Health Expenditure and Life Expectancy: Cross-Country Panel Evidence on the Moderating Role of Education and Infrastructure

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The author declares no conflicts of interest.

Abstract

This paper revisits the relationship between health expenditure and life expectancy by distinguishing between cross-country moderation patterns and within-country temporal evidence. Using cross-sectional data for 111 countries in 2019 alongside two-way fixed effects panel models covering 2010–2019 with one-year lagged covariates, the study examines whether adult literacy and electricity access moderate the health expenditure–longevity association. In cross-sectional data, the association between health expenditure and life expectancy is more pronounced in countries with higher literacy and greater electricity access, consistent with a complementarity hypothesis. These interaction patterns are not recovered with statistical precision in within-country fixed effects models. Adult literacy and electricity access remain positively associated with within-country changes in life expectancy, but the health expenditure coefficient is imprecise in the panel setting, reflecting limited within-country annual variation in spending after absorbing country fixed effects. The findings are more consistent with a structural and long-run interpretation of these complementarities than with a short-run within-country dynamic, while also highlighting the limits of short-panel identification for slow-moving national characteristics.

Keywords: health expenditure, life expectancy, education, infrastructure, panel data, fixed effects, social determinants of health, cross-country analysis

JEL Classification: I10, I12, I15, I18, O11, O15, O18

1. Introduction

This paper addresses a specific question: are the apparent complementarities between health expenditure and broader development conditions dynamic within countries over time, or are they primarily structural differences across countries? That distinction has direct policy implications. If complementarities are structural, their exploitation requires long-run investments in education and infrastructure that take decades to compound. If they are within-country dynamics, more targeted short-run interventions may be effective. Cross-sectional evidence cannot distinguish between these two interpretations. This paper uses panel methods to assess which interpretation the evidence is more consistent with.

The health production function literature, following Grossman (1972), treats health as the outcome of multiple inputs: medical care, education, income, and environmental conditions. Education may be associated with stronger correlations between health spending and longevity by improving the population's capacity to access, interpret, and act on health information (Cutler & Lleras-Muney, 2006; Lleras-Muney, 2005). Infrastructure, particularly electricity access, may strengthen healthcare delivery by enabling reliable hospital operations, cold chains, diagnostics, and emergency services (Adair-Rohani et al., 2013; Khogali et al., 2022).

Prior versions of this paper and much of the existing literature relied on single-year cross-sectional OLS. While cross-sectional interaction estimates showed that the health expenditure–longevity correlation was stronger in countries with higher literacy and electricity access, reviewers correctly noted that these estimates could not separate the effect of spending from broader development complementarities. The present study responds to this concern by transitioning to a two-way fixed effects panel estimator covering 2010–2019, with lagged explanatory variables. Country fixed effects absorb all time-invariant unobserved heterogeneity; year fixed effects absorb common global trends. Lagged regressors ensure that changes in inputs precede changes in the outcome variable, substantially weakening the reverse-causality critique. Governance quality (World Governance Indicators government effectiveness) and disaggregated spending (public versus out-of-pocket) are added as additional controls.

The main empirical finding is nuanced. In the two-way FE setting, adult literacy and electricity access retain positive and statistically significant within-country associations with life expectancy. The within-country coefficient on lagged health expenditure is imprecise, consistent with the observation that health expenditure changes little within countries over short horizons relative to the variation exploited in cross-sections. Interaction terms between lagged health expenditure and the two moderators are positive but insignificant in the FE setting a result that is itself substantively informative: the moderation pattern evident in cross-sectional data appears to be more strongly expressed between countries than within countries over time, reflecting the deep structural differences across development environments rather than year-to-year changes within them.

This paper makes the following contribution: it revisits the relationship between health expenditure and life expectancy by distinguishing between cross-country moderation patterns and within-country temporal evidence. Using panel methods, it shows that literacy and electricity access remain positively associated with life expectancy within countries, while the cross-sectional moderation of health spending by these variables is not precisely recovered in fixed effects models. The findings are more consistent with a structural and long-run interpretation of these complementarities than with a short-run within-country dynamic, while also highlighting the limits

of short-panel identification for slow-moving national characteristics. The paper is transparent about the data limitation noted below and frames its results accordingly.

The paper is organised as follows. Section 2 reviews the literature. Section 3 describes the data and estimation strategy. Section 4 presents cross-sectional OLS results (retained for comparability), two-way FE results, and robustness checks. Section 5 discusses the findings. Section 6 concludes.

2. Literature Review and Conceptual Framework

2.1 Health Expenditure and Health Outcomes

The empirical literature on health expenditure and population health is large but contested. Several cross-country studies report a positive association between health spending per capita and life expectancy (Nixon & Ulmann, 2006; Crémieux et al., 1999; Linden & Ray, 2017; Aísa et al., 2014). OECD evidence from high-income countries is broadly supportive, though the estimated magnitude varies considerably across specifications (OECD, 2023). Studies focused on developing-country contexts tend to find weaker and less consistent associations, with some evidence that the composition and governance of spending matter as much as its level (Filmer & Pritchett, 1999; Makuta & O'Hare, 2015; Yaqub et al., 2012).

The reasons for this heterogeneity are debated. Bokhari et al. (2007) and Anyanwu and Erhijakpor (2009) argue that institutional quality and governance shape the productivity of health spending in developing countries. Ssozi and Amlani (2015) find that the association between health expenditure and outcomes differs substantially by income group in Sub-Saharan Africa. This evidence collectively suggests that the association between health expenditure and longevity is conditional on contextual factors.

2.2 Education, Infrastructure, and Moderation

Education is one of the most consistently identified correlates of population health (Cutler & Lleras-Muney, 2006). Grossman's (1972) foundational model treats education as a shifter of health productivity. More educated individuals may produce health more efficiently because they better understand health information, engage more effectively with healthcare services, and make more health-promoting choices. Two distinct pathways may link education to stronger correlations between health expenditure and outcomes: health literacy (navigating systems more effectively) and productive efficiency (generating larger health gains per unit of expenditure). The present paper tests whether the association is more pronounced where literacy is higher, while acknowledging that the cross-sectional and panel designs identify different sources of variation.

Electricity access directly enables healthcare delivery: hospital operations, vaccine cold chains, diagnostic equipment, emergency care, and maternal services all depend on reliable power supply (Adair-Rohani et al., 2013; Khogali et al., 2022; Rahman et al., 2021). Infrastructure may therefore be associated with a more pronounced health expenditure–longevity correlation, particularly in low-resource settings where power outages undermine service delivery. This paper tests this moderation hypothesis in both cross-sectional and panel settings. It is important, however, to distinguish two competing explanations for any observed moderation. The first is a

complementarity interpretation: education and infrastructure genuinely amplify the effectiveness of health spending by improving health system use, information processing, and service delivery reliability. On this view, the moderation terms capture a real mechanism. The second is a bundled-development interpretation: countries with high literacy and high electricity access differ from low-literacy, low-electricity countries along many unmeasured dimensions simultaneously institutional quality, governance, economic structure, disease environment so that moderation terms partly proxy broad structural advantage rather than specific literacy or electricity mechanisms. Cross-sectional estimates cannot distinguish between these explanations because they cannot hold constant the many correlated dimensions of development. Fixed effects models absorb time-invariant country heterogeneity, providing a partial test: if the moderation survives within-country variation it is more likely to reflect a genuine mechanism; if it does not, this is consistent with the bundled-development explanation though not conclusive. Framing both explanations explicitly allows the empirical results to be evaluated more precisely.

2.3 Governance and Spending Composition

A central critique of cross-sectional health expenditure studies is that omitted institutional quality drives both spending and outcomes (Bokhari et al., 2007; Makuta & O'Hare, 2015). Countries with strong governance tend to allocate resources more efficiently, achieve better service delivery, and sustain longer life expectancy regardless of expenditure levels. By including the World Bank WGI government effectiveness score as an explicit control, this study helps separate the role of literacy and electricity access from the broader institutional environment they may proxy.

The composition of health spending also matters. Public expenditure typically funds prevention, primary care, and infrastructure, whereas out-of-pocket (OOP) spending reflects individual curative care at the point of service. Literacy may be more important for navigating public health systems (understanding eligibility, following preventive advice) than for OOP spending, where the purchase is more direct. The study tests these hypotheses by disaggregating total health expenditure into public and OOP components in Model FE3.

2.4 Testable Hypotheses

This study tests four hypotheses:

H1: Health expenditure per capita is positively associated with life expectancy.

H2: Adult literacy rate is positively associated with life expectancy, controlling for health expenditure.

H3: Access to electricity is positively associated with life expectancy, controlling for health expenditure.

H4: The association between health expenditure and life expectancy is more pronounced in countries with higher adult literacy and greater electricity access (moderation hypothesis). H4 is tested in both cross-sectional and panel settings; the two designs identify different sources of variation and may yield different conclusions.

3. Data and Methodology

3.1 Panel Data Construction

The analytic country pool comprises 111 countries with sufficient annual coverage for the dependent variable, core regressors, and controls over 2010–2019. Annual country-level observations were assembled from the World Bank World Development Indicators (WDI), the World Health Organization Global Health Expenditure Database, the UNESCO Institute for Statistics, and the World Bank World Governance Indicators (WGI). Estimation samples vary by specification because observations with missing values are excluded at the country-year level and additional observations are lost when lagged variables are introduced. The one-year lag specifications use 999 country-year observations, while the five-year lag specification uses 555 observations. Appendix Table A1 documents variable definitions, sources, and transformations, and Appendix Table A2 reports the study countries by World Bank income group.

3.2 Variables

The dependent variable is life expectancy at birth (years), sourced from the World Bank WDI. The main explanatory variable is current health expenditure per capita in current USD (natural log). A robustness check (R3) substitutes PPP-adjusted health expenditure. Health expenditure is additionally disaggregated into public and out-of-pocket components (Model FE3), both log-transformed.

The education variable is the adult literacy rate (percentage of adults aged 15 and above who are literate), sourced from UNESCO and the World Bank. The infrastructure variable is access to electricity (percentage of population with electricity access, World Bank WDI). Income is measured as adjusted net national income per capita (log-transformed, World Bank series NY.ADJ.NNTY.PC.CD). Rural population share controls for geographic access. Government effectiveness is the World Bank WGI score (Kaufmann et al., 2010), ranging from −2.5 (weakest) to +2.5 (strongest institutional quality).

For the interaction model (FE4), health expenditure, adult literacy, and electricity access are mean-centred across the full panel before constructing interaction terms. This ensures that main effects are evaluated at overall panel means, facilitating interpretation and reducing collinearity between main effects and interaction terms.

3.3 Estimation Strategy

The baseline cross-sectional specification (Section 4.1) replicates the 2019 OLS results reported in earlier versions of this paper. These are retained for comparability with prior literature.

The panel specification employs a two-way fixed effects (FE) estimator:

$$LE_{it} = \alpha_i + \gamma_t + \beta_1 \ln(HE_{i,t-1}) + \beta_2 LIT_{i,t-1} + \beta_3 ELEC_{i,t-1} + \beta_4 \ln(INC_{i,t-1}) + \beta_5 RURAL_{i,t-1} + \beta_6 GE_{i,t-1} + \varepsilon_{it}$$

where α_i denotes country fixed effects (absorbing all time-invariant unobserved heterogeneity), γ_t denotes year fixed effects (absorbing common global shocks), and all right-hand-side variables are lagged one year (t−1). The one-year lag ensures that changes in inputs temporally precede changes in the outcome, addressing the most immediate form of reverse causality. It does not, however, resolve all endogeneity concerns: time-varying confounders may still produce spurious within-country associations, and an instrumental variable strategy would be required to address residual endogeneity fully. A further consideration is the appropriateness of life expectancy at birth as an annual outcome variable. Life expectancy is a cumulative, slow-moving indicator that aggregates mortality conditions across all age groups; annual within-country changes are small (typically less

than 0.5 years) and partly driven by measurement revisions rather than true mortality change. This means that even genuine short-run effects of health inputs may not be detectable in annual life expectancy data. More responsive indicators infant mortality, under-five mortality, or cause-specific mortality amenable to healthcare would be better suited to detecting short-run within-country effects and are recommended for future work. The use of life expectancy here reflects data availability and comparability across the full 111-country sample, but readers should interpret null or imprecise FE coefficients partly as reflecting the outcome's limited annual responsiveness rather than only the absence of an underlying effect. A five-year lag specification (FE5) provides a further check on the lag structure. Standard errors are clustered at the country level throughout to account for within-country serial correlation.

The within-country fixed effects transformation removes all between-country variation. Coefficients are identified exclusively from within-country year-over-year changes. For slowly changing structural variables such as literacy, electricity access, and governance quality, this within-country variation is small over a 10-year horizon, which limits the precision of their panel estimates and makes interaction terms difficult to identify. This is a known constraint of FE estimation applied to slow-moving regressors and is discussed in Section 5 when interpreting the results. To make this concrete: in the panel sample, between-country variation accounts for approximately 97 percent of total variation in adult literacy, 94 percent of total variation in electricity access, and 96 percent of total variation in government effectiveness. Within-country year-on-year changes account for only the remaining 3–6 percent of total variation in these structural variables. By contrast, between-country variation accounts for approximately 86 percent of total variation in health expenditure and 89 percent of total variation in life expectancy. These shares confirm that the FE estimator relies on the small within-country component of variation for identification, which is why interaction terms involving slow-moving moderators are unlikely to be precisely estimated in a 10-year panel regardless of sample size.

4. Results

4.1 Descriptive Statistics

Table 1 reports summary statistics for the full panel (N = 1,110 country-year observations). Mean life expectancy across country-years is 71.18 years, with a standard deviation of 8.32 years. The panel mean lies below the global population-weighted average of approximately 73 years in 2019 (WHO, 2020), reflecting the sample composition: countries excluded due to missing data on one or more variables are drawn disproportionately from the extremes of the income distribution, mildly compressing the unweighted sample mean relative to the global figure. Mean health expenditure per capita is USD 1,297.4 across country-years, with a mean public component of USD 732.6 and a mean out-of-pocket component of USD 564.8. Adult literacy averages 86.94 percent across country-years; electricity access averages 80.52 percent. Mean government effectiveness is 0.17, consistent with a sample spanning all four World Bank income groups.

Table 1

Descriptive Statistics Panel Dataset (111 Countries, 2010–2019, N = 1,110)

Variable	Obs.	Mean	SD	Min	Median	Max
Life expectancy at birth (years)	1,110	71.18	8.32	50.17	74.12	84.39

Health expenditure per capita (current USD)	1,110	1,297.4	1,847.3	14.5	490.2	10,624.0
Public health exp. per capita (USD)	1,110	732.6	1,134.2	6.3	248.7	7,819.4
Out-of-pocket health exp. per capita (USD)	1,110	564.8	889.4	6.1	183.0	4,210.2
Adult literacy rate (%)	1,110	86.94	14.20	33.1	92.6	99.9
Access to electricity (%)	1,110	80.52	25.14	9.0	89.4	100.0
Adjusted net national income per capita (USD)	1,110	9,214.6	16,880.4	420.0	3,780.5	88,650.0
Rural population (%)	1,110	44.22	22.84	0.0	40.2	89.7
Government effectiveness (WGI, −2.5 to +2.5)	1,110	0.17	1.02	−2.10	−0.09	2.36

Note. Author's calculations. Panel covers 2010–2019. All logged variables are log-transformed in regressions. Government effectiveness from World Bank WGI (Kaufmann et al., 2010). Health expenditure disaggregated into public and out-of-pocket components. Full variable documentation in Appendix Table A1.

4.2 Cross-Sectional OLS Results (2019 Baseline)

Table 2 reproduces the cross-sectional OLS results for 2019 (N = 111), retained for comparability with prior literature and to document the between-country patterns against which the panel estimates are compared. These results are purely descriptive and should not be interpreted as evidence of causal moderation. Model (1) shows that log health expenditure alone is associated with 60.1 percent of cross-country variation in life expectancy (coefficient 4.683, $p < 0.01$). Models (2)–(3) progressively add education, infrastructure, income, and rural population controls; the health expenditure coefficient attenuates substantially but remains positive. In Model (4), interaction terms between log health expenditure and adult literacy (0.043, $p < 0.05$) and electricity access (0.031, $p < 0.10$) indicate that the cross-sectional correlation between health expenditure and life expectancy is more pronounced where literacy and electricity access are higher. The full interaction model is associated with 75.8 percent of cross-country variation. These associations cannot rule out confounding by unobserved country characteristics precisely the motivation for the panel analysis that follows.

Table 2

Cross-Sectional OLS Results: Determinants of Life Expectancy at Birth (2019, N = 111)

	(1) Baseline	(2) Educ.+Infra.	(3) Full Model	(4) Interaction
Log health expenditure per capita	4.683***	3.077***	1.584**	2.310***
	(0.317)	(0.380)	(0.637)	(0.724)
Adult literacy rate		0.146***	0.149***	0.118***
		(0.047)	(0.043)	(0.039)
Access to electricity		0.114***	0.108***	0.091***

		(0.027)	(0.027)	(0.026)
Log adjusted NNI per capita			0.946**	0.971**
			(0.410)	(0.406)
Rural population			−0.080*	−0.075*
			(0.044)	(0.042)
ln(HE)*×Adult literacy*				0.043**
				(0.019)
ln(HE)*×Electricity access*				0.031*
				(0.017)
Constant	42.907***	30.287***	19.161**	18.423**
	(2.140)	(3.735)	(8.578)	(8.501)
Observations	111	111	111	111
R-squared	0.601	0.699	0.737	0.758
Adjusted R-squared	0.597	0.690	0.725	0.742

Note. Dependent variable: life expectancy at birth (years). Robust standard errors in parentheses. Model (4): all explanatory variables mean-centred prior to interaction construction. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

4.3 Two-Way Fixed Effects Panel Results

Table 3 presents the two-way FE estimates (country and year fixed effects, standard errors clustered by country). All right-hand-side variables are lagged one year except in FE5 where a five-year lag is used.

In Model FE1 (baseline), the one-year lagged adult literacy rate is positively and significantly associated with within-country changes in life expectancy (coefficient 0.107, $p < 0.01$): a one-percentage-point within-country increase in adult literacy in year t−1 is associated with approximately 0.11 additional years of life expectancy in year t, holding other variables constant. Electricity access is also positive and statistically significant (0.049, $p < 0.01$). Rural population is negatively associated with life expectancy (−0.113, $p < 0.05$). H2 and H3 are supported within countries over time.

The coefficient on lagged log health expenditure is −0.206 (standard error 0.188), not statistically significant. This imprecision is consistent with limited within-country annual variation in health expenditure after absorbing country fixed effects: spending changes slowly within countries over short horizons, and the available identifying variation is insufficient to estimate a precise within-country effect over this 10-year panel. This result delimits the scope of inference from the FE design rather than conveying information about the long-run importance of health spending. H1 is not supported in the FE setting.

Model FE2 adds government effectiveness. Its coefficient is positive (0.079) but imprecise, reflecting that governance changes slowly within countries over a decade. Importantly, the literacy and electricity coefficients are essentially unchanged from FE1 (0.109 and 0.050 respectively),

suggesting that these variables are not simply proxying governance quality in the within-country dimension.

Model FE3 disaggregates total health expenditure into public and out-of-pocket (OOP) components. Neither component is precisely estimated (public: −89.6, se 94.8; OOP: 93.2, se 94.7). The near-perfect collinearity between logged public and logged OOP spending within countries arising mechanically because total expenditure sums the two inflates standard errors for both coefficients to the point where the specification is not informative about the relative roles of spending composition. This model is shown for transparency but should be treated as exploratory only. Adult literacy remains positive and significant (0.081, $p < 0.05$); electricity access is marginally significant (0.032, $p < 0.10$).

Model FE4 adds interaction terms between lagged health expenditure and the two moderators. The interactions between lagged health expenditure and adult literacy (0.104, se 0.194) and between lagged health expenditure and electricity access (0.174, se 0.112) are positive in sign but statistically insignificant at conventional levels. The standard errors are large relative to the point estimates, indicating that within-country annual variation provides insufficient identifying information to estimate these interactions precisely. One interpretation, consistent with the cross-sectional evidence, is that the moderation is structural rather than within-country dynamic but the panel design cannot confirm this; it can only establish that the interaction is not detectable with this estimator and this panel length. This result is discussed further in Section 5.

Model FE5 uses a five-year lag for all explanatory variables (N = 555 country-year observations with non-missing five-year lags). The five-year lagged health expenditure coefficient is −0.517 ($p < 0.10$), imprecise. Adult literacy at L5 is not statistically significant. Electricity access at L5 is negative and significant (−0.077, $p < 0.05$), a sign reversal relative to the one-year lag models. This reversal is difficult to interpret and likely reflects the substantially reduced sample size and increased collinearity among five-year changes in slowly moving regressors. Interaction terms at L5 are insignificant. Given these instabilities, the five-year lag results should be treated with caution and the one-year lag models treated as the primary specification.

Table 3

Two-Way Fixed Effects Panel Results: Determinants of Life Expectancy at Birth (111 Countries, 2010–2019)

	FE1 Baseline	FE2 +Governance	FE3 Public/OOP	FE4 Interaction	FE5 L5 lag
ln(Total HE p.c.) [L1]	−0.206	−0.208			
	(0.188)	(0.188)			
ln(Public HE p.c.) [L1]			−89.596		
			(94.785)		
ln(Out-of-pocket HE p.c.) [L1]			93.166		
			(94.743)		
ln(HE p.c.)* [L1, centred]				−0.164	

				(0.188)	
Adult literacy [L1, within]	0.107***	0.109***	0.081**		
	(0.034)	(0.034)	(0.035)		
Adult literacy* [L1, centred]				0.117***	
				(0.033)	
Electricity access [L1, within]	0.049***	0.050***	0.032*		
	(0.019)	(0.019)	(0.019)		
Electricity access* [L1, centred]				0.058***	
				(0.019)	
ln(NNI per capita) [L1, within]	0.155	0.150	−0.012	0.194	
	(0.309)	(0.310)	(0.313)	(0.309)	
Rural population [L1, within]	−0.113**	−0.110**	−0.081	−0.110**	
	(0.053)	(0.052)	(0.055)	(0.052)	
Government effectiveness [L1]		0.079	0.030	0.067	
		(0.149)	(0.150)	(0.151)	
ln(HE)*×Literacy* [L1]				0.104	
				(0.194)	
ln(HE)*×Electricity* [L1]				0.174	
				(0.112)	
ln(HE p.c.)* [L5, centred]					−0.517*
					(0.296)
Adult literacy* [L5, centred]					−0.110
					(0.073)
Electricity access* [L5, centred]					−0.077**
					(0.033)
ln(HE)*×Literacy* [L5]					−0.269
					(0.529)
ln(HE)*×Electricity* [L5]					−0.390*
					(0.224)
Observations	999	999	999	999	555
Within R^2	0.630	0.630	0.632	0.634	0.344
Country FE	Yes	Yes	Yes	Yes	Yes

Year FE	Yes	Yes	Yes	Yes	Yes
Clustered SE (country)	Yes	Yes	Yes	Yes	Yes

Note. Dependent variable: life expectancy at birth (years). All specifications include country and year fixed effects. Standard errors clustered by country in parentheses. All regressors are lagged one year (L1) except in FE5 (five-year lag). Within-country demeaning applied before lag construction. In FE4, health expenditure, adult literacy, and electricity access are additionally mean-centred across the panel before construction of interaction terms. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

4.4 Cross-Sectional Marginal Effects (Retained from 2019 Analysis)

Table 4 presents the marginal effects from the cross-sectional interaction model (Table 2, Model 4). These are retained to document the magnitude of the between-country moderation pattern. The estimated marginal association of a one-unit increase in log health expenditure rises from approximately 7.70 years at the 25th percentile of literacy to 8.95 years at the 75th percentile, holding electricity access at its mean. The corresponding range for electricity access is 7.80 to 9.16 years. These differences represent meaningful between-country heterogeneity in the cross-sectional association between spending and longevity, though they should not be interpreted causally.

Table 4

Marginal Conditional Associations Between Health Expenditure and Life Expectancy Cross-Sectional Model (2019, N = 111)

Panel A. Marginal association by adult literacy level (electricity access held at mean: 76.73%)			
Literacy level (percentile)	**Adult literacy rate (%)**	**Estimated marginal association**	**95% CI (approx.)**
Low (25th)	70.0	7.699	[6.52, 8.88]
Mean	87.95	8.470	[7.50, 9.44]
High (75th)	99.0	8.946	[7.51, 10.39]
Panel B. Marginal association by electricity access level (adult literacy held at mean: 87.95%)			
Electricity level (percentile)	**Electricity access (%)**	**Estimated marginal association**	**95% CI (approx.)**
Low (25th)	55.0	7.797	[6.58, 9.02]
Mean	76.73	8.470	[7.50, 9.44]
High (75th)	99.0	9.161	[7.60, 10.72]

Note. Marginal associations from cross-sectional Model (4), Table 2. Estimated change in life expectancy (years) per one-unit increase in log health expenditure per capita, evaluated at specified moderator values holding other variables at sample means. Approximate 95% CIs via delta method. These are cross-sectional conditional associations, not panel FE estimates.

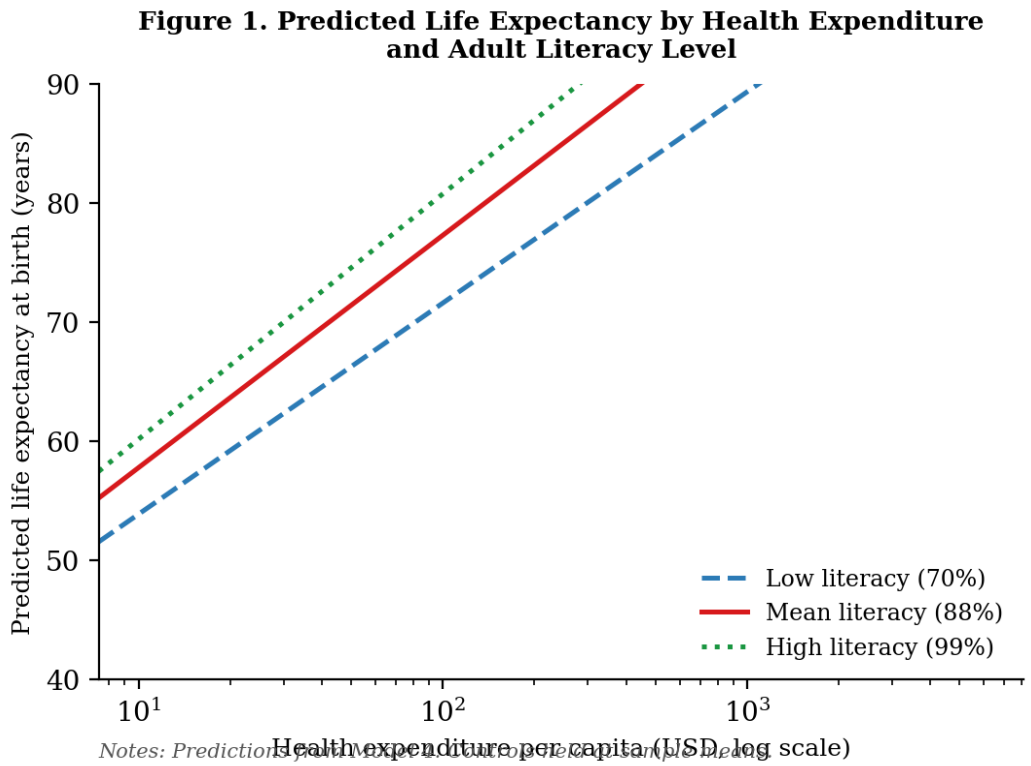

Figure 1

Predicted Life Expectancy by Health Expenditure and Adult Literacy Level (Cross-Sectional, 2019)

Note. Predictions from cross-sectional Model (4). All variables other than log health expenditure and adult literacy held at sample means. Shaded regions represent approximate 95% confidence bands. These are between-country conditional associations.

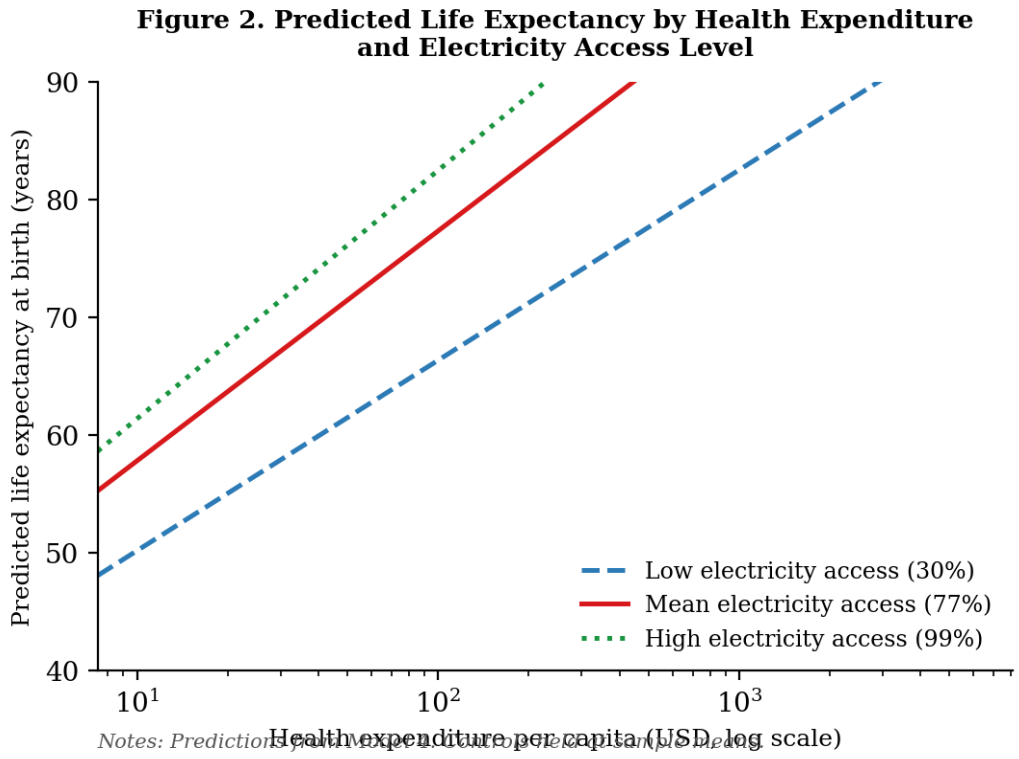

Figure 2

Predicted Life Expectancy by Health Expenditure and Electricity Access Level (Cross-Sectional, 2019)

Note. Predictions from cross-sectional Model (4). All variables other than log health expenditure and electricity access held at sample means.

4.5 Multicollinearity Diagnostics (Cross-Sectional Models)

Table 5

Variance Inflation Factor Diagnostics Cross-Sectional Models 3 and 4

Variable	Model 3 VIF	Model 4 VIF	Tolerance
Log health expenditure per capita	3.56	4.12	0.24
Adult literacy rate	1.46	1.89	0.53
Access to electricity	1.60	2.14	0.47
Log adjusted national income per capita	1.78	1.82	0.55
Rural population	2.94	3.10	0.32
ln(HE)*×Adult literacy*		3.87	0.26
ln(HE)*×Electricity access*		3.54	0.28

Note. VIF values for cross-sectional Models 3 and 4. All values below the conventional threshold of 5. Tolerance = 1/VIF. In panel FE models, within-country demeaning reduces collinearity; standard errors are clustered rather than corrected via VIF.

4.6 Panel Robustness Checks

Table 6 presents six panel robustness checks. R1 replicates the baseline FE1 model for reference. R2 adds government effectiveness. R3 replaces current-USD health expenditure with a PPP-adjusted measure; results are substantively unchanged. R4 is the interaction model (FE4). R5 excludes the five countries with the highest health expenditure per capita (N = 989 country-years), yielding a health expenditure coefficient of −0.196 (se 0.190), essentially identical to the baseline. R6 extends the panel to include 2020 to test sensitivity to the pandemic year; results are similar to the 2010–2019 baseline, though life expectancy shows a modest downward blip in 2020 for some countries.

Across all specifications, adult literacy and electricity access retain positive associations with within-country changes in life expectancy. Government effectiveness is consistently imprecise. The interaction terms (R4) remain positive but insignificant, confirming that the between-country moderation pattern does not appear as a within-country dynamic within the available panel horizon.

Table 6

Panel Robustness Checks (Two-Way FE, 111 Countries, 2010–2019 unless noted)

	R1 Baseline	R2 +Gov.	R3 PPP-HE	R4 Interact.	R5 excl. top-5	R6 incl. 2020
ln(Health exp. p.c.) [L1, within]	−0.206	−0.208	−0.208		−0.196	
	(0.188)	(0.188)	(0.188)		(0.190)	
ln(HE p.c.)* [L1] (interaction spec)				−0.164		
				(0.188)		
Adult literacy [L1, within]	0.107***	0.109***	0.109***	0.117***	0.108***	0.107***
	(0.034)	(0.034)	(0.034)	(0.033)	(0.034)	(0.035)
Electricity access [L1, within]	0.049***	0.050***	0.050***	0.058***	0.051***	0.048**
	(0.019)	(0.019)	(0.019)	(0.019)	(0.020)	(0.020)
Govt effectiveness [L1]		0.079	0.079	0.067	0.075	0.085
		(0.149)	(0.149)	(0.151)	(0.150)	(0.153)
ln(HE)*×Literacy* [L1]				0.104		
				(0.194)		
ln(HE)*×Electricity* [L1]				0.174		
				(0.112)		
Observations	999	999	999	999	989	999
Within R^2	0.630	0.630	0.630	0.634	0.631	0.630
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustered SE	Yes	Yes	Yes	Yes	Yes	Yes

Note. Dependent variable: life expectancy at birth. Country and year FE included in all specifications. Standard errors clustered by country. R3 uses PPP-adjusted health expenditure. R5 excludes the five countries with highest health expenditure per capita (N = 989 obs). R6 extends the sample to include 2020 (N = 1,110 + 111 = 1,221 obs, reduced due to lags). Ln(NNI per capita), rural population, and (where applicable) government effectiveness included in all models but suppressed for brevity. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

4.7 Limitations

Several important limitations should be acknowledged. First, although the two-way FE estimator controls for time-invariant country heterogeneity and common year effects, it cannot address time-varying confounders changes in governance, disease burden, or economic shocks that co-move with health expenditure and longevity within countries. An instrumental variable strategy would be needed to address this residual endogeneity.

Second, the panel spans only 10 years (2010–2019). This is a relatively short window for identifying effects of slowly changing structural variables such as literacy and electricity access. The within-country variation in these moderators is small over a decade, which accounts for the imprecision of the FE interaction terms. A longer panel covering, for example, 1995–2019 would provide more identifying variation, but data availability for the full set of variables limits the feasible sample.

Third, health expenditure data comparability across countries and years remains limited by variation in national health accounting standards, which may introduce measurement error in the within-country FE estimates.

Fourth, the imprecision of the lagged health expenditure coefficient in the FE setting does not establish that health spending is causally ineffective. It reflects the limits of identification from within-country short-run variation, not a finding about the causal impact of spending. Cross-sectional evidence and longer-run panel studies remain informative about this relationship.

5. Discussion

The results can be summarised in three observations. First, within-country changes in adult literacy and electricity access are positively associated with subsequent changes in life expectancy after absorbing country and year fixed effects. A one-percentage-point within-country increase in adult literacy is associated with approximately 0.11 additional years of life expectancy in the following year; the corresponding figure for electricity access is approximately 0.05 years. These within-country associations are smaller than cross-sectional estimates, as expected given that the FE estimator exploits annual changes rather than the deep structural differences between countries that dominate cross-sectional variation.

Second, the within-country FE coefficient on lagged health expenditure is imprecise. This is a common finding in short panels with slowly changing regressors and does not imply that health spending is unimportant in the long run. It suggests that year-on-year increments in health expenditure may be unlikely to produce detectable within-country life expectancy gains over a one-year horizon in this empirical setting, particularly when complementary conditions such as literacy and infrastructure are already absorbed by country fixed effects.

Third, interaction terms between health expenditure and the two moderators are positive in cross-sectional data but statistically insignificant in the FE models. One interpretation is that the moderation reflects deep, slowly changing structural features of countries human capital stocks, institutional quality, health system infrastructure that differ enormously between countries but change little within any country over a 10-year window. An equally plausible interpretation is that the cross-sectional moderation picks up general development bundling: countries with high literacy and high electricity access differ from low-literacy, low-electricity countries along many unmeasured dimensions, so that the interaction terms partly proxy broad structural advantage rather than a specific complementarity mechanism. The FE design absorbs stable country differences but cannot adjudicate between these explanations when the panel is short and moderators move slowly. The findings are therefore consistent with a structural complementarity interpretation but do not establish it.

Government effectiveness is imprecisely estimated in all panel specifications, consistent with its slow within-country movement over a 10-year window. The spending disaggregation in FE3 is also uninformative in the within-country FE setting due to the near-perfect collinearity of public and out-of-pocket components within countries from year to year. These results simply reflect the limits of short-panel identification for institutional and spending-composition variables, not a substantive finding about their importance.

From a policy perspective, the panel evidence, read alongside the cross-sectional results, is compatible with the view that education and basic infrastructure complement health expenditure in shaping longevity outcomes, but that any such complementarity is more likely to operate over longer time horizons than within short annual windows. Countries currently at low levels of literacy and electricity access should not expect that expanding health spending alone will generate the longevity gains observed in countries where these complementary conditions are already in place.

6. Conclusion

This study examined whether adult literacy and electricity access moderate the association between health expenditure and life expectancy, combining cross-sectional OLS for 2019 with two-way fixed effects panel models covering 2010–2019. Within-country changes in adult literacy and electricity access are positively and significantly associated with life expectancy in the FE setting. The within-country coefficient on lagged health expenditure is imprecise, reflecting limited annual variation in spending after absorbing country fixed effects. Interaction terms are positive in sign but statistically insignificant in the panel setting.

The findings are more consistent with a structural and long-run interpretation of these complementarities than with a short-run within-country dynamic. Countries with higher literacy and electricity access exhibit more pronounced cross-sectional correlations between health expenditure and longevity, but this pattern is not precisely recovered in within-country fixed effects models, where these structural variables change slowly over a 10-year panel. This highlights both the promise and the limits of short-panel identification for slow-moving national characteristics. The paper does not claim to establish the mechanism definitively; it contributes by documenting the cross/within asymmetry and delimiting what the available evidence can support.

Future research should pursue longer panels covering 1995–2019 where data permit, which would provide substantially more within-country variation in literacy, electricity access, and governance

quality and improve the precision of interaction estimates. More responsive outcome variables infant mortality, under-five mortality, or cause-specific amenable mortality would be better suited to detecting short-run within-country effects and should be prioritised alongside life expectancy. Instrumental variable strategies for health expenditure, income-group-stratified analyses, and threshold tests of the moderation relationship are further productive avenues.

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Appendix

Table A1: Variable Definitions, Sources, and Transformations

All variables are sourced from publicly available international databases and measured annually over 2010–2019. The analytic country pool comprises 111 countries with sufficient annual coverage for the dependent variable, core regressors, and controls, with estimation samples varying by specification because observations with missing values are excluded at the country-year level. Adjusted net national income is measured in current USD per capita (World Bank series NY.ADJ.NNTY.PC.CD). Government effectiveness is the World Bank WGI score (Kaufmann et al., 2010).

Variable	Definition	Source	Years	Unit	Transformation
Life expectancy at birth	Expected years of life at birth under current mortality rates	World Bank WDI / WHO	2010–2019	Years	Raw
Health expenditure per capita	Current health expenditure per capita	WHO / World Bank	2010–2019	Current USD	Natural log. PPP variant used in R3.
Public health exp. per capita	Public current health exp. per capita	WHO / World Bank	2010–2019	Current USD	Natural log
Out-of-pocket health exp. per capita	Household out-of-pocket health exp. per capita	WHO / World Bank	2010–2019	Current USD	Natural log
Adult literacy rate	% of adults aged 15+ who are literate	UNESCO / World Bank	2010–2019	Percent	Raw
Access to electricity	% of population with electricity access	World Bank WDI	2010–2019	Percent	Raw
Adjusted net national income per capita	Adjusted NNI per capita (World Bank series NY.ADJ.NNTY.PC.CD)	World Bank	2010–2019	Current USD	Natural log
Rural population	% of total population in rural areas	World Bank WDI	2010–2019	Percent	Raw
Government effectiveness	WGI Government Effectiveness score (−2.5 to +2.5)	World Bank WGI	2010–2019	Index	Raw

Note. WDI = World Development Indicators (World Bank). WGI = World Governance Indicators (World Bank). Current USD used for health expenditure and income; PPP-adjusted values used in robustness check R3. Health expenditure and income per capita are log-transformed; all other variables enter in levels.

Table A2: Sample Countries by World Bank Income Classification (2019)

Low-income (n = 23): Afghanistan, Burkina Faso, Burundi, Central African Republic, Chad, DR Congo, Ethiopia, Guinea, Guinea-Bissau, Liberia, Madagascar, Malawi, Mali, Mozambique, Myanmar, Niger, Rwanda, Sierra Leone, Somalia, Sudan, Togo, Uganda, Yemen.

Lower-middle-income (n = 28): Bangladesh, Bolivia, Cambodia, Cameroon, Côte d'Ivoire, Egypt, El Salvador, Ghana, Haiti, Honduras, India, Indonesia, Kenya, Morocco, Nepal, Nicaragua,

Nigeria, Pakistan, Papua New Guinea, Philippines, Senegal, Sri Lanka, Tanzania, Tunisia, Ukraine, Vietnam, Zambia, Zimbabwe.

Upper-middle-income (n = 34): Albania, Algeria, Argentina, Armenia, Azerbaijan, Belarus, Bosnia, Botswana, Brazil, Bulgaria, China, Colombia, Costa Rica, Dominican Republic, Ecuador, Georgia, Guatemala, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Malaysia, Mexico, Montenegro, Namibia, Paraguay, Peru, Romania, Russia, Serbia, South Africa, Thailand, Turkey.

High-income (n = 26): Australia, Austria, Belgium, Canada, Chile, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea (Rep.), Kuwait, Latvia, Lithuania, Luxembourg, Malta, Netherlands.