

Climate Change, Environmental Degradation, And Public Health Spending: Drivers Of Life Expectancy In Central Asian Economies

^{*1}Shahid Akbar, ²Muhammad Iqbal, ³Rukhsana Kausar

^{*1}Assistant Professor, Department of Economics, The University of Lahore, Lahore Pakistan.

²Assistant Professor, Department of Economics, University of Mianwali, Mianwali Pakistan.

³Senior Lecturer, WBS- University of Westminster

shahid.akbar@econ.uol.edu.pk muhammad.iqbal@umw.edu.pk r.kausar@westminster.ac.uk

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Corresponding Author: *
Shahid Akbar

Abstract

The paper explores how long-term climate change, environmental degradation, investing in people health, and several macroeconomic indicators can influence the life expectancy of Central Asian economies between the years 2004-2022. With an unbalanced panel data, where the major source of data is the World Development Indicators, the cross-sectional dependence, slope heterogeneity, and the mixed orders of integration are considered in the analysis. There is utilization of a strong second-generation panel econometric model that consists of the Pesaran CD test, CIPS unit root test, slope heterogeneity test, and the Westerlund cointegration test, and then the Mean Group (MG) and Augmented Mean Group (AMG) estimators. The diagnostic tests confirm the existence of cross sectional dependence, heterogeneous slopes and long run cointegrating relationship of the variables. The experimental results show that the MG estimator does not provide significantly meaningful results, but the AMG estimator can identify stronger and policy-related correlations. To be more exact, the negative influence of environmental degradation (CO2 emissions), annual temperature change, and spending on health of the population is statistically significant, but the positive influence of foreign direct investment has a substantial impact on health outcomes. The impact of economic growth and trade openness, however, do not indicate significant impacts in the long run. All in all, the findings demonstrate the significance of the common shocks and unobserved heterogeneity control, as well as the vital value of the environmental quality, effective health expenditure, and foreign capital to the life expectancy enhancement in Central Asia.

1. Introduction

The longevity of humankind is generally regarded as life expectancy at birth and is a complicated interaction of the socioeconomic development, governmental health measures, living conditions, and the demographic factors. Conventionally, the increase in life expectancy has been credited to the increase in sanitation, access to health and increase in income. Nevertheless, the accelerating rate of climate change and environmental degradation in the 21st century has become a significant movement that defines the health outcomes of the population around the world. As a growing amount of literature will show, climate variability and an increase in temperature have a direct and indirect impact on human mortality and morbidity, and profound implications on life expectancy trends. Particularly, warming patterns, aggravated extreme weather conditions, and the changing disease vectors become more of a threat of the progress achieved in population health over the past decades, and it may be implied that climatic forces need to be included in health and longevity models.

Greenhouse gas emissions, deforestation, air and water pollution are all major causes of environmental degradation, which is a major aspect of this threat. The main cause of anthropogenic climate change is carbon emissions, which is also used as a proxy of the more general air quality degradation. The empirical panel data analysis reveals that increased levels of carbon dioxide (CO₂) emissions have negative links with life expectancy and positive links with infant mortality and other undesired outcomes (Global panel data analysis, 1990-2016) (Majeed, and Ozturk, 2020). Moreover, health-related costs of air pollution are reported to exist at comparatively low levels of emissions, and ambient fine particulate matter (PM_{2.5}) is associated with respiratory, cardiovascular and other chronic conditions that reduce lifespan. The current climate trajectories indicate that millions of deaths will be estimated by the year 2025 due to the poor air quality and heat stress caused by the burning of fossil fuels and environmental degradation (Hartinger et al., 2025).

At the same time, state health expenditure is a major determinant of the ability of people to survive environmental and climatic disasters. There are gains in life expectancy rates, associated with increased government spending on health due to better accessibility to preventive care, emergency preparedness, and treatment of chronic illnesses. The recent empirical studies have proven that health spending in conjunction with other social investments like education and good governance has in fact positive life expectancy outcomes

even under the pressure of the environment (Khan et al., 2024). Nevertheless, that literature also suggests that the performance of spending on health depends on the other environmental factors; in the world with high pollution levels or extreme climatic stresses, the healthcare systems will experience higher rates of burden, which will weaken the longevity benefits unless the mitigation and adaptation programs are developed.

The interplay of climate change, environmental degradation as well as health spending has been discussed in many regional settings however very few studies are done in Central Asia which is a country with a high rate of climatic changes, a high rate of past industrial contamination and also types of community health spending. As an illustration, the Asian and African countries have provided a panel evidence that suggests that CO₂ emissions have a detrimental impact on life expectancy, and long-run models show that the greater emissions are, the shorter life expectancy is (Ali et al., 2025). Equally, other studies of emerging economies have established that public health expenditure can soften certain negative effects of environmental degradation on health outcomes, contingent on the institutional effectiveness and structures of environmental policy (Saudi Arabia evidence) (Omri et al., 2023).

The interaction of environmental stressors and health systems is especially important in the Central Asian region, where an increase in temperatures, water shortages due to glacial melting, and land degradation pose specific challenges to the health of the population. According to the prognosis of the climate of the region, Central Asia can become warmer than the global averages, which increases the risks of heat stress, the spread of infectious diseases, and food and water insecurity. Mining and heavy industry also degrade the environment, which leads to toxic exposures to air and water, making the health outcomes even more complicated. Nevertheless, there are still limited cases of comprehensive empirical inquiries which model climate variation, carbon emissions and health spending together in relation to life expectancy in Central Asian economies.

An emergent methodological literature presents the benefits of panel data and dynamic modeling methods in understanding long-run and short-run dynamics of interrelations among environmental, economic and health variables. Other methods like panel ARDL and error-correction models enable the investigators to separate the enduring structural association between climatic and environmental conditions and temporal variations, which offer vigorous information on the extent to which population health indicators respond to climatic and

environmental conditions as time goes by. Further, as obtained in recent reviews, climate adaptation and mitigation policies should be incorporated in investigations of health inequality, as there are significant, but uneven impacts on population health in countries and demographic groups due to these policies (Hjelmskog et al., 2025).

It is within this context that the current paper aims to contribute to the existing knowledge on the impacts of climate change, environmental degradation, as reflected by carbon emission and the cost of health on the population on the life expectancy in the Central Asian economies. Based on analyzing a balance panel dataset in the five regions of Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan, this paper explores the individual and interactive impacts of these five determinants. Using dynamic panel estimators that are applicable in a small-N, large-T structure, the research is expected to deliver information on the relative size of climatic, environmental, and policy-related factors influencing life expectancy. The results will likely shape the policy discourse of sustainable development, the investment in the population health, and the climate change adaptation strategies in a region that is acutely experiencing both environmental and demographical transitions.

2. Literature Review

Life-expectancy patterns in Central Asia are the result of a complicated combination of environmental degradation (air pollution and land/water degradation), climatic stressors, and governmental investments in the health of the population. The analysis of regional syntheses and global burden studies highlights that air pollution and climate-related extremes are having a significant adverse effect on the life expectancy and disease burden, which suggests that significant benefits would be achieved through mitigation and health-sector adaptation (Abbasi-Kangevari et al., 2023). One of the biggest proximate pathways between environmental degradation and mortality is air pollution. Both global and regional reports indicate that long term exposure to fine particulate matter (PM_{2.5}) and indoor air pollution decreases life expectancy by more than one year in most of the areas; even lowering PM_{2.5} down to theoretical minimum levels would increase average life expectancy significantly. These measurements offer the empirical explanation to the need to consider the air quality as the fundamental determinant of population health in policy considerations in Central Asia, (Yin et al., 2020).

A sharp environmental crisis is experienced in Central Asian countries which increases health hazards. The Aral Sea basin, a paradigm case of environmental catastrophe in the area, is an example of how land-use, salinization of water, desertification, and industrial pollution work together to suppress health outcomes; recent empirical research on the Aral Sea countries results that CO₂ emission and environmental degradation play an adverse role in life expectancy, whereas increased public health expenditure and income positively influence it. This highlights the dual role of environmental stressors (both negative health outcomes) and expenditure by the population (chiefly vulnerability mediation) (Saidmamatov et al., 2024). At the regional-policy level, WHO and allied evaluations emphasize the fact that Central Asian health systems are run on a heritage of Soviet infrastructure, financing transition, and disproportionate public-health capacity; such an institutional setting mediate the effectiveness of health expenditure in delivering returns to life-expectancy and climate-shock and pollution resilience. According to the synthesis of the Europe and Central Asia by World Health Organization, heatwaves, water stress, air pollution and changing vectors are the notable climate-health risks necessitating integrated health-sector responses.

Emerging economics literature supports the existence of positive links between public health spending and health outcomes, such as life expectancy, but the impact of spending is extremely varied depending on the nature of governance, efficiency, and spending composition. Cross-country, panel studies demonstrate uniformly positive relationships between health spending and life expectancy at long-run and results point to diminishing relationships, heterogeneous effects based on income group and significance of institutional quality in translating spending to results. The recent empirical research, applied to the Central Asia case, suggests significant returns to improved public health investments as well as environmental cleanup (Raeesi et al., 2018).

The methodological approach taken in recent research on these relationships is to progressively apply second-generation panel methods (CCE/AMG/CS-ARDL) to address cross-sectional dependence (common global shocks) and slope heterogeneity across countries - needed when one is analysing a small set of interconnected economies (e.g., Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan). Geographical-specific reviews also require mixed integration and cointegration frameworks as a means of estimating short-run and long-run relationships between emissions, health expenditure, and life expectancy (Legro, 2024).

Overall, the literature has arrived at three policy-relevant conclusions: (1) environmental degradation and air pollution have a material negative effect on life expectancy and must be considered central determinants of population health; (2) the overall effect of public health spending is positive, but its impacts are highly contingent on governance, allocation, and compatibility with environmental measures; and (3) Central Asia has a unique environmental crisis (Aral Sea, land degradation, dust storms, glacier melt) that requires a combined policy response (reducing mitigation, restoring the environment and gaining health).

3. Data and Econometric Methodology

This paper uses an unbalanced panel dataset of the Central Asian economies, and this data was collected by the compilation of the World Development Indicators (WDI) database by the World Bank. The data set includes the years 2004-2022, which was chosen to make sure that the data is sufficient and uniform within the countries and reflects the recent events related to environmental quality, climate change, government expenditures on health, and life expectancy. Life expectancy at birth is the dependent variable, and it is an overall measure of the health outcomes of the population. Explanatory variables comprise environmental degradation (CO₂ emission) measures, economic performance (GDP), trade liberalization, foreign direct investment and government spending on health, all directly obtained in WDI to be comparable and reliable. And the Annual temperature change is a variable which is acquired in the site <https://www.fao.org/faostat/en/#data/ET>. Where necessary, standard transformations used, such as logarithmic scaling, are used to minimize heteroscedasticity and permit coefficient interpretation in elastic ways.

In this study, a strong panel econometric model is used to control cross-sectional dependence, heterogeneity and mixed integration features in economies of Central Asia. The Pesaran (2004) cross-sectional dependence (CD) test is used first to identify the dependence of cross sectional units i.e. whether the units are interdependent because of common shocks, spillovers at regional levels or some common unobserved factor. Cross-sectional dependence would nullify first-generation estimators in panel studies hence the application of second-generation estimators. Second, Pesaran (2007) Cross-sectionally Augmented IPS (CIPS) unit root test is used to test the stationarity properties of investigation variables and the explicit dependence of cross-sectional dependence is taken into consideration. The test enables the possibility of heterogeneous autoregressive parameters in countries and is reliable in making

inferences in panels which share common dynamic processes. Third, slope heterogeneity test developed by Pesaran and Yamagata (2008) is applied to determine whether the slope coefficients are similar among panel units. Accepting the non-homogeneity of slopes in the null hypothesis means that the associations of the explanatory factors with life expectancy are not identical in all the countries, and it is reasonable to use heterogeneous estimators. Westernlund cointegration test is also implied to determine long-run relationship between variables.

According to the results of the given preliminary diagnostics, the study applies the Mean Group (MG) estimator developed by Pesaran and Smith (1995), which estimates country-specific regressions, and calculates the average of the coefficients, thus allowing the complete slope heterogeneity. In order to additionally deal with unobserved common dynamic factors and cross-sectional dependence, the Augmented Mean Group (AMG) estimator proposed by Bond and Eberhardt (2009) and Eberhardt and Teal (2010) is also used. The AMG estimator is a refinement of the MG framework that adds a shared dynamic process to the framework and produces smoother and efficient long-run estimates. The basic econometric model is,

$$lLE_{i,t} = \beta_0 + \beta_1 ATC_{i,t} + \beta_2 lHE_{i,t} + \beta_3 lTO_{i,t} + \beta_4 lCO2_{i,t} + \beta_5 GDP_{i,t} + \beta_6 FDI_{i,t} + \epsilon_{i,t}$$

The combination of this econometric approach provides credible inferences, as it directly accounts for cross-sectional dependence, slope heterogeneity, and dynamic interdependence, and thus the results obtained through this method can be used in policy analysis in the Central Asian economies.

A finding evidences of the developing nations concerning several kinds of economic indicators are well-defined in (Sanneh et al. (2026a); Sanneh et al. (2026b); Akbar et al. (2025(a)); Akbar et al. (2025(b)); Akbar et al. (2025(c)); Akbar et al. (2025(d)); Akbar et al. (2025(e)); Akbar et al. (2025(f)); Akbar et al. (2025(g)); Akbar et al. (2025(h)); Raza et al., 2024; Ali et al., 2024; Sana et al., 2024; Akbar et al., 2024(a); Akbar et al., 2024(b); Khan et al., 2023; Raza et al., 2021(a); Raza et al., 2021(b)).

4. Results

This section shows and talks about the empirical findings based on a detailed panel econometric model. The analysis will start with the Pesaran (2004) cross-sectional dependence (CD) test to check the existence of common shocks among cross-sectional units and the Pesaran (2007) CIPS panel unit root test to test the order of integration of the variables in the

cross-sectional dependence. It is then followed by the Pesaran and Yamagata (2008) slope heterogeneity test that is used to determine whether there is a difference in the slope coefficient of panel units. The long-run relationship between variables is determined by using Westernlund cointegration test. According to these preliminary diagnostics, the analysis will be developed using the Mean Group (MG) and Augmented Mean Group (AMG) estimators to estimate heterogeneous long-run relationships, with AMG having explicit control over unobserved common dynamic factors. When used together, the approaches guarantee high-intensity and uniform inference when there is cross-sectional dependence, heterogeneity and mixed integration characteristics.

Table 1: *Descriptive Analysis of Variables*

Variable	Obs	Mean	Std. dev.	Min	Max
ILE	95	4.2409	0.0280	4.1750	4.2994
ICO2	95	1.2364	1.1951	-0.9317	2.7913
IGDP	95	1.8251	0.4886	0.0953	2.6878
IFDI	95	1.3422	0.8515	-1.6246	3.1146
ITO	95	4.3044	0.3884	3.3739	4.9843
IHE	95	1.6070	0.3223	0.9564	2.1850

According to the Pesaran (2004) cross-sectional dependence (CD) test results in Table 2, the results show strong evidence of cross-sectional dependence that exists in a few variables. In particular, the ITO, GDP, ILE and ATC have large and statistically significant CD test value at the 1 percent level, which rejects the null hypothesis of cross-sectional independence. This implies that the variables are affected by similar shocks or unobserved similar factors in cross-sectional units. Conversely, FrDI, IHE, and ICO2 exhibit negligible values of CD which means that these series do not depend on each other cross-sectionally or not significantly. The findings are supportive of the existence of cross-sectional dependence of significant variables hence the application of second generation panel estimators and tests that clearly take into consideration cross-sectional dependence.

Table 2: *Results of Pesaran CD Test*

Variable	CD Test Statistics	P-value
ITO	4.94	0.0000
GDP	5.56	0.0000

FrDI	-0.06	0.9550
IHE	0.56	0.5740
ILE	12.95	0.0000
ICO2	-1	0.3180
ATC	10.2	0.0000

The unit root test of CIPS panel (Pesaran, 2007) is a cross-sectional dependence test which shows that there is a mixed order of integration between the variables in Table 3. The null hypothesis of non-stationarity is rejected in GDP, ILE and ATC with the level of 5 percent that the variables are at the level of stationarity, whereas FrDI is at the level of 10 percent. Conversely, ITO, IHE and ICO2 are not stationary in amounts implying that they are of order one integrated. Notably, none of the variables can be considered as I(2), which proves a mixed I(0)/I(1) structure. Since there is cross-sectional dependence and mixed integration orders, such findings justify the use of second generation panel estimators, including AMG, to analyse.

Table 3: *Results of CIPS Test*

Variable	CIPS Statistic	10% CV	5% CV	1% CV	Decision
ITO	-1.195	-2.21	-2.34	-2.6	Non-stationary
GDP	-3.242	-2.21	-2.34	-2.6	Stationary
FrDI	-2.29	-2.21	-2.34	-2.6	Stationary (10%)
IHE	-1.357	-2.21	-2.34	-2.6	Non-stationary
ILE	-3.798*	-2.21	-2.34	-2.6	Stationary
ICO2	-1.454	-2.21	-2.34	-2.6	Non-stationary
ATC	-3.857	-2.21	-2.34	-2.6	Stationary

The Table 4 findings of the slope heterogeneity test by Pesaran and Yamagata (2008) give overwhelming evidence against the slope homogeneity in the panel. The Delta (4.184) and adjusted Delta (5.499) values are both significant to reject any null hypothesis that the slope coefficients are the same across cross-sectional units because the values are highly significant at the 1% level. This shows that there is slope heterogeneity meaning the effect of the explanatory variables in the panel will vary among units. This means that estimators based on homogeneous slopes like the pooled OLS, fixed effects models or the random effects models, are not suitable. The findings, in fact, substantiate using heterogeneous panel estimators

including Mean Group (MG) and Augmented Mean Group (AMG) where the coefficients can differ in cross-sections and give consistent estimates in heterogeneity.

Table 4: *Results of Slope Heterogeneity*

	Delta	P-value
	4.184	0.0000
adj.	5.499	0.0000

The Westerlund (2007) variance ratio cointegration test gives weak yet strong support to the long-run cointegration of the panel variables, Table 5. The null hypothesis of no cointegration is disapproved at the 10 percent significance level, and the statistic value of the variance ratio is 1.5983 having a p-value of 0.0550. This implies that there is a long-run equilibrium relationship across the panel albeit not found with a strong level of evidence of 5%. Since we have a cross-sectional dependence, and slope heterogeneity in the panel then this result is sufficient to use second-generation cointegration-based estimators, including CS-ARDL, AMG, or CCEMG to get credible long-run and short-run dynamics.

Table 5: *Results of Westerlund Cointegration Test*

	Statistic	p-value
Variance ratio	1.5983	0.055

The results of the estimation of determination of life expectancy in relation to the determinants are reported in the Table 6 in the form of Mean Group (MG) and Augmented Mean Group (AMG) estimates. When the MG estimator is used, the majority of the explanatory variables are statistically significant, which points to weak average long-run effects in the absence of an express control over cross-sectional dependence. The ATC is the only variable with a positive but not statistically significant impact on the life expectancy at the 10 percent level, whereas the impact of CO2 emissions, GDP, FDI, trade openness and health expenditure are negative. This implies that the MG framework, though it accommodates the increase or decrease in the slope, might not be able to target frequent unobserved shocks that affect life expectancy among countries.

As opposed to the previous, the AMG estimator provides more informative and strong results once all unobserved common dynamic effects have been taken into consideration, the common factor is very significant. In the AMG model, ATC and health expenditure (IHE) have

statistically significant negative effects on life expectancy, whereas foreign direct investment (IFDI) has a positive and strongly significant effect on the latter, which is likely to enhance health outcomes due to income, technology transfer, and high living standards. The negative and insignificant impact of CO₂ emissions means that environmental degradation has a negative impact on life expectancy. In the meantime, GDP and trade openness are statistically insignificant, which means that economic growth and openness are not necessarily the causes of improved health in Central Asian economies. All in all, the comparison indicates that AMG does better than MG since it reveals important relationships hidden behind MG estimation. The results indicate that cross-sectional dependence and common shocks should be accounted to examine determinants of life expectancy and implies that environmental quality, the efficiency of health expenditures, and foreign investment are of greater significance in determining health outcomes in the region than aggregate growth or trade openness.

Table 6: *Results of MG and AMG Estimators*

Variable	MG				AMG			
	Coefficient	SE	z	P>z	Coefficient	SE.	z	P>z
ATC	0.0073	0.0040	1.8500	0.0640	-0.0028	0.0012	-2.3200	0.0200
ICO ₂	-0.0415	0.0522	-0.7900	0.4270	-0.0224	0.0124	-1.8100	0.0700
IGDP	0.0017	0.0059	0.3000	0.7660	-0.0015	0.0019	-0.7900	0.4280
IFDI	-0.0068	0.0064	-1.0700	0.2830	0.0028	0.0009	3.2900	0.0010
ITO	-0.0340	0.0296	-1.1500	0.2500	-0.0025	0.0051	-0.5000	0.6190
IHE	-0.0098	0.0163	-0.6000	0.5480	-0.0265	0.0133	-2.0000	0.0450
_OR_c	-	-	-	-	0.9819	0.1393	7.0500	0.0000
_cons	4.5126	0.0962	46.8900	0.0000	4.2922	0.0363	118.40	0.0000

5. Conclusion

This research is a new empirical study on the determinants of the life expectancy in the Central Asian economies, aiming at simultaneously addressing climate change, environmental degradation, the government expenditure on health and macroeconomic factors through a powerful second-generation panel econometric model. The initial diagnostics is a strong indicator of the cross-sectional dependence, heterogeneous slope, mixed integration orders, and long-run cointegrating relationship between the variables, thus, justifying the use of MG

and AMG estimators. The comparative analysis shows that AMG estimator is much better than the MG estimator because it can effectively capture unobserved common dynamic factors and regional spillovers which are especially pertinent in closely related economies like in the case of Central Asia. The results of the AMG show that life expectancy is greatly decreasing due to the growing CO₂ emissions and the growing changes in the annual temperatures, which represent the negative health outcomes of climate change and environmental deterioration. Oppositely, to the common beliefs, on the long-run, public health spending is observed to negatively impact, which means there is inefficiency in health spending allocation, governance complication, or inequity in obtaining healthcare services within the region. Conversely, foreign direct investment has become a major beneficial predictor of life expectancy, and presumably, it works due to the effects of enhanced levels of income, transfer of technology and enhanced infrastructure. In the meantime, the effects of GDP growth and trade openness are not statistically significant, which means that the growth of economies cannot produce any effective health improvements without additional changes in the environment and institutions. Policy-wise, the results indicate that Central Asian economies should incorporate environmental sustainability in health and development policies. The significance of environmental regulations, efficiency and targeting of public health spending, and attracting quality foreign investment may have a significant role to play in the improvement of population health. In future studies, this study can be broadened to include governance indicators, disaggregated health expenditure, or non-linear impacts of climate variables to enhance policy implications of sustainable health results in the region.

5.1. Policy Implications and Directions for Future Research

The empirical evidence suggests that in order to enhance the life expectancy of the Central Asian economies, the policies should be more than the classic economic growth strategies. The serious negative outcomes of climate change and environmental harm point out the necessity of more powerful environmental laws, clean energy investment, and climate-resolute developmental policies as the means of preserving human health. Further, the evidence of the correlation between the life expectancy and the government spending on health is negative, and this indicates that spending on health is inefficient, and as such, the government should focus on its governance, efficiency, and targeting of its health resources instead of simply increasing the amount of budget allocations. The upside of foreign direct investment shows

that with environmental friendly and health conscious FDI, these factors could add value toward improved health performance, whereas the lack of significance of the GDP growth and trade openness shows the sensitivity of the need of inclusive and sustainable development models. Further studies are advised to expand this analysis with institutional quality, governance and indicators of health system efficiency to elucidate cross-country variations in health results. Future research can also focus on non-linear and thresholds in the climate-health interaction, disaggregate health spending on prevention and cure or preventive and curative, and encompass other environmental measures like air and water pollution. Methodologically, the use of alternative second-generation panel methods and short- and long-run dynamics would make the results more robust, whereas comparative studies with other developing regions would also increase the generalizability and policy implications of the results.

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