *i*, year *t*;

ε_{it} - the residual.

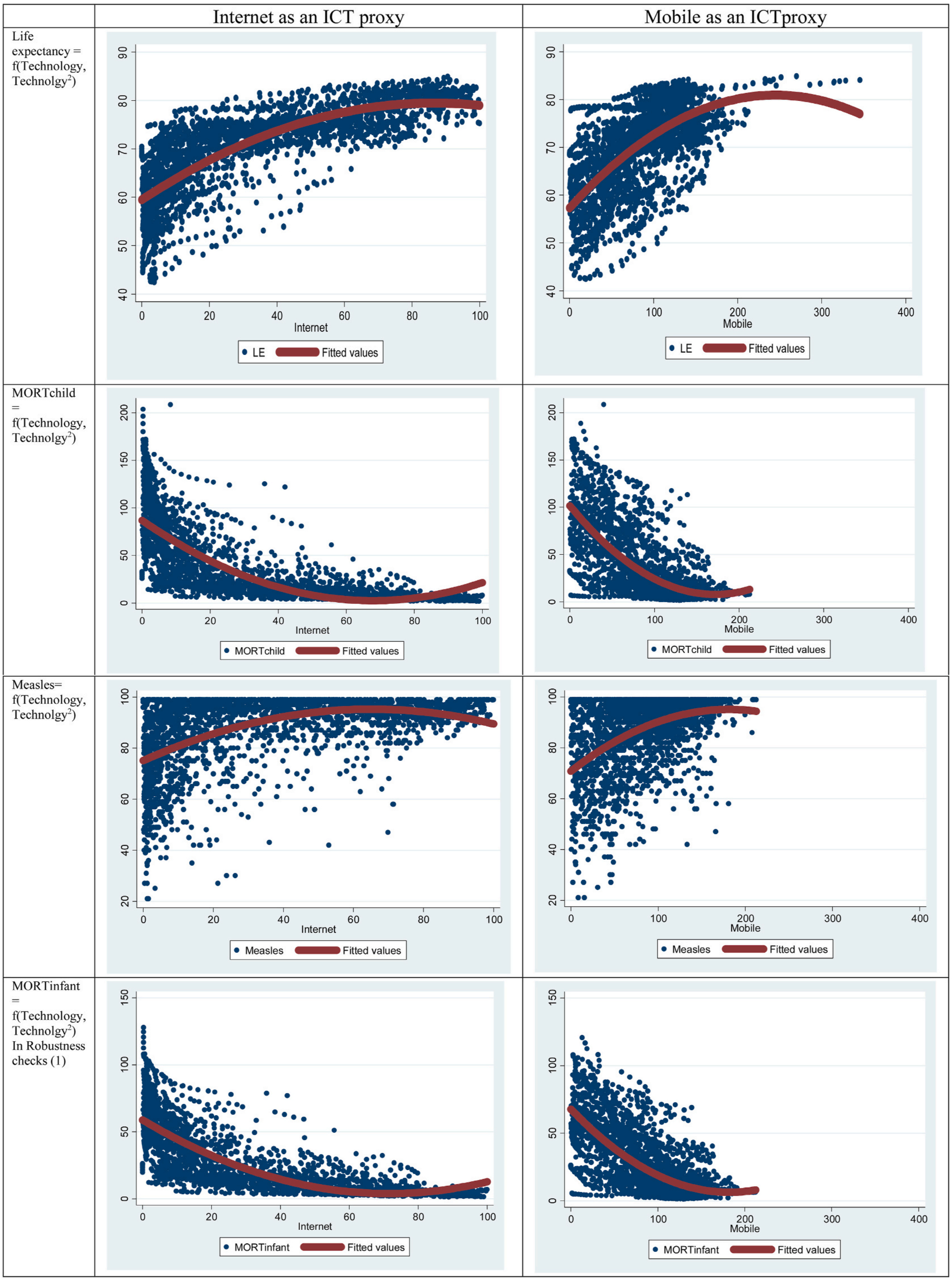

Fig. 1. Plot of ICTs against health outcomes.

At first, simple regression modelling explicates health outcomes as a function of ICT proxies. Further on, the second-order polynomial is tried, as the first order polynomial proved unsatisfactory. Arbitrary fitting of higher-order polynomials can be a serious abuse of regression analysis, so the order of the polynomial model is kept as low as possible, still targeting a better fit of the data [41]. The quadratic model fit is further used when controls are added on turn, using the forward addition estimation technique for our unbalanced panel data. The baseline Pooled OLS validated model (Eq. (1)) is then estimated through a fixed effects model FEM and a random effects model REM, the Hausman test supporting mainly the former.

We expect β_1 to be positive and β_2 to be negative when life expectancy and measles immunisation rate are regressed against Internet and Mobile (the inverted U-shaped graphs from Fig. 1), and we also expect a negative β_1 and a positive β_2 when under five mortality rate is regressed against ICT proxies (the U-shaped graphs from Fig. 1). In order to measure the turning point for the maximum or minimum ICT levels, the thresholds are computed as follows:

$$ICT_0 = -\frac{\beta_1}{2\beta_2} \quad (2)$$

$$Health\_outcomes_0 = f(ICT_0) = \frac{-\beta_1^2 + 4\beta_0\beta_2}{4\beta_2} \tag{3}$$

Basically ICT_0 and $Health\_outcomes_0$ are the coordinates of translations of the quadratic function. The turning point $\boldsymbol{V}$ (ICT_0, $Health\text{-}Outcomes_0$) is called the vertex of the parabola. It's a point of maximum health outcomes for the system. Up to that turning point, the more technologized a nation is, the better imprinted health outcomes it has. After that turning point, more ICT bring along less health benefits.

4. Results and discussions

4.1. Main results

Tables 2–4 show our main results, using the Ordinary Least Squares (OLS) technique for panel data. The first column of each table contains the results of a simple regression model, showing that higher technologized countries have better health outcomes (improved life expectancies and immunisation rates and decreased mortalities). In the second column, the technology proxy (Internet, models (2) and then Mobile, models (7)) is entered in a quadratic form (a second-order model), estimating a parametric regression without any controls. In Tables 2 and 4 the coefficients of ICT have the expected signs ($\boldsymbol{\beta_1} > \mathbf{0}$ and $\boldsymbol{\beta_2} < \mathbf{0}$) and they are all significant at a 1% level, while in Table 3 models (2) and (7) estimate the linear model of children mortality rate through a second-order polynomial in one variable: ICT ($\boldsymbol{\beta_1} < \mathbf{0}$ and $\boldsymbol{\beta_2} > \mathbf{0}$), significant at 1% level. Basically these models prove that the relationship between study (physical health proxies) and explanatory variables (information and communication technologies proxies) is curvilinear, as Fig. 1 reflects. The following columns are dedicated to adding our supplementary control variables: the logarithm of per capita GDP, the cultural dimensions and the environmental performance index of world countries, for the entire sample. Moreover, Tables 2a and 2b, Tables 3a and 3b and Tables 4a and 4b respectively, estimate Equation (1) for the subsample of 54 developed countries (2a, 3a, 4a) and the subsample of 131 developing countries (2b, 3b, 4b), proving that the influence of ICT upon health outcomes may be up to almost four times more prominent in developing countries than in developed countries.

Table 2 estimates the life expectancy of nations using *Internet* (models (1)–(5)) and *Mobile* (models (6)–(10)) and the previously mentioned controls as explanatory variables. Models (1) and (6) are simple regression models that show a direct and significant impact of technology upon life expectancy: at a 1 unit increase in the technology proxy, the life expectancy of people increases with 0.2324 units (Adjusted $R^2 = 0.5957$) and 0.1184 units (Adjusted $R^2 = 0.389$) on average, everything else unchanged. Models (2) and (7) portrait a concave representation of life expectancy as a function of the two technological proxies, *Internet* and *Mobile* (see Fig. 1 as well), better fitting the data, compared to the simple regression modelling (Adjusted $R^2 = 0.6407$ in model (2) and Adjusted $R^2 = 0.4155$ in model (7)). Further on, we add the controls, on turn, in models (3)–(5) and (8)–(10) respectively, and the signs and significances are always kept for the two technology proxies ($\beta_1 > 0$ and $\beta_2 < 0$, significant at 1% level). Models (3) and (8) control for economic development and prove their direct influence upon health outcomes. In model (3) we have that 2.7479 is the expected change in *Life expectancy* when per capita *GDP* is multiplied by *e,* ceteris paribus. In other words for percentage changes, 0.261 (about 3 extra months) is the expected increase in the life expectancy of nations when per capita *GDP* is multiplied by 1.1, i.e. increases by 10%, on average, ceteris paribus. The linear-log model (8) has a similar estimated impact, after the effect of Mobile as a technology proxy is taken into account: 0.3782 (more than 4 extra months) is the expected increase in the life expectancy of nations when per capita *GDP* increases by 10%, on average, at an explicative power of 66.1%. Then, models (4) and (9) keep the significant cultural dimensions (PD, IDV, MAS and IND) within the multiple parametric regression, revealing the indirect influence of

Table 2
Life expectancy, full sample, with *Internet* as a Technology proxy (models (1)–(5)) and *Mobile* as a Technology proxy (models (6)–(10)).

	Internet						*Mobile*					
Life expectancy, full sample	Simple regression (1) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) OLS	Parametric regression (5) OLS	Parametric regression (5′) FEM	Simple regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) OLS	Parametric regression (9) OLS	Parametric regression (10) OLS	Parametric regression (10′) FEM
constant	62.0027***	59.4887***	40.8173***	41.5151***	41.2864***	55.1443***	59.9965***	57.3549***	32.5479***	33.0362***	33.8016***	57.381***
Internet	0.2324***	0.4625***	0.3024***	0.186***	0.188***	0.0503***						
Internet^2		−0.0026***	−0.0021***	−0.0011***	−0.0011***	−0.00002						
Mobile							0.1184***	0.1925***	0.0647***	0.0792***	0.1164***	0.0194
Mobile^2								−0.0004***	−0.0001***	−0.0003***	−0.0005***	−0.0001
LogGDP			2.7479***	3.6937***	3.5006***	1.4608***			3.9819***	4.7707***	3.9299***	3.7026***
PD				−0.0302***	−0.0258**					−0.0323***	−0.0264**	
IDV				−0.0588***	−0.0616***					−0.0626***	−0.0646***	
MAS				0.0208***	0.0224***					0.0204***	0.0186**	
UAI												
LTO				0.0149**	−0.0186**							
IND				−0.0628***	−0.0618***					−0.0677***	−0.06***	
EPI					0.0353*	0.0494***					0.0898***	−0.0153
Threshold	n/a	88.94	72	84.54	85.45	1257.5	n/a	246.88	189.07	119.67	116.4	97
R^2	0.5959	0.6410	0.7042	0.7648	0.7573	within $R^2 =$ 0.4765	0.3892	0.4159	0.6614	0.7447	0.7502	within $R^2 =$ 0.0593
Adjusted R^2	0.5957	0.6407	0.7038	0.7630	0.7546	between $R^2 =$ 0.7119	0.3890	0.4155	0.6610	0.7430	0.7478	between $R^2 =$ 0.1145
Obs	2418	2418	2381	1059	816	overall $R^2 =$ 0.6985	2527	2527	2481	1085	842	overall $R^2 =$ 0.1060

Table 2a
Life expectancy, High-income subsample, with *Internet* as a Technology proxy (models (1)–(5)) and *Mobile* as a Technology proxy(models (6)–(10)).

	Internet						Mobile					
Life expectancy, High-income subsample	Simple regression (1) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) OLS	Parametric regression (5) OLS	Parametric regression (5′) FEM	Simple regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) OLS	Parametric regression (9) OLS	Parametric regression (10) OLS	Parametric regression (10′) FEM
constant	69.3441***	62.5962***	31.8542***	32.2817***	32.9095***	68.0407***	73.97***	67.3568***	26.3407***	37.9289***	32.8534***	50.8646***
Internet	0.1331***	0.3982***	0.4178***	0.1015***	0.061*	−0.0364***						
Internet^2		−0.0022***	−0.0028***	−0.0004*	−0.0001	0.0008***						
Mobile							0.0372***	0.1332***	0.1242***	−0.0313*	0.03004	0.0064
Mobile^2								−0.0003***	−0.0003***	0.00009	−0.0002**	0.00002
LogGDP			3.1375***	4.0039***	3.1573***	0.7276***			4.0897***	4.0636***	3.1441***	2.1746***
PD												
IDV				−0.0241***	−0.0143***							
MAS				0.0135***	0.0082*					0.0099**	0.00309	
UAI				0.0296***	0.0433***					0.0157***	0.0341***	
LTO				−0.0117***	−0.0181***							
IND												
EPI					0.1195***	0.0213***					0.1462***	0.0591***
Threshold	n/a	90.5	74.61	126.87	305	22.75	n/a	222	207	173.88	75.1	160
R^2	0.3615	0.4287	0.5441	0.6065	0.6930	within R^2 = 0.7699	0.0891	0.1500	0.4262	0.4816	0.6450	within R^2 = 0.4253
Adjusted R^2	0.3606	0.4271	0.5422	0.6014	0.6871	between R^2 = 0.4270	0.0879	0.1477	0.4239	0.4772	0.6402	between R^2 = 0.5117
Obs	728	728	728	553	422	overall R^2 = 0.4475	742	742	742	588	451	overall R^2 = 0.4986

Table 2b
Life expectancy, Low income subsample, with *Internet* as a Technology proxy (models (1)–(5)) and *Mobile* as a Technology proxy (models (6)–(10)).

	Internet						Mobile					
Life expectancy, Low-income subsample	Simple regression (2) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) OLS	Parametric regression (5) OLS	Parametric regression (5′) FEM	Simple regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) OLS	Parametric regression (9) OLS	Parametric regression (10) OLS	Parametric regression (10′) FEM
constant	61.3684***	58.6646***	39.1677***	43.5678***	43.7338***	53.8834***	59.7574***	58.2532***	0.2915***	36.9876***	36.5319***	64.6543***
Internet	0.2509***	0.5867***	0.3677***	0.2667***	0.3365***	0.1318***						
Internet^2		−0.0052***	−0.0034***	−0.0021***	−0.0029***	−0.0012***						
Mobile							0.0986***	0.1544***	0.0574***	0.094***	0.0919***	0.0952***
Mobile^2								−0.0003***	−0.0001***	−0.0003**	−0.0003**	−0.0003***
LogGDP			2.9328***	3.6939***	3.6677***	1.253***			4.4888***	4.6006***	4.2119***	−0.498
PD				−0.0392*	−0.0343					−0.0455**	−0.0368	
IDV				−0.1231***	−0.1267***					−0.1327***	−0.1386***	
MAS				0.033*	0.0453*					0.0353**	0.0363*	
UAI												
LTO												
IND				−0.091***	−0.0928***					−0.0989***	−0.0964***	
EPI					−0.0296	0.0588***					0.0706***	0.0706***
Threshold	n/a	56.41	54.07	63.5	58.01	54.91	n/a	214.74	156.65	147.15	131.43	136.46
R^2	0.4120	0.4883	0.5570	0.6507	0.6528	within R^2 = 0.4574	0.2837	0.2923	0.4927	0.6141	0.6165	within R^2 = 0.5140
Adjusted R^2	0.4116	0.4877	0.5562	0.6460	0.6458	between R^2 = 0.5680	0.2833	0.2915	0.4918	0.6090	0.6091	between R^2 = 0.4553
Obs	1690	1690	1653	520	405	overall R^2 = 0.5348	1785	1785	1739	539	424	overall R^2 = 0.3489

Table 3
MORTchild, full sample, with Internet as a Technology proxy (models (1)–(5)) and Mobile as a Technology proxy (models (6)–(10)).

MORTchild, full sample	Internet						Mobile					
	Simple regression (1) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) OLS	Parametric regression (5) OLS	Parametric regression (5′) FEM	Simple regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) OLS	Parametric regression (9) OLS	Parametric regression (10) OLS	Parametric regression (10′) FEM
constant	69.7325***	86.8823***	168.9612***	157.083***	157.6639***	111.3427***	85.7785***	101.5738***	187.1686***	175.8624***	168.4473***	41.5624***
Internet	−0.9131***	−2.4885***	−1.7922***	−1.2788***	−1.266***	−0.4741***						
Internet^2		0.0183***	0.0162***	0.0108***	0.0113***	0.0044***						
Mobile							−0.5625***	−1.0893***	−0.6171***	−0.7456***	−0.7553***	−0.5593***
Mobile^2								0.0031***	0.0021***	0.0029***	0.0031***	0.0022***
LogGDP			−12.0913***	−13.8536***	−12.881***	−7.1952***			−13.8463***	−14.7609***	−11.9561***	2.524*
PD												
IDV				0.1514***	0.1718***					0.1835***	0.217***	
MAS												
UAI												
LTO												
IND				0.2904***	0.2827***					0.3338***	0.3211***	
EPI					−0.2067***	−0.2218***					−0.3448***	−0.1835***
Threshold	n/a	67.88	55.18	59.12	56.01	53.87	n/a	172.02	146.94	127.11	121.82	127.11
R^2	0.4868	0.6001	0.6729	0.7132	0.7166	within R^2 = 0.3495	0.4192	0.4514	0.6235	0.6945	0.7035	within R^2 = 0.4913
Adjusted R^2	0.4866	0.5998	0.6725	0.7118	0.7145	betweenR^2 = 0.6647	0.4189	0.4509	0.6230	0.6931	0.7014	between R^2 = 0.6254
Obs	2389	2389	2352	1045	816	overall R^2 = 0.6476	2493	2493	2447	1071	842	overall R^2 = 0.4472

PD, IDV and IND upon life expectancy and the direct influence of MAS, significant at 1% level. Regressions (5) and (10) add environmental performances within the parametric regression, estimating its positive effect upon health outcomes: at a 1 point increase in EPI, the life expectancy of nations increases on average with approximatively 13 days (0.0353 units, in model (5)) or 33 days (0.0898 units, in model (10)), after the effects of the other explanatory variables are taken into account. The 1% and 10% significance thresholds show that pollution contributes significantly to the regression after the effects of Technology, per capita GDP and Culture are taken into account. Models (5′) and (10′) use another modelling technique, in order to estimate life expectancy as a health outcome through various exogenous variables: the fixed effects modelling (FEM) and the random effects modelling (REM) of our unbalanced panel data. The optimal estimation technique pointed out by the Hausman test is FEM for Table 2, so these results are kept and bolded out. In model (5′), the signs of the Internet and Internet^2 are kept and so is the significance of the coefficient estimated for Internet. The cultural dimensions are omitted due to collinearity reasons, and the economic and environmental performance variables keep their signs and significances. The FEM model (10') eliminates the cultural dimensions compared to model (10), but it keeps the signs of most other variables and the significance of economic development. So, our OLS results and overall impact are strengthened.

Our main finding is validated: there's an inverted U-shaped relationship between ICT and health outcomes, suggesting that for the first stages of technological development, the increase in the weight of the population that uses the Internet (% of population) and that of mobile cellular subscriptions leads to better health outcomes, with a peak of 88.94% of the people using the Internet and a threshold of 246.88 mobile cellular subscription per 100 people, respectively. These maximum levels of the parametric functions given by models (2) and (7), for ICT_0 proxies of 88.94 and 246.88, correspond to Life $Expectancies_0$ of 80.056 years and 80.5111 years, on average (the vertexes of the parabola, also noticeable in Fig. 1). Above these $Internet_0$ and $Mobile_0$ thresholds, the effects of technology upon health are diminishing, and the slopes are downwards, so more ICT (anything above 88.94% of the population using Internet or above 246.88 mobile subscriptions per 100 persons, national averages) means less health. Nonetheless, considering only *Internet* (model (2)) and *Mobile* (model (7)) as explanatory variables for *Life expectancy*, the parabolic function gives a maximum Life expectancy of a little over 80 years on average, for both cases, the utmost high level of years to live.

Table 2a estimates *Life expectancies* of high-income countries through Equation (1) using Internet as an ICT proxy in models (1)-(5′) and Mobile as an ICT proxy for models (6)-(10′), while Table 2b does just the same but on the subsample of low-income countries. In Table 3a, for the subsample of high-income countries, the coefficients of ICT, when significant, mostly have the expected signs, similar to Table 2. In Table 2b, the coefficients of ICT have the expected signs ($\beta_1 > 0$ and $\beta_2 < 0$) and they are all significant at a 1% threshold, except for models (9) and (10), where we have a 5% level of significance. The effect of Internet usage upon life expectancy is striking as it varies among the two subsamples of countries, as follows: the positive effect of Internet access and online information usage is almost doubled for the subsample of low-income states compared to that of high-income ones (0.2509 in model (1) Tables 2b, i.e. an addition of 92 days to the average life expectancy in low-income countries versus 0.1331 in model (1) Tables 2a, i.e. an addition of 49 days to the average life expectancy in high-income countries), while the effect of Mobile subscriptions is almost tripled in low-income countries compared to high-income countries (0.0986 in model (6) Tables 2b, i.e. an addition of 36 days to the average life expectancy of people in low-income countries versus 0.0372 in model (6) Tables 2a, i.e. an addition of 14 days to the average life expectancy of people in high-income countries). The effect of economic development is almost always significant and positive for the two subsamples of states, and that of environmental performances as well. Both Tables 3a and 3b

Table 3a
MORTchild, High-income subsample, with Internet as a Technology proxy (models (1)–(5)) and Mobile as a Technology proxy (models (6)–(10)).

	Internet						Mobile					
MORTchild, High- income subsample	Simple regression (1) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) OLS	Parametric regression (5) OLS	Parametric regression (5′) FEM	Simple regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) OLS	Parametric regression (9) OLS	Parametric regression (10) OLS	Parametric regression (10′) FEM
constant	33.2472***	73.7171***	97.902***	49.7691***	49.2623***	26.4784***	35.4062***	114.8924***	145.8282***	56.0962***	49.587***	34.2843***
Internet	−0.3621***	−1.9597***	−1.98***	−0.1844***	−0.1457***	−0.0963***						
Internet^2		0.0134***	0 .0139***	0.001***	0.0008***	0.0003***						
Mobile							−0.2295***	−1.6847***	−1.625***	−0.1381***	−0.0243	−0.0292*
Mobile^2								0.0062***	0.006***	0.0006***	0.0001	0.00003
LogGDP			−2.4654***	−3.8046***	−2.5863***	−1.354***			−3.3472***	−4.5086***	−3.0767***	−2.0997***
PD												
IDV				−0.021***	−0.0166***					−0.0215***	−0.018***	
MAS				0.0229***	0.0295***					0.0245***	0.0317***	
UAI				−0.029***	−0.0336***					−0.022***	−0.0282***	
LTO										−0.0113*	−0.0174**	
IND				0.0962***	0.0862***					0.1011***	0.085***	
EPI					−0.1893***	−0.0259***					−0.1896***	−0.0554***
Threshold	n/a	72.83	70.91	90.66	81.63	143.49	n/a	134.04	134.31	106.13	65.08	401.32
R^2	0.2546	0.4906	0.4973	0.5815	0.6985	within R^2 = 0.7041	0.1794	0.5613	0.5790	0.5697	0.6877	within R^2 = 0.5090
Adjusted R^2	0.2535	0.4891	0.4951	0.5758	0.6925	between R^2 = 0.3739	0.1782	0.5601	0.5771	0.5632	0.6808	betweenR^2 = 0.3071
Obs	688	688	688	525	411	overall R^2 = 0.3953	700	700	700	532	418	overall R^2 = 0.3201

support the idea that increased economic development and high quality environment facilitate better life expectancies in both subsamples of countries. The validated cultural dimensions which are kept for both sets of countries when Internet is used as an ICT proxy are IDV with a negative impact and MAS with a positive impact, with stronger effects in low-income nations. Further on, at the use of Mobile as a proxy of ICT, the positive effect of MAS is present for both subsamples of countries, with a stronger impact in low-income countries. Table 2a supplementary validates a positive effect of UAI for high-income countries (models (4), (5), (9) and (10)), for both ICT proxies, and a negative effect of LTO when Internet is used as an ICT proxy (models (4) and (5)). Then Table 3b shows that the peculiarities of low-income countries' cultural traits include the negative effect of PD (models (4) and (9)) and the negative effect of IND (models (4), (5), (9) and (10)).

Table 3 models *Under 5 mortality rate in children* for our full sample as a first degree function of ICT proxies (Internet in model (1) and Mobile in model (6)) proving the indirect relationship between ICT and mortality rates. Further on, second degree polynomials are estimated (models (2) and (7) respectively) and the Adjusted R^2 increases from 0.4866 in model (1) to 0.5998 in model (2) and from 0.4189 in model (6) to 0.4509 in model (7), so we do get a better fit. The U shaped relationship between mortality rates and ICT proxies from Fig. 1 is supported: the more ICT countries use, the smaller their mortality rates are, but only up to a certain threshold (67.88% of the people using the Internet and 172.02 mobile cellular subscription per 100 people, respectively). Above 67.88% of the population using the internet and almost 2 mobile cellular subscriptions per person, mortality rates are no longer decreased through technologies. The ceiling values of these thresholds are supported by the thresholds computed on the extended models (3)–(5) and (8)–(10), when we control for economic development, cultural and environmental specific dimensions. As expected, the higher the number of explanatory variables, the better the multiple regression estimated models (Adjusted $R^2 = 0.7145$ in model (5) and Adjusted $R^2 = 0.7014$ in model (10)).

Models (3) and (8) from Table 3 control for per capita GDP and prove their indirect influence upon mortality, significant at a 1% level. In model (3) we have that a one-unit increase in logGDP (basically multiplying GDP by $e \approx 2.72$ *or* GDP increases by 172%) will basically decrease the number of dead children before reaching the age of 5, out of 1000 live births by almost 12 children, on average, everything else unchanged, thus revealing the positive influence of economic development on health outcomes, as expected. Model (8) has a similar estimated impact, after the effect of Mobile as a technology proxy is taken into account: each 1 unit increase of logGDP of countries (i.e. unlogged GDP increases by 172%), decreases the number of dead children before reaching the age of 5 by almost 14 children out of 1000 live births, on average, at an explicative power of 62.3%.

Then, models (4) and (9) keep the significant cultural dimensions (IDV and IND) within the multiple parametric regression, revealing the direct influence of both cultural dimensions upon under 5 mortality, significant at 1% level. When EPI is added within the multiple regression models (5) and (10), all the influences exerted by the independent variables are kept and all their significance levels as well, showing that a better environmental quality reduces the mortality rates of nations, as expected. Moreover, when the FEM validated technique is applied, the cultural dimensions are dropped due to multicollinearity but all the other variables remain significant within the regressions and the U shape of the modelled Under 5 mortality rate is kept (models (5′) and (10′), with $\beta_1 < 0$ and $\beta_2 > 0$).

The U-shaped relationship between *Under 5 mortality rate in children* and ICT proxies shows that an increase in the use of ICT decreases mortality up to the thresholds of 67.88% of Internet users and 172.02 mobile subscriptions per 100 people, respectively, corresponding to children mortalities $MORTchild_0$ of 2.28 and 5.92 dead children before reaching the age of 5, out of 1000 live births, on average (the vertexes of the parabola). After these $Internet_0$ and $Mobile_0$ thresholds are attained,

Table 3b
MORTchild, Low income subsample, with Internet as a Technology proxy (models (1)–(5)) and Mobile as a Technology proxy (models (6)–(10)).

MORTchild, Low- income subsample	Internet						Mobile					
	Simple regression (2) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) OLS	Parametric regression (5) OLS	Parametric regression (5′) FEM	Simple regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) OLS	Parametric regression (9) OLS	Parametric regression (10) OLS	Parametric regression (10’) FEM
constant	75.8117***	91.4211***	205.3082***	188.8766***	199.515***	126.3288***	86.4399***	96.6272***	240.043***	192.6844***	198.7674***	43.8082***
Internet	−1.2097***	−3.1571***	−1.8338***	−1.4168***	−1.3669***	−0.7715***						
Internet^2		0.0305***	0.0193***	0.0136***	0.0151***	0.009***						
Mobile							−0.5138***	−0.8911***	−0.3868***	−0.4698***	−0.4556***	−0.6351***
Mobile^2								0.0024***	0.0014***	0.0014**	0.0016**	0.0026***
LogGDP			−17.2099***	−18.3062***	−17.3921***	−7.6305***			−22.4238***	−21.5236***	−18.4292***	4.8661**
PD										0.1768*	0.129	
IDV				0.3261***	0.3537***					0.4573***	0.481***	
MAS												
UAI										0.1016*	0.1029	
LTO				−0.1296***	−0.1485**					−0.1122**	−0.1386**	
IND				0.3388***	0.3179***					0.394***	0.3532***	
EPI					−0.4325888	−0.30001***					−0.6027***	−0.2645***
Threshold	n/a	51.75	47.51	52.08	45.26	42.86	n/a	185.64	138.14	167.78	142.37	122.13
R^2	0.4037	0.5092	0.6160	0.6425	0.6574	within R^2 = 0.4169	0.3277	0.3443	0.5672	0.6268	0.6487	within R^2 = 0.5215
Adjusted R^2	0.4033	0.5087	0.6153	0.6383	0.6513	betweenR^2 = 0.6209	0.3274	0.3436	0.5664	0.6212	0.6411	betweenR^2 = 0.4069
Obs	1701	1701	1664	520	405	overall R^2 = 0.5860	1793	1793	1747	539	424	overall R^2 = 0.2862

the decreasing effect of ICT upon mortalities is reversed, and the slopes are upwards, so more ICT (anything above 67.88% of the population using Internet or above 172.02 mobile subscriptions per 100 persons, national averages) means less health. These thresholds are supported by the multiple regressions models with control variables (models (3)–(5) with equation minimums between 55.18 and 59.12% of people using the internet, and models (8)–(10) with equation minimums of 121.82–146.94 mobile cellular subscriptions per 100 people), just like we mention before.

Table 3a estimates children mortality rates (*Mortality rate under 5)* of high-income countries through Equation (1) using Internet as an ICT proxy in models (1)-(5′) and Mobile as an ICT proxy for models (6)-(10’), while Table 4b does the same for our subsample of low-income states. In Table 3a, the coefficients of ICT, when significant, have the expected signs, similar to Table 4, supporting the U shaped relationship of Mortality as a function of ICT and ICT^2, for our subsampled high-income states. In Table 4b, the coefficients of ICT have the expected signs once again ($\beta_1 < 0$ and $\beta_2 > 0$) and they are all significant at 1% or 5% levels. The effect of both ICT proxies upon mortality rates has a multiplier effect from high-income countries to low-income countries, as follows: the negative effect of Internet access and online information usage is 3.34 time stronger in low income countries compared to high-income countries (−1.2097 in model (1) Table 3b for low-income countries versus 0.3621 in model (1) Table 3a for high-income countries), while the effect of Mobile subscriptions is 2.24 times stronger for the subsample of low-income states compared to that of high-income states (−0.5138 in model (6) Table 3b for low-income countries versus −0.2295 in model (6) Table 3a for high-income countries).

The effect of economic development is almost always significant and negative, regardless of the two samples of countries, with a more potent effect in low-income countries, so basically an improved economic prosperity decreases mortality rates of nations, just like Table 4 sustains for the entire sample of countries. The validated cultural dimensions which are kept for both sets of countries when Internet is used as an ICT proxy are IDV and IND, with a negative effect of IDV for high-income countries (Table 3a, models (4) and (5)), a positive effect of IDV for low-income countries (Table 3b, models (4) and (5)) and a positive effect of IND for both sets of countries (Tables 4a and 4b, models (4) and (5)), all significant at 1% level. Supplementary, high-income countries have a positive effect from MAS and a negative effect from UAI (Table 4a), while low-income countries validate a negative effect of LTO (Table 3b).

Then, when Mobile is used as an ICT proxy, models (9) and (10) from Tables 3a and 3b estimate a negative effect of LTO and a positive effect of IND for both sets of countries, with differences with respect to the effect held by IDV and UAI, as follows: on one hand, high-income countries register a negative impact of IDV upon mortality rates while the effect of IDV in low-income countries is positive, just like for the entire sample; on the other hand, UAI has a negative impact for high-income states (models (9) and (10), Table 3a) and a positive impact for low-income states (model (9), significant at only 10% level, Table 3b). On top of these, MAS is supplementary validates through Table 3a as having a direct impact upon health outcomes in high-income countries, while PD has a slight direct impact upon low income countries (model (9), Tables 3b, 1% level).The effect of environmental performances is negative for both subsamples of countries, with a stronger effect upon decreasing mortalities in low-income countries (Table 3b, models (5)-(5’) and (10)-(10’) versus Table 3a, corresponding models).

Table 4 uses *Measles Immunisation of children* (% of children ages 12–23 months) as a health outcome proxy and estimates it as a function of ICT proxies (Internet and Mobile) through a first degree polynomial, a second degree polynomial and further by adding controls to the OLS regression models, in order to build up Equation (1). There is a direct relationship between ICT proxies and *Measles immunisation rate* (models (1) and (6)), showing that the more people have access to information through their personal devices, the more they acknowledge the importance of vaccination as a health benefit. The parametric regression in

Table 4
Measles, full sample, with *Internet* as a Technology proxy (models (1)–(5)) and *Mobile* as a Technology proxy (models (6)–(10)).

	Internet						Mobile					
Measles, full sample	Simple regression (1) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) OLS	Parametric regression (5) OLS	Parametric regression (5′) FEM	Simple regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) OLS	Parametric regression (9) OLS	Parametric regression (10) OLS	Parametric regression (10′) FEM
constant	79.5565***	75.1001***	62.2842***	89.5704***	89.362***	57.381***	74.5082***	70.7998***	56.9823***	78.777***	82.3038***	71.7478***
Internet	0.211***	0.6205***	0.5227***	0.3579***	0.3489***	0.0194						
$Internet^2$		−0.0047***	−0.0045***	−0.0024***	−0.0026***	−0.0001						
Mobile							0.1451***	0.2687***	0.2054***	0.2002***	0.1931***	0.1309***
$Mobile^2$								−0.0007***	−0.0006***	−0.0006***	−0.0007***	−0.0006***
LogGDP			1.8895***	0.6541*	−0.4231	3.7026***			2.1892***	1.5718***	−0.3076	1.5146*
PD				−0.0566***	−0.0297					−0.0583***	−0.03	
IDV				−0.0805***	−0.0822***					−0738***	−0.0816***	
MAS				−0.0259*	−0.0377**					−0.0224*	−0.0323**	
UAI												
LTO												
IND				−0.1273***	−0.1148***					−0.1398***	−0.1251***	
EPI					0.163***	−0.0153					0.2185***	−0.0157
Threshold	n/a	66.01	58.07	74.56	67.09	97	n/a	191.92	171.16	166.83	137.93	109.08
R^2	0.2037	0.2636	0.2868	0.2946	0.3269	within R^2 = 0.0593	0.2130	0.2265	0.2696	0.2865	0.3268	within R^2 = 0.0995
Adjusted R^2	0.2033	0.2630	0.2859	0.2898	0.3203	between R^2 = 0.1145	0.2127	0.2259	0.2687	0.2818	0.3203	Between R^2 = 0.1480
Obs	2388	2388	2351	1045	816	overall R^2 = 0.1060	2491	2491	2445	1071	842	overall R^2 = 0.1408

Table 4a
Measles, High-income subsample, with *Internet* as a Technology proxy (models (1)–(5)) and *Mobile* as a Technology proxy (models (6)–(10)).

	Internet						*Mobile*					
Measles, High-income subsample	Simple regression (1) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) OLS	Parametric regression (5) OLS	Parametric regression (5′) REM	Simple regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) OLS	Parametric regression (9) OLS	Parametric regression (10) OLS	Parametric regression (10′) REM
constant	84.1438***	69.4486***	80.9585***	93.2741***	92.993***	93.9947***	76.9298***	47.3357***	49.4433***	75.3178***	78.7135***	81.377***
Internet	0.1317***	0.7118***	0.7021***	−0.1836***	−0.1709***	−0.1422***						
$Internet^2$		−0.0048***	−0.0046***	0.0018***	0.0017***	0.0014***						
Mobile							0.1373***	0.6791***	0.6832***	0.0786*	0.0345	−0.0136
$Mobile^2$								−0.0023***	−0.0023***	−0.0002	−0.0001	0.00007
LogGDP			−1.1733**	0.2693	−0.0772	0.2328			−0.228	1.1486***	0.7314*	1.0613
PD				0.072***	0.087***	0.0841***				0.0786***	0.0923***	0.0895***
IDV				−0.0161*	−0.0129	−0.009						
MAS				−0.0172***	−0.0258***	−0.0245				−0.0313***	−0.0394***	−0.0385**
UAI				0.0221***	0.02**	0.0161				0.0194**	0.0172*	0.0154
LTO												
IND				−0.0477***	−0.0471***	−0.0483*				−0.0426***	−0.0434***	−0.0483*
EPI					0.0429*	−0.0214					0.048**	0.0112
Threshold	n/a	72.85	75.61	49.27	48.93	47.53	n/a	145.14	145.01	140.23	148.48	90.86
R^2	0.1086	0.2089	0.2138	0.3371	0.3705	within R^2 = 0.0639	0.1978	0.3607	0.3609	0.2856	0.3271	within R^2 = 0.0095
Adjusted R^2	0.1073	0.2066	0.2103	0.3268	0.3564	betweenR^2 = 0.5001	0.1966	0.3589	0.3582	0.2760	0.3139	betweenR^2 = 0.4702
Obs	688	688	688	525	411	overall R^2 = 0.3574	700	700	700	532	418	overall R^2 = 0.3204

Table 4b
Measles, Low income subsample, with *Internet* as a Technology proxy (models (1)–(5)) and *Mobile* as a Technology proxy (models (6)–(10)).

	Internet						Mobile					
Measles, Low income subsample	Simple regression (1) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) OLS	Parametric regression (5) OLS	Parametric regression (5′) FEM	Simple regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) OLS	Parametric regression (9) OLS	Parametric regression (10) OLS	Parametric regression (10′) FEM
constant	78.2745***	73.6618***	52.6636***	115.088***	110.9518***	50.3417***	74.8658***	71.8518***	43.1863***	108.3372***	107.5795***	69.3470***
Internet	0.2833***	0.8591***	0.6502***	0.4905***	0.4783***	0.1114*						
$Internet^2$		−0.009***	−0.0074***	−0.0039***	−0.0043***	−0.0015**						
Mobile							0.1324***	0.244***	0.1584***	0.1994***	0.1814***	0.1615***
$Mobile^2$								−0.0007***	−0.0006***	−0.0005**	−0.0005*	−0.0008***
LogGDP			3.1515***	−0.2388	−0.9671	4.6359***			4.4382***	1.1178*	−0.4752	1.65
PD				−0.2784***	−0.2502***					−0.3048***	−0.2813***	
IDV				−0.2163***	−0.2169***					−0.245***	−0.2576***	
MAS												
UAI										−0.0519*	−0.0467	
LTO												
IND				−0.1563***	−0.142***					−0.1802***	−0.1613***	
EPI					0.1792***	−0.0195					0.2687***	−0.0244
Threshold	n/a	47.51	43.36	61.63	55.49	35.13	n/a	170.3	129.65	175.61	160.89	97.78
R^2	0.1558	0.2207	0.2615	0.2969	0.3342	within R^2 = 0.0998	0.1496	0.1595	0.2295	0.2922	0.3420	within R^2 = 0.1360
Adjusted R^2	0.1553	0.2198	0.2602	0.2886	0.3224	between R^2 = 0.0549	0.1491	0.1586	0.2281	0.2829	0.3293	between R^2 = 0.0645
Obs	1700	1700	1663	520	405	overall R^2 = 0.0617	1791	1791	1745	539	424	overall R^2 = 0.0739

models (2) and (7) has an inverted U shape ($\beta_1 > 0$ and $\beta_2 < 0$, stable at a 1% level through models (2)–(5) and (7)–(10)). Basically, the more ICT populations use, the higher their measles immunisation rates, but only up to a certain threshold (66.01% of the people using the Internet and 191.92 mobile cellular subscription per 100 people, respectively). The values of these thresholds are supported up to a certain extent by the thresholds computed on the extended models (3)–(5) (between 58.07% and 74.56%) and (8)–(10) (between 137.93 and 171.16 subscriptions per 100 people). The explicative power of these models reaches 32.02% (Adjusted $R^2 = 0.3203$) in model (5) and 32.03% (Adjusted $R^2 = 0.3203$) in model (10).

Models (3) and (8) control for economic prosperity and prove their direct influence upon measles immunisation rate as a health proxy, significant at a 1% level. Further on, models (4)-(5′) and models (9)-(10’) estimate a positive effect of economic prosperity upon measles immunisation rates of nations, when significant. Then, models (4) and (9) keep the cultural dimensions of PD, IDV, MAS and IND as significant within the multiple parametric regression, revealing their indirect influence upon immunisation rates (negative coefficients in models (4)–(5) and (9)–(10), significant at various thresholds, except for the negative effect of PD in models (5) and (10) from Table 4). Out of these cultural variables, PD, IDV and IND keep their sign compared to Table 3. Environmental performances have a positive health impact in models (5) and (10) (see Table 4).

The inverted U-shaped relationship between measles immunisation rates and ICT proxies shows that an increase in the use of ICT increases immunisation rates but only up to the thresholds of 66.01% of the people using the Internet and 191.92 mobile cellular subscriptions per 100 people, respectively, corresponding to immunisation rates $Measles_0$ of 95.58% (model (2)) and 96.58% (model (7)) of children ages 12–23 months on average (the vertexes of the parabola from Fig. 1).

The FEM estimation technique is optimal according to the Hausman test, so models (5′) and (10′) use our independent variables (Internet, $Internet^2$ and Mobile, $Mobile^2$) and the previously validates controls (LogGDP and EPI), except for the cultural dimensions, omitted due to multicollinearity. Here, the direct impact of economic prosperity remains significant and the signs of the ICT proxies are kept (($\beta_1 > 0$ and $\beta_2 < 0$), significant only for model (10′). The impact of EPI isn't significant.

Table 4a estimates *Measles immunisation rate* of the 54 subsampled high-income states through Equation (1) using Internet as an ICT proxy in models (1)-(5′) and Mobile as an ICT proxy for models (6)-(10’), while Table 4b does just the same for our subsample of 131 low-income states. In Table 4a, the coefficients of ICT, when significant, have the expected signs from Table 4 in more than half of the estimated models. In Table 4b, the coefficients of ICT always have the expected signs ($\beta_1 > 0$ and $\beta_2 < 0$) and they are all significant at various levels. The positive effect of Internet usage upon measles immunisation rates is more than doubled for low-income states versus high-income states (0.2833 in model (1) Table 4b for low-income countries versus 0.1317 in model (1) Table 4a for high-income countries), while the effect of Mobile subscriptions among subsamples (0.1324 in model (6) Table 4b versus 0.1373 in model (6) Table 4a). The effect of economic development, when this variable is significant, is almost always positive for the two subsamples of countries, and that of environmental performances as well (Tables 4a and 4b).

The validated cultural dimensions which are kept for both subsets of countries when Internet is used as an ICT proxy are PD, IDV and IND, with negative effects of IDV and IND on both subsets of countries and a positive effect of PD for high-income countries and a negative effect of PD for low-income countries (models (4) and (5) Table 4a versus Table 4b). Besides these three cultural dimensions, in Table 4a, when Internet is used as and ICT proxy, MAS and UAI are also validated as explanatory variables of the Measles immunisation rates of high-income countries (models (4) and (5) Table 5a versus Table 4b where they are missing), with a positive effect of femininity and uncertainty avoidance.

Then, when Mobile is used as an ICT proxy, the indirect effect of IND is present for both subsamples of countries (models (9) and (10) Table 4a versus Table 4b) with a stronger impact in low-income countries. The same negative effect of Indulgence versus restraint was previously validated through Table 4 models (9) and (10) for the entire sample. PD and UAI are validated for both subsamples: there's a positive impact for the subsample of high-income states (models (9) and (10), Table 4a) and a negative impact for the subsample of low-income states (model (9) Table 5b). Then, Table 4a estimates a negative effect of MAS for high-income countries (models (9) and (10), Table 4a). Nonetheless, Table 4b validates a negative effect of IDV (models (9) and (10), Table 4b, significant at a 1% level), also present in Table 4 for our full sample.

Our main finding, that of an inverted U-shaped relationship between ICTs and health outcomes, is validated, proving that at the very first stages of technological development, the rise in the weight of the population that uses the Internet (% of population) and that of mobile cellular subscriptions leads to better health outcomes, with a peak of 88.94% of the people using the Internet and a threshold of 246.88 mobile cellular subscription per 100 people, respectively. These maximum levels of the parametric functions given by models (2) and (7), for ICT_0 proxies of 88.94 and 246.88, correspond to Life $Expectancies_0$ of 80.056 years and 80.5111 years, on average (the vertexes of the parabola, also noticeable in Fig. 1). Above these *$Internet_0$* and *$Mobile_0$* thresholds, the effects of technology upon health are diminishing, and the slopes are downwards, so more ICT (anything above 88.94% of the population using Internet or above 246.88 mobile subscriptions per 100 persons, national averages) brings along less health.

Concluding, we find an inverted U relationship between ICT and health outcomes when we analyse the full sample (Tables 2–4) and the two subgroups as well (Tables 2a, 2b, Tables 3a, 3b and Tables 4a, 4b). Thus, higher technologized countries have better health outcomes (improved life expectancies and immunisation rates and decreased mortalities) until a certain threshold is attained; afterwards the more ICT become less and their effects turn negative. With our inverted U shape estimation, we may explain the positive relationship found in the literature between ICT and health outcomes [1,7,11,14], and also the negative relationships found by other studies [11,21,26].

The effect of economic development is usually significant and positive, regardless of the two samples of countries. Thus, an increase in per capita GDP increases *Life expectancy* and *Measles Immunisation of children rate* and it reduces *Mortality rate under 5*. Our results are supported by the literature [28–30,42,43] and show that indeed, an improved income leads towards a better access to living conditions, education, healthcare systems and other elements which can boost health, happiness and human development, increase life expectancies and reduce mortality rates. Regarding the environmental performances control variable, its coefficients are positive and significant, meaning that the clearer the air is, the better effects it has on increasing the *Life expectancy* and reducing the *Mortality rate under 5*. Similar findings are documented by Ref. [15] who also find that carbon dioxide pollution results measured by CO2 emissions (metric tons per capita) have adverse effects on life expectancy at birth and infant mortality.

Regarding the impact of culture as another set of control variables for health outcomes, we find evidence regarding the negative impact of PD on Life expectancy for the full sample and for the low-income countries. This means that a higher Power distance reduces the years of Life expectancy. Similarly, the influence of PD on Measles Immunisation of children *(Measles)* is also negative for the full sample and for the subsample of low-income states. Thus, a higher power distance has a negative influence on health outcomes, reducing both *Life expectancy* and *Measles.* However, no significant influence is found for Power distance on *Mortality rate under 5*. Power distance refers to the way in which power is distributed within a society and it is associated with the idea of democracy [44]. A high power distance characterizes the dictatorial governments that tend to be oppressive, this resulting in diminished life satisfaction and finally life expectancy [44]. Thus, our finding is in line with the assumption of [44] regarding the negative relationship between Power distance and Life expectancy. Then, we find a negative impact of Individualism-collectivism (IDV) on *Life expectancy* and *Measles* for the entire sample, high and low-income countries respectively. In addition, both for *Life expectancy* and *Measles,* higher levels of impacts are found for the low-income states versus the high-income ones. In other words, an improved level of collectivism boosts the level of *Life expectancy* and *Measles Immunisation of children* and this impact is higher for low-income countries. Some similar results are obtained when we analyse the influence of IDV on *Mortality rate under 5.* Thus, we find a positive influence of IDV on *Under 5 mortality rate in children* when the full sample is analysed and for the subsample of low-income states respectively, and then we find a negative influence for high-income states. It means that lower collectivism boosts the *Mortality rate under 5.* However, our findings suggest that for high-income states, an increased level of individualism is good for health, reducing their *Mortality rate under 5.* Similar results are found by the study of [29] who also find that the influence of IDV upon Life expectancy is negative (and it is positive upon Mortality rate under 5, respectively), and more prominent for low-income states as opposed to high-income states. The explanations are linked to the cultural patterns of nations. Thus, people from low-income nations are significantly much more collectivistic than people from high-income nations [45]. points out the fact that collectivist societies are the cultures "in which people from birth onwards are integrated into strong, cohesive in-groups", groups which carry on with their protection, asking unquestioning loyalty in return. Thus, a more collectivistic culture boosts the ties established among its members, resulting in greater care for the closed ones and thus, good health outcomes [46]. considers that collectivism actually is highly functional in developing countries because it is perceived as a "survival mechanism".

Furthermore, we find a positive impact of *Masculinity versus femininity* (MAS) upon *Life expectancy* for the full sample and for the two subsamples as well. According to Ref. [37] the *Masculinity versus femininity* dimension of culture (MAS) regards the responsibility of a society for accomplishment, courage, determination and material remunerations for success (masculinity) or for collaboration, discreetness, caring for the weak and quality of life (femininity). These findings are similar to those of [29] according to which it is the masculine societies that actually live longer than feminine societies and their results are validated for a mixed sample of countries and separately for a subsample of high-income states. However, our findings suggest that higher masculinity may have a bad impact within high-income countries, through increased *Mortality rates under 5* (Table 3a, models (4), (5), (9) and (10)) and decreased Measles Immunisation rates of children (Table 4a, models (4), (5), (5′), (9), (10) and (10')).

In addition to these, we find negative effects of *Indulgence versus restraint* (IND) on *Life expectancy* for the full sample and then separately for the subsample of low-income states. The results are similar to those of [29] who validate the indirect relationship between the level of indulgence and that of Life expectancies, for a mixed sample of countries and separately for a subsample of low-income states. The explanation considers the idea that a more indulgent society is more exposed to enjoyment and leisure activities that further promote messiness and the exposure to larger health-threatening dangers. As opposed to this, a restraint society is characterized by considering order „a high priority" [45,47], which decreases its exposure to health risks, thus the potentially improved health outcomes. We also find negative effects of IND on *Mortality rate under 5* for all the analysed samples, meaning higher indulgence increases the exposure to risk and therefore the *Mortality rate under 5* decreases. In addition, an enlarged indulgence is related to decreased levels of *Measles* for the full sample and separately for the subsamples of high-income and low-income states as well (Tables 4, 4a and 4b).

4.2. Robustness checks

To reinforce our main results, we conduct a series of robustness checks, that include the following aspects, on turn: (1) we consider an alternative measure of our dependent variables, another proxy for the health outcomes of nations, i.e. the *Infant mortality rate*; (2) we consider an alternative measure of our main independent variables, the two information and communication technologies' proxies *Internet* and *Mobile*, i.e. *Telephone* (Fixed telephone subscriptions) and (3) we control for other effects by supplementing our regressions with some other control variables. Additional descriptions of the control variables are included in Appendix 1.

(1) First, we check the robustness of our main results through testing an alternative proxy for our dependent variables, an alternate well-known measure for the physical health of nations. Our main results use the life expectancy, the children mortality rate and the immunisation against measles as health proxies, so this subpart of the robustness tests will re-estimate the main model (Equation (1)) using the *Infant mortality rate (MORTinfant)* of nations as a dependent variable. The results reported in Table 5 show that our basic results are stable. The U-shaped relationship between the mortality rate under the age of 1 per 1000 live births on the one hand and *Internet* (models (1)-(5′)) and *Mobile* (models (6)-(10′)) on the other is always kept, at a significance level of 1% for the estimated $\beta_1 < 0$ and $\beta_2 > 0$. Fig. 1 also includes the graphical representation of these findings. The thresholds are of 71.93% of the people using the Internet and 187.55 mobile cellular subscription per 100 people, respectively. Above these, the influence of ICT upon infant mortality rate starts to become direct, increasing mortalities (see Fig. 1 as well), which is undesirable.

(2) We further consider *Telephone* as an alternative measure to our main independent variables, *Internet* and *Mobile*, in order to explore if the effect of technology on health is driven by the choice of technology proxies (Table 6). The *Telephone* variable represents the sum of active number of analogue fixed telephone lines, voice-over-IP (VoIP) subscriptions, fixed wireless local loop (WLL) subscriptions, ISDN voice-channel equivalents and fixed public payphones, basically the fixed telephone subscriptions per 100 people in each country of our original sample and it has also been previously validated as a technological proxy by the literature [15]. The variables kept within the multiple regression modelling of the original dependent variables as a function of Telephone are the control variables previously used for our basic results: economic prosperity, cultural dimensions and environmental performances. Basically, the simple regressions show that ICT has a positive influence upon health outcomes, increasing life expectancies and immunisation rates and decreasing mortalities. Still, we have proven that the parametric regression is a better approach to modelling these data, and the U-shaped relationships hold strong when Telephone is used as an ICT proxy, at a 1% level of significance everywhere. The influences of the controls are also robust as sign and significance. Nonetheless, the thresholds are of 45.73 fixed telephone subscriptions per 100 people, 38.31 and 35.29 respectively. Above these, too many ICT come with fewer health outcomes.

(3) To confirm our main findings, we further control for other effects by supplementing our initial regression model (Equation (1)) with some other control variables. As such, we add dimensions of *Urbanization, Unemployment, Alcohol consumption* and *Religion,* on turn, as they are detailed within Appendix 1. Urbanization (Urban) represents the percentage of total population living in urban areas and in comes with positive benefits for health outcomes, after the effects of all the other previously included variables is estimated. The estimated coefficients of Urban are positive in Tables 7a and 7c and negative in Table 7b, significant at 1%, and stable at various ICT proxies. It seems that urbanization brings along more knowledge and openness towards a healthy lifestyle of the population and an improved access to healthcare services. When the unemployment rate (Unempl) is added to the baseline model, the signs and significances established by our main results remain stable. Therefore, we find that the level of *Urbanization* has a positive impact on *Life expectancy* and *Measles immunisation* and reduces the level of *Mortality rate under 5.* The results are in line with those of [7] who also find positive effects of *Urbanization* on various health outcomes. In addition, according to Ref. [16] the construction of smart cities conducts towards improving the medical conditions with a higher degree in rural areas than in urban areas, thus the gap between urban and rural medical treatment reduces.

Table 5
Robustness checks (1): *MORTinfant* as an alternative measure of Health outcome with *Internet* as a Technology proxy (models (1)–(4)) and *Mobile* as a Technology proxy (models (5)–(8)).

Internet Mobile								
MORTinfant, full sample	Simple regression (1) OLS	Parametric regression (2) OLS	Parametric regression (3) OLS	Parametric regression (4) FEM	Simple regression (5) OLS	Parametric regression (6) OLS	Parametric regression (7) OLS	Parametric regression (8) FEM
constant	48.7877***	58.8605***	102.5719***	70.8658***	58.6363***	67.8761***	111.5126***	39.1079***
Internet	−0.614***	−1.5393***	−0.7367***	−0.2859***				
$Internet^2$		0.0107***	0.0064***	0.0024***				
Mobile					−0.367***	−0.6752***	−0.3942***	−0.2922***
$Mobile^2$						0.0018***	0.0016***	0.0011***
LogGDP			−7.9976***	−4.3698***			−7.8195***	0.1886
PD								
IDV			0.0986***				0.1273***	
MAS			0.0313*					
UAI								
LTO								
IND			0.1788***				0.2008***	
EPI			−0.1955***	−0.1318***			−0.2815***	−0.1269***
Threshold	n/a	71.93	57.55	59.56	n/a	187.55	123.18	132.81
R^2	0.5386	0.6342	0.7759	within R^2 = 0.4553	0.4356	0.4625	0.7600	within R^2 = 0.5616
Adjusted R^2	0.5384	0.6339	0.7740	between R^2 = 0.7254	0.4354	0.4621	0.7583	between R^2 = 0.7554
Obs	2389	2368	816	overall R^2 = 0.7118	2493	2493	842	overall R^2 = 0.6347

Table 6
Robustness checks (2): *Telephone* as an alternative measure of Technology.

Telephone	*Life expectancy* estimated through Telephone as a Technology proxy			*MORTchild* estimated through Telephone as a Technology proxy			*Measles* estimated through Telephone as a Technology proxy		
	Simple regression OLS	Parametric regression OLS	Parametric regression OLS	Simple regression OLS	Parametric regression OLS	Parametric regression OLS	Simple regression OLS	Parametric regression OLS	Parametric regression OLS
constant	63.7041***	60.8904***	41.1856***	62.9428***	79.4746***	139.4921***	81.362***	76.5198***	93.8526***
Telephone	0.3867***	0.869***	0.3381***	−1.5252***	−4.4057***	−2.2908***	0.3424***	1.1857***	0.7477***
Telephone^2		−0.0095***	−0.0036***		0.0575***	0.0302***		−0.0168***	−0.0091***
LogGDP			3.0153***			−8.9049***			−1.8584***
PD						−0.1099**			
IDV			−0.0471***			0.137***			−0.0652***
MAS			0.0206***						−0.0317**
UAI									
LTO			−0.0265***			0.0807**			
IND			−0.0593***			0.2897***			−0.1031***
EPI			0.0822***			−0.37***			0.2197***
Threshold	n/a	45.73	46.95	n/a	38.31	37.92	n/a	35.29	41.08
R^2	0.5501	0.6488	0.7655	0.4460	0.6308	0.7372	0.1741	0.2968	0.3650
Adjusted R^2	0.5499	0.6485	0.7632	0.4457	0.6305	0.7347	0.1738	0.2962	0.3597
Obs	2512	2512	840	2478	2478	840	2476	2476	840

We also find that unemployment has an indirect impact upon life expectancies (Table 7a). Thus, because increased unemployment generates additional social tension, it has a negative impact upon the wellbeing level of nations [14]. A higher level of the unemployment rates increases the number of attempts of looking for anti-depression solutions [48]. The total alcohol per capita consumption (Alcohol) is expected to have a negative impact upon health outcomes. When Alcohol is added to our main model, our main estimated coefficients remain mostly significant and they keep their previously determined impact. As expected, an increased alcohol consumption reduces *Life expectancy* and *Measles immunisation* (Tables 7a and 7c, with negative sign) and increases *Mortality rate under 5* (Table 7b, with positive sign). Ultimately, the weights of different types of people with various religious beliefs into the total population: Protestant, Catholic, Muslim and Other religion are considered, and Protestant, Catholic and Muslim are added supplementary to our baseline model. We find that an increased weight of Protestants has a detrimental impact upon health outcomes (Table 7a Internet and Mobile and Table 7c for Mobile – a negative sign and Table 7b Mobile as main independent variable) while the weight of Muslims has a positive effects on Life expectancy (Table 7a for Internet and Mobile as main independent variables, a positive sign). The positive effects of Muslim on Life expectancy may be explained by the changes in health-related behaviours. Most Muslims do not use alcohol or tobacco, or eat pork [49]. Religion is found to be positively associated with a healthy diet [50,51]. All these good health behaviours result in improved quality of life, increased immune function, decreased length of hospital stay and duration of fever in septic patients [52] and finally result in increased longevity [53,54].

5. Conclusions

In this paper, we investigate the nature of the relationship between

Table 7a
Robustness checks (3): control for other effects, for Life expectancy as a dependent variable, full range.

LE	Internet					Mobile				
	Parametric regression (5) OLS	Add Urban	Add Unempl	Add Alcohol	Add religions	Parametric regression (10) OLS	Add Urban	Add Unempl	Add Alcohol	Add religions
constant	41.2864***	45.5528***	41.3531***	41.81***	45.4962***	33.8016***	38.3948***	34.4362***	34.0169***	36.5807***
Internet	0.188***	0.1743***	0.1904***	0.2343***	0 .1716***					
Internet^2	−0.0011***	−0.001***	−0.0012***	−0.0016***	−0.0008***					
Mobile						0.1164***	0.1089***	0.1256***	0.1262***	0.1049***
Mobile^2						−0.0005***	−0.0005***	−0.0006***	−0.0006***	−0.0005***
LogGDP	3.5006***	0.0017***	3.513***	3.5722***	3.2946***	3.9299***	2.8991***	3.8358***	4.0981***	3.9419***
PD	−0.0258**	−0.0371***	−0.0229**	−0.0383***	−0.0569***	−0.0264**	−0.038***	−0.0216**	−0.0337***	−0.0538***
IDV	−0.0616***	−0.0618***	−0.0567***	−0.048***	−0.051***	−0.0646***	−0.0634***	−0.0587***	−0.055***	−0.0491***
MAS	0.0224***	0.0263***	0.0216***	0.0131*	−0.0066	0.0186**	0.0225***	0.0187***	0.0136*	−0.0106
UAI										
LTO	−0.0186**	−0.0112	−0.0207***	0.0061	−0.0086					
IND	−0.0618***	−0.0677***	−0.0649***	−0.0589***	−0.0563***	−0.06***	−0.0695***	−0.062***	−0.069***	−0.0573***
EPI	0.0353*	0.0478***	0.0419**	0.0528***	0.0301*	0.0898***	0.1001***	0.0942***	0.1158***	0.0962***
Urban		0.0808***					0.0824***			
Unempl			−0.0735**					−0.1113***		
Alcohol				−0.429***					−0.3748***	
Protestant					−0.0546***					−0.0534***
Catholic					0.0082					0.0047
Muslim					0.0196***					0.0116**
Threshold	85.45	81.6	55.62	73.21	103.8	116.4	108.9	104.67	105.16	104.9
R^2	0.7573	0.7717	0.7589	0.7853	0.7806	0.7502	0.7654	0.7540	0.7747	0.7691
Adjusted R^2	0.7546	0.7688	0.7559	0.7825	0.7772	0.7478	0.7629	0.7514	0.7720	0.7659
Obs	816	816	816	768	794	842	842	842	769	820

Table 7b
Robustness checks (3): control for other effects, for MORTchild as a dependent variable, full range.

MORTchild	Internet					Mobile				
	Parametric regression (5) OLS	Add Urban	Add Unempl	Add Alcohol	Add religions	Parametric regression (10) OLS	Add Urban	Add Unempl	Add Alcohol	Add religions
constant	157.6639***	142.7605***	158.3192***	160.2536***	158.4563***	168.4473***	152.4066***	169.9061***	171.5899***	169.8113***
Internet	−1.266***	−1.1956***	−1.2593***	−1.3826***	−1.2575***					
Internet^2	0.0113***	0.0106***	0.0111***	0.0125***	0.011***					
Mobile						−0.7553***	−0.7152***	−0.7432***	−0.7975***	−0.7241***
Mobile^2						0.0031***	0.0029***	0.003***	0.0033***	0.003***
LogGDP	−12.881***	−8.4648***	−12.8852***	−13.4968***	−12.8312***	−11.9561***	−7.2781***	−12.084***	−12.4927***	−12.0828***
PD										
IDV	0.1718***	0.1477***	0.1793***	0.1171***	0.1623***	0.217***	0.1839***	0.2213***	0.1847***	0.1645***
MAS										
UAI										
LTO										
IND	0.2827***	0.3204***	0.2779***	0.3068***	0.2809***	0.3211***	0.358***	0.3165***	0.3447***	0.3077***
EPI	−0.2067***	−0.2678***	−0.193**	−0.2749***	−0.1905**	−0.3448***	−0.4026***	−0.3405***	−0.4267***	−0.3406***
Urban		−0.3559***					−0.3816***			
Unempl			−0.1605					−0.137		
Alcohol				1.2902***					1.0551***	
Protestant					0.0149					0.1057***
Catholic					−0.0179					−0.0241
Muslim					−0.0305					0.0138
Threshold	56.01	56.39	56.72	55.3	57.16	121.82	123.31	128.14	120.83	120.68
R^2	0.7166	0.7348	0.7171	0.7343	0.7164	0.7035	0.7246	0.7039	0.7181	0.7100
Adjusted R^2	0.7145	0.7325	0.7146	0.7319	0.7132	0.7014	0.7223	0.7014	0.7155	0.7068
Obs	816	816	816	768	794	842	842	842	769	820

Table 7c
Robustness checks (3): control for other effects, for Measles as a dependent variable, full range.

Measles	Internet					Mobile				
	Parametric regression (5) OLS	Add Urban	Add Unempl	Add Alcohol	Add religions	Parametric regression (10) OLS	Add Urban	Add Unempl	Add Alcohol	Add religions
constant	89.362***	93.1219***	89.3568***	91.342***	91.8269 ***	82.3038***	86.2375***	82.6034***	83.3471***	84.8604***
Internet	0.3489***	0.3367***	0.3485***	0.4143***	0.3519***					
Internet^2	−0.0026***	−0.0025***	−0.0026***	−0.0032***	−0.0025***					
Mobile						0.1931***	0.1867***	0.1974***	0.206***	0.1889***
Mobile^2						−0.0007***	−0.0006***	−0.0007***	−0.0007***	−0.0006***
LogGDP	−0.4231	−1.3009**	−0.4235	−0.3594	−0.6697	−0.3076	−1.1904**	−0.352	−0.3684	−0.4408
PD	−0.0297	−0.0386*	−0.0301	−0.041*	−0.0399*	−0.03	−0.04*	−0.0278	−0.03	−0.042*
IDV	−0.0822***	−0.0821***	−0.0829***	−0.0727***	−0.0772***	−0.0816***	−0.0806***	−0.0789***	−0.0724***	−0.0689***
MAS	−0.0377**	−0.0339*	−0.0375**	−0.0485***	−0.0557***	−0.0323**	−0.029*	−0.0323**	−0.04**	−0.05676***
UAI										
LTO										
IND	−0.1148***	−0.1232***	−0.1145***	−0.1267***	−0.1116***	−0.1251***	−0.1333***	−0.1265***	−0.1303***	−0.1218***
EPI	0.163***	0.1728***	0.162***	0.1707***	0.1796***	0.2185***	0.2273***	0.2206***	0.2408***	0.2385***
Urban		0.0694***					0.0705***			
Unempl			0.0109					−0.0525		
Alcohol				−0.3556***					−0.2854***	
Protestant					−0.0323					−0.0465**
Catholic					−0.0039					−0.0063
Muslim					0.0098					−0.0045
Threshold	67.09	67.34	67.01	64.73	70.38	137.93	155.58	141	147.14	157.41
R^2	0.3269	0.3338	0.327	0.3488	0.3395	0.3268	0.3337	0.3273	0.3406	0.3389
Adjusted R^2	0.3203	0.3263	0.3194	0.3411	0.3302	0.3203	0.3265	0.3200	0.3328	0.3299
Obs	816	816	816	768	794	842	842	842	769	820

Source: Authors' processings

ICT and health outcomes, using data from 185 countries over the 2005–2018 time period and controlling for economic prosperity, cultural dimensions and environmental performances. Our empirical approach finds clear evidence for an inverted U-shaped relationship between ICT and health outcomes. Specifically, increasing ICT development brings along improved healthcare outcomes but only up to a certain threshold, beyond which more ICTs provide less health benefits. The parametric approach confers a very good estimation for the impact of ICT upon health, original in itself and, to our knowledge, even within the specialized literature. This relationship is stable for various healthcare outcomes (life expectancy at birth, under 5 mortality rate in children, measles immunisation rate and infant mortality rate), several ICT indicators (the percentage of people using the internet, mobile cellular telephone subscriptions and fixed telephone subscriptions), and diverse control variables (per capita gross domestic product, culture, environmental quality, urban population proportion, unemployment rate, total alcohol per capita consumption and the weights of main religions). The vertexes of the parabola are located around 70% of the population using the Internet and about 2 mobile cellular telephone subscriptions per person, on average. These thresholds are an extremely important contribution our paper adds to the literature because they quantify, for each particular nation, the level from which on ICTs no longer bring along positive effects upon health.

Estimations on the two income related subsamples of states have supported our main results, so the inverted U-shaped relationship between ICT and health status of nations holds for income differences in countries, as well. Still, major findings reside in the fact that the impact of technologies upon health outcomes is generally a couple of times more prominent in low-income countries than in high-income countries. Our main results validate that the impact of Internet upon life expectancies, children mortality rates and measles immunisation rates varies between 1.88 and 3.34 times larger in low-income countries than in high-income nations, while the impact of Mobile upon the same health outcomes is up to 2.24 times stronger in low-income countries than in high-income ones. So, developing countries should more than ever consider ICT as an important leverage in boosting their national health proxies, strongly recommended.

Regarding the influence held by the control variables we find clear evidence about the positive effects of economic development, environmental quality, urbanization and the negative effects of unemployment and alcohol consumption upon the health outcomes of nations. Moreover, the cultural peculiarities of nations bring along interesting influences that differ among the two subsamples of states. Thus we may conclude that although there are common determinant factors of life expectancies, mortalities and immunisation rates, there also are influences that are highly related to the level of economic development of countries.

Originality is related to conducting our analysis on the two subsamples of countries from which we may extract specific findings related to the level of economic development. Then, the parametric approach of the impact held by ICT on health outcomes is new in the literature, being a pioneer in itself. Nonetheless, the robustness checks we perform are complex and they strongly support our main findings.

Regarding policy implications, on top of the many benefits of technology investments and development, one more may be certainly added: the improvements in the field of health outcomes of nations. Because health has been regarded as the greatest wealth from historical times, governments have always been preoccupied by preserving and improving the health state of their people, thus hoping for better health outcomes. The present study thoroughly validates this idea and it is in the interest of international governments to improve the development of ICT in order to get better health benefits for their people. ICT are actually effective in improving health and they are worthy of implementation. For the healthcare domain, ICT development brings along better capacities of medical services, eliminating inefficiencies, which may be of great help especially in the context of the present COVID-19 pandemic. Furthermore, because of the many control variables it uses and the two subsamples of worldwide countries it separately tests, several policy adjustments may be sketched, according to the existing different types of impact. Especially within low-income countries, ICT would boost health outcomes in a more pronounced manner than within high-income countries. Our actual results establish maximum thresholds for the boosting of health outcomes through ICT. Once these thresholds are attained, the continuous development of ICT would bring less health benefits for those nations. Clearly, continuous ICT development in low-income countries may have a multiplier effect upon their life expectancies, mortality rates and immunisation schemes, health outcomes which are generally lower here than in high-income countries. Nonetheless, our control variables imprint certain effects upon health outcomes as well, of major interest when sketching national healthcare recommendations.

This study is useful for regular individuals as well. In a consumerist era where everything becomes possible, digitisation spreads and develops at a high pace. People should establish certain thresholds for ICT usage for themselves and their families as well. One needs to know when too much ICT usage can become harmful and actually bring along less health benefits. Indeed, information is power and people need to stay connected with each other through technologies as well, but only up to a certain limit of internet and mobile usage. The validated thresholds of our main results provide the reader with these health secure limits. Furthermore, the evolution of online medical services and telemedicine has spread a lot within the last years, proving itself of great importance especially under pandemic situations.

One inherent limit is the fact that our data are up to 2018. They do not comprise the effect of the COVID-19 pandemic in anyway; we would include it if we found a way. Another limit of this paper is the fact that its econometric modelling relies mainly on the multiple regression analysis technique. In the future, we intend to surpass this limit by using other data analysis techniques, such as structural equation modelling for multiple relationships of dependent and independent variables.

Authors' contributions

The authors contributed equally to the development of the study. All authors have read and approved the final manuscript.

Sample CRediT author statement

Monica Violeta Achim: Conceptualization, Writing- Reviewing and Editing, Supervision, Visualization, Investigation, Project administration, Funding acquisition.

Viorela Ligia Văidean: Data curation, Writing- Original draft preparation, Methodology, Software, Validation, Funding acquisition.

Availability of data and materials

All the data provided from public database.

Authors' contributions

The authors contributed equally to the development of the study. All authors have read and approved the final manuscript.

Declaration of competing interest

none.

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Appendix 1. Variables – description and source

Variables	Way of expressing and description	Units/scale	Sources
Dependent variable			
Health outcomes	*1. Life expectancy (LE)* reflects the average number of years an infant born in that country is expected to live if prevailing patterns of age-specific mortality rates at the time of birth in the country stay the same throughout the infant's life. Life expectancy is commonly used as an overall indicator of the standard of health in a country.	Years	World Bank (2020)
	2. Mortality rate, under 5 (per 1000 live births) *(MORTchild)* reflects the probability per 1000 that a newborn baby will die before reaching the age of five, if subject to age-specific mortality rates of the specified year.	Number of dead children before reaching the age of 5, out of 1000 live births	
	3. Measles Immunisation of children (Measles) measures the percentage of children ages 12–23 months who received the measles vaccination before 12 months or at any time before the survey. A child is considered adequately immunized against measles after receiving one dose of vaccine	% of children ages 12–23 months	
	*4. Infant mortality rate/*Mortality rate, under 1 (per 1000 live births) *(MORTinfant)* shows the number of infants dying before reaching one year of age, per 1000 live births in a given year.	Number of dead babies before reaching the age of 1, out of 1000 live births	
Independent variable			
Information and Communication Technologies' (ICTs)	*1. Individuals using the Internet (Internet)* counts individuals who have used the Internet (from any location) in the last 3 months. The Internet can be used via a computer, mobile phone, personal digital assistant, games machine, digital TV etc.	% of population	World Bank (2020)
	2. Mobile cellular telephone subscriptions (Mobile) cover subscriptions to a public mobile telephone service that provide access to the PSTN using cellular technology. The indicator includes (and is split into) the number of postpaid subscriptions, and the number of active prepaid accounts (i.e. that have been used during the last three months). The indicator applies to all mobile cellular subscriptions that offer voice communications. It excludes subscriptions via data cards or USB modems, subscriptions to public mobile data services, private trunked mobile radio, telepoint, radio paging and telemetry services.	Number of subscriptions per 100 people	
	3.Fixed telephone subscriptions (Telephone) refer to the sum of active number of analogue fixed telephone lines, voice-over-IP (VoIP) subscriptions, fixed wireless local loop (WLL) subscriptions, ISDN voice-channel equivalents and fixed public payphones.	Number of subscriptions per 100 people	
Control Variables			
Economic development	per capita Gross Domestic Product (*GDP*)	in US dollars	World Bank (2020)
Culture (Hofstede model)	Power distance (*PD*); Individualism versus collectivism (*IDV*); Masculinity versus femininity (*MAS*); Uncertainty avoidance (*UAI*); Long-term orientation (*LTO*); Indulgence and restraint (*IND*).	From 0 points to 100 points for each of dimension	Hofstede Insights (2020)
Environmental performances	The Environmental Performance Index (*EPI*) ranks 180 countries on 32 performance indicators across 11 issue categories covering environmental health and ecosystem vitality.	Score points; a higher EPI score indicates countries that are doing best against the array of environmental pressures	Yale University (2020)
Urbanization	*Urban population (Urban)* refers to people living in urban areas as defined by national statistical offices. The data are collected and smoothed by United Nations Population Division.	% of total population	World Bank (2020)
Unemployment	The *total unemployment rate* (modelled ILO estimate) (*Unempl)* refers to the share of the labor force that is without work but available for and seeking employment.	% of total labor force	World Bank (2020)
Alcohol	*Total alcohol* per capita *consumption (Alcohol)* is defined as the total (sum of recorded and unrecorded alcohol) amount of alcohol consumed per person (15 years of age or older) over a calendar year, in liters of pure alcohol, adjusted for tourist consumption.	liters of pure alcohol, projected estimates, 15+ years of age	World Bank (2020)
Religion	*Religion* measures the weights of different types of people with various religious beliefs into the total population: Protestant, Catholic, Muslim and Other religion. This is a set of variables that identifies the percentage of a country's population in the 1980s that follows Protestant, Catholic, Muslim or Other religions.	% of total population	La Porta et al. (1999, 2008) [55, 56]

Appendix 2. The sample countries classified as 'high-income' and 'low-income'

Developed Countries (*High-income countries*) (54)	High-income (54)	Australia, Brunei New Zealand, Singapore, South Korea, Austria, Czech Republic, Denmark, Ireland, Italy, Israel, Qatar, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, UK, Bahamas, Puerto Rico, Trinidad and Tobago, Uruguay Kuwait, Malta, Saudi Arabia, United Arab Emirates, USA, Hong Kong, Japan, Belgium, Croatia, Cyprus, Estonia, Finland, France, Germany, Greece, Iceland, Luxembourg, Barbados, Chile, Bahrain, Oman, Canada, Macao, Taiwan, Equatorial Guinea
Developing countries (*Low-income countries*) (131)	Upper middle income (50)	Albania, Algeria, Angola, Argentina, Azerbaijan, Belarus, Belize, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, Gabon, Grenada, Hungary, Iran, Iraq, Jamaica,

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(*continued*)

	Jordan, Kazakhstan, Lebanon, Libya, Macedonia, Malaysia Maldives, Mauritius, Mexico, Montenegro, Namibia, Panama, Peru, Romania, Saint Lucia, Saint Vincent and the Grenadines, Serbia, Seychelles, South Africa, Suriname, Thailand, Tonga, Tunisia, Turkey, Turkmenistan, Venezuela.
Lower middle income (47)	Armenia, Bhutan, Bolivia, Cambodia, Cameroon, Cape Verde, Congo Republic, Côte d'Ivoire, Djibouti, Egypt, El Salvador, Georgia, Ghana, Guatemala, Guyana, Honduras, India, Indonesia, Kiribati, Kosovo, Kyrgyzstan, Laos, Lesotho, Mauritania, Moldova, Mongolia, Morocco, Nicaragua, Nigeria, Pakistan, Papua New Guinea, Paraguay, Philippines, Samoa, Sao Tome and Principe, Senegal, Sri Lanka, Sudan, Swaziland, Syria, Timor-Leste, Ukraine, Uzbekistan, Vanuatu, Vietnam, Yemen, Zambia.
Low income (34)	Afghanistan, Bangladesh, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Congo Democratic Republic, Eritrea, Ethiopia, Haiti, Kenya, Korea (North), Gambia, Guinea, Guinea-Bissau, Liberia, Madagascar, Malawi, Mali, Mozambique, Myanmar, Nepal, Niger, Rwanda, Sierra Leone, Somalia, South Sudan, Tajikistan, Tanzania, Togo, Uganda, Zimbabwe.

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