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Inequality and adult mortality: A vector autoregression–Granger analysis of three European countries

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Abstract

Health outcomes are shaped by the conditions influenced by social, political, and economic forces. This study analyzes the effect of the human development index (HDI), gender inequality index (GII), and the proportion of youth neither in education, employment, nor training (NEET) on adult mortality rates using data from the United Nations, the World Bank, and Our World in Data. This study explores data from 2004 to 2022, employing the vector autoregressive model and Granger causality test, focusing on Bosnia and Herzegovina, North Macedonia, and Moldova. Granger causality analysis reveals one-way directional causality between HDI and adult mortality rate in North Macedonia and Moldova and between NEET and adult mortality in North Macedonia. In addition, a causal relationship was found between adult mortality and GII in Bosnia and Herzegovina and North Macedonia, suggesting that gender inequality is a significant determinant of mortality rates over time. These findings underscore that persistent gender differences remain a key challenge for sustainable development in these countries. The causal relationship between HDI and adult mortality in North Macedonia and Moldova reveals that the influence of historical and socioeconomic conditions, such as the overall standard of living and well-being, has a substantial effect on adult mortality rates in these two countries. These findings highlight the need for targeted policies to reduce social inequalities and mitigate their health consequences. The insights gained from this research contribute to a better understanding of structural determinants of mortality and support evidence-based approaches to sustainable development in these European countries.

Keywords: Adult mortality; Inequality; Human development index; Gender inequality index; Granger causality analysis; Moldova Republic; Bosnia and Herzegovina; North Macedonia

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1. Introduction

Long-term trends in economic inequality have recently attracted significant attention from scholars and academia, increasing the perception of inequality as a potential societal problem and elevating it to a primary issue in policy debates (Alfani, 2024; Guvenen *et al.*, 2022; Guzi & Kahanec, 2018; Jachimowicz *et al.*, 2023; Savoia, 2024). Inequality refers to the unequal distribution of resources and opportunities among different groups in

society and can manifest in income, opportunities, health, gender, and other areas of life (Dizon, 2023). Income inequality is the most common and widespread measure of inequality, largely because income data are freely available and often considered a reflection of economic growth (Dizon, 2023; Roberts, 2023). Household structure describes the composition of household members in terms of number, age, and common relations (e.g., parents). This is particularly important in income inequality research studies, as equalized income is computed based on the number of household members and their ages (Muszynska & Wedrowska, 2020). Economic inequality is the basis of all forms of social inequality, while social determinants of health are crucial drivers of health outcomes (Flavel *et al.*, 2022; Roberts, 2023). On the other hand, social inequality can take many forms and is present in all aspects of social needs such as income and wealth inequality; gender inequality within households; inequalities based on age and ethnicity; disparities related to disability, health, and medical care; and inequality in housing, education, and life expectancy (Kiniorska, 2021; Roberts, 2023). From a political aspect, a country with greater income inequality tends to experience instability that threatens to harm social order and integration (EI Feky *et al.*, 2023). Societies characterized by greater equality tend to be healthier, with stronger social cohesion, better social relations, and lower stress levels. Conversely, people living in unequal societies usually have poorer health outcomes. Income poverty, combined with inequality, increases the risk of premature mortality and higher morbidity rates (Xiang *et al.*, 2022). The rise of inequality is not inevitable, nor does it stem solely from an inefficient market-based economic system; rather, it results from a set of rules shaped by those with political power. Nonetheless, governments and policymakers bear responsibility, as they can influence the administration of outcomes and inequality through public policy (Polacko, 2021).

The objective of this research is to address the key question: how do different inequality indicators, such as the human development index (HDI), gender inequality index (GII), and the proportion of youth neither in education, employment, or training (NEET), affect adult mortality (ages 15 – 50) in three European countries (North Macedonia, Bosnia and Herzegovina, and Moldova) over the period 2004 – 2022? The central hypothesis posits that there is Granger causality between the lagged values of these inequality indicators (HDI, GII, and NEET) and the adult mortality rate, which serves as the dependent variable in a time series data model for the three countries.

The concept of the adult mortality rate was developed in Europe to assess the economic value of individuals during their productive years (Ranabhat *et al.*, 2018). Adult mortality threatens family income sources, significantly affects child development, restricts support for the elderly, and disrupts household economic activities. Thus, compared to total mortality, adult mortality is of greater importance in terms of national economy, sustainable development, and family welfare (Ranabhat *et al.*, 2018). Consequently, countries must strive to improve population health, described as the health outcomes of individuals in a society (Sart *et al.*, 2024), in light of their economic roles.

The motivations for this research study are also grounded in theory, as people's well-being is influenced by their specific social, economic, and institutional circumstances; therefore, a more focused examination may yield valuable insights into inequality. Furthermore, with the integration process that led the Balkans and part of the Eastern Bloc countries into the European Union, regional aspects have obtained further importance, revealing diverse patterns of regional inequality. The transitional position of these three countries on the European mortality map is particularly noteworthy. Bosnia and Herzegovina, North Macedonia, and Moldova lie at the crossroads of various cultural and economic systems, which shape lifestyles, health, and life expectancy, expressed in differing mortality levels. These three countries also present intriguing contexts due to significant changes in their labor market over the last three decades. For example, after experiencing soaring unemployment rates throughout the 1990s and early 2000s, the Macedonian labor market experienced a striking turnaround starting around 2008, with unemployment rates falling steadily from over 35% to less than 14% in 2023. With the significant decline in unemployment in all three countries, policymakers and the public increasingly focused on inequality. In subsequent years, pressures for higher wages became evident, exemplified by more assertive collective bargaining negotiations. In addition, in 2015, all three countries introduced a national minimum wage for the first time.

Therefore, this research aims to investigate the multiple relations between adult mortality and various indicators as narrow proxy measures of inequality. This study assesses the impact of different social determinants, human development, universal health coverage, education, gender inequality, and related factors on adult mortality within the context of Bosnia and Herzegovina, North Macedonia, and Moldova. The key contribution of this paper is to provide causal evidence of the well-known inequality indicators on adult mortality in a European setting. The remainder of the paper is structured as follows. As part of the introduction, Section 1.1 reviews the relevant literature and presents the conceptual research framework. Section 2 describes the data, methods, and measures of inequality used in this study. Section 3 presents the main findings on the

strength of associations between the inequality measures and adult mortality by country. Section 4 discusses the key findings and their implications, while Section 5 provides a conclusion of the study.

1.1. Background

In the past, economists highlighted the structural causes of rising inequality, with globalization and technological change at the forefront (Guvenen *et al.*, 2022; International Monetary Fund, 2017; Naoaj, 2024; Polacko, 2021; Rabhi & Parsons, 2024; Rodrik, 2024; Šoltés *et al.*, 2023; Vella & Camilleri, 2021). However, in recent decades, this view has shifted to highlight institutional political factors associated with the adoption of neoliberal reforms such as privatization, deregulation, and tax and welfare cuts in the early 1980s (International Monetary Fund, 2017; Kahanec *et al.*, 2014; Morris, 2023; Polacko, 2021). These reforms were first adopted and most strongly advocated by the United Kingdom and the United States, and later spread globally, presenting key mechanisms of rising inequality. Globalization and the transformation of global capitalism from industrialization to an economy of knowledge and innovation produced gainers and losers not only at the individual level but also at the regional level (Vasilopoulou & Talving, 2023). Especially in Europe, regions faced different socioeconomic conditions and a different economic context that varied significantly over time in terms of Gross Domestic Product, employment, and productivity (Guzi & Kahanec, 2018; Vasilopoulou & Talving, 2023). Some regions have concentrated high-wage, high-skill employment, enjoyed better public services, and offered stronger prospects for intergenerational mobility, enabling them to prosper and adapt to the knowledge economy. On the other side, other European regions have borne the brunt of globalization's negative effects, including deindustrialization and demographic challenges. These regions have experienced prolonged pressures from declining manufacturing employment, greater exposure to international economic fluctuations, and vulnerability to trade shocks. Consequently, these regions have been marginalized from knowledge and innovation economies, resulting in lower wages, skills, and educational attainment (Vasilopoulou & Talving, 2023).

During economic development, income inequality typically rises but then declines or improves at more advanced stages (Roberts, 2023; Shen & Zhao, 2022; Šoltés *et al.*, 2023). However, more recent authors foresee that inequality will continue to increase due to the growing division of wealth, labor, and power (Hartmann & Pineiro, 2022; Šoltés *et al.*, 2023). Thomas Piketty's (2014) hypothesis claims that, contrary to traditional expectations, inequality will persistently rise in modern economies unless governments intervene. He advocates for measures such as an annual wealth tax on the top 1%, progressive taxation, closing tax evasion and avoidance loopholes, shutting down "tax havens," and introducing a global minimum tax on corporate profits. Piketty's theory of unfettered capitalism suggests that without intervention, the rate of return on capital remains stable, causing the capital income share of top earners to grow to levels that threaten to consume society's total output. The wealthy are a central source of both economic growth and inequality and have substantial political and economic power; thus, understanding not only who the poor are but also who the rich are is crucial for effective public policy design (D'Attoma & Matteucc, 2024).

Inequality is often viewed as a result of economic growth, with many studies in recent decades arguing for a positive relationship between the two concepts, while others suggest a negative relationship or emphasize a mixed outcome (Mădălina, 2024; Shen & Zhao, 2022; Sutanto *et al.*, 2024). To sustain economic growth, an important indicator of an increase in living standards and welfare conditions in a country (Altiner & Toktas, 2017), there needs to be a demand for new physical capital, which in turn requires an efficient deployment of human resources (Sutomo *et al.*, 2022). Human capital is a crucial resource for a country's growth (D'Attoma & Matteucc, 2024). Classical economists, who believed in a market-driven system that constantly seeks balance or equilibrium, argue that all resources, including labor, should be fully utilized (Altiner & Toktas, 2017; Sutomo *et al.*, 2022). As a result, unemployment should not exist in such a system because jobs are available, and unemployed individuals would accept lower wages rather than remain jobless. According to Sutomo *et al.* (2022), minimum wages, employment, and educational attainment are a key to eradicating inequality. Gains in population and education are associated with increases in human capital, minimum wages, and total employment. Furthermore, as gaps in education and health remain significant in many countries, closing these gaps through better allocation of public spending would effectively address inequality by boosting human capital and productivity (International Monetary Fund, 2017). Human capital theory posits that education increases income levels (Vella & Camilleri, 2021). Thus, in theory, educational expansion reduces income inequality and enhances intergenerational mobility. However, empirical evidence shows that educational expansion increases income disparities, primarily due to the returns on higher education rather than compulsory education. Furthermore, some studies (Mădălina, 2024) suggest that over short periods, the impact of inequality may vary depending on different socioeconomic aspects, such as those captured

by the HDI. While inequality may positively influence economic growth in developing countries, it can harm the educational dimension.

Societies with high levels of inequality tend to have less educated populations and higher fertility rates, and inequality appears to hinder growth mainly through its effects on education, life expectancy, and fertility rates (Shen & Zhao, 2022). Understanding how income inequality affects health has expanded across economics, public health, and social sciences. In general, these works suggest that inequality negatively affects health; however, empirical evidence distinguishes between views that inequality harms the health of all individuals and those that imply that health depends on income but not necessarily for everyone (Ferreira *et al.*, 2022). Notably, greater income equality is associated with better health outcomes in developed economies (Wu, 2022). Ferreira *et al.* (2022) argue from a comprehensive literature review that there is no strong evidence showing income inequality alone as a determinant of population health, although it influences health indirectly through poverty. Health outcomes are shaped by the conditions in which people are born, grow up, live, work, and age – conditions influenced by social, political, and economic forces (Barboza-Solis *et al.*, 2024). Studies from Western European and the United States consistently find that exposure to recessions in early life has significant negative consequences on adult mortality (Heo *et al.*, 2024). Demographic and life course epidemiology research also indicates the importance of early life experiences in understanding health outcomes at both individual and population levels (Hao *et al.*, 2024). For example, Shamsfakhr (2025) found that mortality in Germany is countercyclical; health deteriorates during recessions and improves during economic expansions. In addition, the structure of mortality also varies over business cycles, with the non-working population more exposed to death during recessions, and evidence of increased worker mortality during recent financial and economic crises (Shamsfakhr, 2025). Over the past three decades, Europe has exhibited less mortality inequality across most age groups than the United States (Bonnet *et al.*, 2023). Other high-income countries, such as Canada or France, have experienced even more favorable trends, with mortality inequality remaining lower and more stable from 1990 to 2018 (Bonnet *et al.*, 2023). These differences across age groups and countries raise questions about the capacity of health and social protection systems to avert economic inequalities from translating into health inequalities. Despite its importance, research on adult mortality rates and their relationship with inequality indicators remains limited. Global, regional, and national adult mortality statistics indicate that communicable diseases and major non-communicable diseases, such as heart conditions, injuries, cancer, and weakened childhood immunity, strongly impact adult mortality (Ranabhat *et al.*, 2018). Furthermore, sociobehavioral and biological factors, education, social conflicts, economic inequalities, health financing policies, healthcare costs, quality of life, hygiene and sanitation, alcohol and tobacco use, and childhood vaccination all significantly determine adult mortality risk (Ranabhat *et al.*, 2018).

2. Methodology

2.1. Data sources

The data of this study were primarily gathered from reputable international databases, including the World Bank (World Bank, 2024a), the United Nations World Population Prospects (United Nations, 2022), and the Our World in Data (2024) platform. The analysis focused on inequality differences in adult mortality (ages 15 – 49) across three European countries, Bosnia and Herzegovina, North Macedonia, and Moldova, using annual time series data between 2004 and 2022. These three European countries were chosen to widen the European Union perspective and provide an up-to-date assessment of inequality in adult mortality. Adult mortality data were sourced from the United Nations database. Two well-known indices (HDI and GII) and one indicator (NEET) were used to capture different dimensions of inequality. Data for HDI, GII, and NEET were retrieved from the World Bank, the United Nations, and Our World in Data databases. The data for adult mortality were obtained from the United Nations World Population Prospects, which is recognized as the most detailed, comprehensive, and well-organized set of world population data. Other international organizations rely heavily on the United Nations' historical data series for their calculations, underscoring its reliability (United Nations, 2022). In addition, data for NEETs, GII, and HDI were obtained from the World Bank development indicators dataset and partly from the Our World in Data platform. These datasets are based on the International Labor Organization's Labor Force Statistics database. It is important to note that the NEET data for Bosnia and Herzegovina and North Macedonia have temporal gaps; the series for these countries begins from 2006 to 2022 rather than from 2004. Despite this, no biases or any other quality issues were identified in the dataset used.

2.2. Framework of inequality measures

The outcome variable in this study is the adult mortality rate in a given year, which serves as the main variable of interest. The adult mortality rate represents the probability that individuals who have reached age 15 will die before reaching age 60, expressed per 1,000 population. This

measure is based on a hypothetical cohort of 100,000 individuals exposed to the age-specific mortality rate of the given year (World Bank, 2024b; WHO, 2024). For example, an adult mortality rate of 150 means that out of 1,000 individuals who have reached age 15, 150 are anticipated to die before reaching age 60, while 850 are likely to survive to age 60. The burden of non-communicable diseases among adults who are in the most economically productive age is increasing drastically in developing countries due to epidemiological and aging transitions (WHO, 2024). Consequently, the rate of adult mortality has become a key indicator for assessing the overall mortality pattern in a population.

Our key independent variable represents human development, measured by HDI. To reflect the overall socioeconomic aspects of the countries studied, HDI was selected as a comprehensive indicator illustrating multiple dimensions of human development, including life expectancy, education, health, and social inequality (Mădălina, 2024). Recent research has found HDI to be more useful in ranking countries than income measures alone (Chang *et al.*, 2023). HDI depends on the capability approach and measures multidimensional poverty in regard to health, income, and education (Sedefoğlu, 2023). Therefore, HDI is constructed through a three-dimensional perspective: knowledge, acceptable living standards, and longevity and healthy living (Berwal, 2024; Chang *et al.*, 2023; Kızılkaya *et al.*, 2015; Muarti *et al.*, 2023; Sasmita *et al.*, 2024; Suganda *et al.*, 2024; Yaruingam & Gupta, 2023). In the longevity and healthy living dimension, life expectancy at birth serves as the point of reference, while the knowledge dimension uses indicators such as expected years of schooling and average years of schooling (Muarti *et al.*, 2023). Acceptable living standards are measured by annual per capita expenditure. HDI provides a broad assessment of the overall standard of living and well-being of a nation. Thus, HDI provides an overview of social and economic development by covering key socioeconomic factors that have a substantial impact on a country's human development trajectories (Ogujiuba *et al.*, 2024).

Another independent variable that can have a major impact on the level of adult mortality is the GII. Despite the recent progress made in recognizing gender equity and women's empowerment as central goals for sustainable development, gender differences remain persistent and continue to be a key challenge for both developed and developing countries (Perrin *et al.*, 2023). GII is an important instrument for measuring gender inequality globally. Developed by the United Nations Development Program in 2010 (Ansar, 2023), the GII was designed to measure and track progress toward gender equality. GII is a combined index that measures gender inequalities in three dimensions: reproductive health, empowerment, and labor market participation (Ansar, 2023; Yaruingam & Gupta, 2023). Taking these three dimensions into account, the GII provides a comprehensive view of gender inequality.

Another important variable in our model is NEET. Unemployment is a serious issue in global economic progress. Recently, this challenge has affected both developed and emerging economies, even though unemployment rates have declined significantly in wealthier nations (Rehman *et al.*, 2022). In emerging economies, unemployment is rising rapidly, resulting in lower family incomes and poorer living standards, contributing to an increase in the incidence and severity of poverty. Global changes in the labor market, changes in regimes and policies of countries from the collapse of socialist policies, and the crisis of welfare states and neoliberal regimes, have had a profound impact on the lives of young people. Disruptions in the labor market led to new forms of inequality in addition to existing challenges (Vuksanović *et al.*, 2018). These global changes have increased unemployment and made it more difficult for young generations to enter the labor market. High youth unemployment rates are often attributed to a lack of work experience, weaker job search skills, structural challenges such as inadequate education and training, and restrictive labor market regulation. Unemployed individuals and their household members are deprived of earnings and opportunities to expand human capital. Thus, reducing income inequalities through sustainable development that secures social inclusion remains a top priority for macroeconomic policy, not only in the European Union but also throughout the world (SzulcObłoza & Szczepaniak, 2024).

Among its 20 principles, the European Pillar of Social Rights includes important guidelines for the social inclusion of NEET, such as investing in education and skills to create new opportunities for all and providing active support for employment (Skučienė & Brazienė, 2024). The official document places particular emphasis on young people, who are more vulnerable to the instabilities in the labor market. NEET youth often struggle to navigate school-to-work transitions and encounter difficulties in securing jobs (Quinlan-Davidson *et al.*, 2024). These youth are detached from school, have limited work experience, and face a loss of social, economic, and human capital. NEET status is commonly associated with lower educational attainment, lower socioeconomic status, parental unemployment, low self-confidence, insecure housing, and early parenthood (Quinlan-Davidson *et al.*, 2024). Therefore, the youth need additional help as they have fewer opportunities to enter the labor market for the first time. Accordingly, the reinforced youth guarantee aims to promote stable labor market integration by focusing on quality employment,

training, and internships, facilitating young people's access to the labor market (Skučienė & Brazienė, 2024). The Gini coefficient is a summary indicator that considers the degree of distribution of income inequality within the population. However, the NEET rate is considered a more comprehensive measure, offering insights into the vulnerabilities of young people in terms of labor market participation and social inclusion. This includes factors such as gender discrimination, low wages, precarious jobs, vulnerability to the effects of the financial crisis, persistence of unemployment, ineffective school-to-work transitions, and poor on-the-job training (Maynou *et al.*, 2022). Therefore, NEET can help policymakers implement measures to address the social and economic consequences and predict the risk of social and labor exclusion among young people. The widespread use of the term "NEET" is linked to its presumed potential to address a wide range of vulnerabilities among young people, including unemployment, early school leaving, and discouragement in the labor market. There is a strong link between poverty rates and NEET status. NEET youth are often found in a disadvantaged environment, face a higher risk of poverty, and have lower skill levels. Conversely, poverty can create a cycle where individuals are less likely to succeed in education or the workforce, leading to NEET status. The wide dissemination of NEET represents an alarming social problem, contributing to long-term unemployment and social exclusion among the youth. These populations, in general, live in high-risk and vulnerable situations, and many of them face social inequality. Consequently, this situation has a significant negative impact on the balance of economic growth and prosperity (Harun *et al.*, 2020).

2.3. Methods and analysis

The econometric analysis employs vector autoregression (VAR) separately for each of the three countries, using 15 yearly observations per country after adjustments. This procedure analyzes the relationship between adult mortality rate and different measures of macro-level shock indicators (HDI, GII, and NEET). This approach is valuable as it accounts for the intensity of adult mortality across different years in these three countries. The latest version of VAR models (IHS Global Inc., 2024) introduces extensive enhancements to impulse response analysis, including impulse response through local projection (LP) and extensions of confidence intervals with analytic asymptotic standard errors. Thus, when considering a system of K time series of length T, modeled as a VAR process of order p, the data-generating process can be presented as in Equation I.

$$y_t = \nu + A_1 y_{t-1} + \cdots + A_p y_{t-p} + \epsilon_t \quad (1)$$

where y_t and ν denote $K \times 1$ vectors, $A_1, \ldots A_p$ are $K \times K$ matrices, and $\epsilon_t \sim (0, \Sigma_\epsilon)$, where Σ_ϵ denotes $K \times K$ covariance matrix. The conventional VAR approach to impulse response estimation has both empirical and theoretical limitations, especially since the decomposition could be difficult to attain or even impossible when VAR is co-integrated. Furthermore, impulse response functions obtained from this method are valid only if the estimated VAR model accurately reflects the true data-generating process. Another suggested approach is the estimation of impulse responses through LPs (Jordà, 2005; Jordà, 2009). The LP technique doubts the true process of data generation, and remains justifiable even when the decomposition is unspecified. Therefore, LP describes the response function to a shock in the i-th variable as the distinction between two predictions (Equation II).

$$\Phi_h^{LP} = E\left(y_{t+h-1} \middle| X_t, (\epsilon_t = 1)\right) - E\left(y_{t+h-1} \middle| X_t, (\epsilon_t = 0)\right)$$

for $h = 1,2,\ldots, H$, where the operator E(.|.) signifies the best mean-squared error forecaster and $X_t = (1, y_{t-1}, y_{t-2}, \ldots, y_{t-p})'$ is the matrix of its lags. Therefore, Jordà (2005) displays that Equation I can be estimated as a projection of $yt+\sigma-1$ upon the linear place generated by $(y_{t-1}, y_{t-2}, \ldots, y_{t-p})'$. In addition, instead of estimating the impulse response path sequentially, the response at all horizon steps can be estimated, i.e., $h = 1,\ldots, H$, simultaneously. Determining the proper lag length in a VAR model is a key point for accurate results. In the VAR models, this is usually done using criterion-based techniques such as the Akaike Information Criterion, Bayesian Information Criterion, or the Hannan–Quinn Criterion. Thus, these criteria help point out the lag length that minimizes the prediction error while avoiding overfitting.

3. Results

The aim of the VAR analysis is not primarily to estimate the parameters but to disclose the interaction between variables and to make predictions for the included variables (Cigdem *et al.*, 2023). To validate the results acquired in the estimated VAR model, certain assumptions must be verified. These include ensuring that the residuals satisfy the normality assumption, confirming the absence of autocorrelation at the lag order used in the VAR model, and checking the roots of the inverse characteristic equation. In addition, the dynamic features of the VAR model are used in structural analyses such as impulse response functions, variance decomposition, and Granger causality (Cigdem *et al.*, 2023). The test for these assumptions and the results are provided in the Appendix.

Looking at the residual values (Figures A1-A3), it is apparent that there are no normality issues in the models.

The VAR residual portmanteau tests for autocorrelations (Table A1) show that the null hypothesis of no residual autocorrelations up to lag h is accepted at the 0.01% significance level, indicating no autocorrelation problems. In addition, as shown in Figure A4, all absolute values are below 1, indicating that the stability condition of the model is satisfied. Furthermore, all time series used in the study are at I(0) level and are stationary after differencing, as confirmed by unit root tests conducted to verify stationarity. The estimation results of the VAR model (Table 1) show the linear function of adult mortality and its lagged values, along with the lagged values of other variables – GII, HDI, and NEET – on the adult mortality rate in Bosnia and Herzegovina, North Macedonia, and Moldova.

Table 1 reveals a dynamic relationship between the first lag of GII (−1) and the adult mortality rate in Bosnia and Herzegovina and North Macedonia. Specifically, the current adult mortality rate in Bosnia and Herzegovina is negatively influenced by past values of the GII, whereas in North Macedonia, it is positively influenced by previous GII trends. An increase in the GII variable corresponds to an increase in the adult mortality rate in North Macedonia. A negative coefficient suggests that as the GII variable increases, the adult mortality rate variable tends to decrease. The dynamic relationship was also found to be positive between the first lag of HDI (−1) and adult mortality rate in Bosnia and Herzegovina and negative in Moldova. In addition, the second lag of HDI (−2) shows a negative association with the adult mortality rate in North Macedonia. As the value of the HDI variable increases, the mean of the adult mortality rate variable also tends to increase. A negative coefficient suggests that as the HDI variable increases, the adult mortality rate variable tends to decline. Furthermore, lagged values of NEET exhibit a dynamic relationship with the current adult mortality rate in both Bosnia and Herzegovina and North Macedonia.

To assess the effect of stochastic shocks in the independent variables on adult mortality, impulse response analysis was conducted. The original impulse response figures show the essential response of adult mortality rate to HDI, GII, and NEET for each country. Figures 1-6 show the spool output of joint LP in control of the impulses and responses set out, the horizon length, and the method of estimating confidence intervals. The settings differ depending on whether estimates were made using sequential or joint LP. In this study, joint LP settings were used. These include marginal band confidence intervals, heteroskedasticity, and autocorrelation consistent adjustments for serial correlation and analytic asymptotic methods for standard errors and confidence intervals. The shaded bands around the mean estimate of the impulse response display the largest values for each coefficient estimate in the joint LP.

Table 1: Vector autoregression model estimation

Country	Bosnia and Herzegovina	North Macedonia	Moldova
Variables	Log (adult mortality)		
Log (adult mortality [−1])	0.6846 (0.2907) [2.3547]	1.2797 (0.3476) [3.6813]	1.2518 (0.2220) [5.6393]
Log (adult mortality [−2])	−0.0353 (0.2860) [−0.1234]	−0.7763 (0.4985) [−1.5574]	−0.4723 (0.2435) [−1.9399]
Dlog (GII [−1])	−1.3256 (0.3460) [−3.8316]	1.3617 (0.5850) [2.3276]	0.4418 (0.6611) [0.6683]
Dlog (GII [−2])	−0.5154 (0.4054) [−1.2714]	−0.6445 (0.6521) [−0.9883]	−0.4810 (0.6631) [−0.7254]
Dlog (HDI [−1])	7.9106 (2.2109) [3.5780]	0.7581 (0.7862) [0.2721]	−2.0777 (1.0057) [−2.0660]
Dlog (HDI [−2])	−1.4265 (2.8397) [−0.5024]	−2.7435 (3.0707) [−0.8935]	−1.1466 (1.2168) [−0.9423]
Log (NEET [−1])	−0.5880 (0.2238) [−2.6275]	−1.0417 (0.3370) [−3.0911]	−0.0151 (0.1514) [−0.1000]
Log (NEET [−2])	0.6557 (0.2422) [2.7068]	1.1090 (0.3474) [3.1926]	0.1710 (0.1348) [1.2689]
Constant (intercept)	0.7205 (0.4696) [1.5343]	2.7653 (2.6221) [1.0546]	0.5322 (0.3039) [1.7511]
Summary statistics			
R^2	0.9733	0.9662	0.9725
Adjusted R^2	0.9377	0.9211	0.9524
Sum squared residuals	0.0086	0.0183	0.0097
Standard error equation	0.0378	0.0552	0.0296
F-statistic	27.349	21.425	48.561
Log likelihood	34.721	29.024	47.981
Akaike Information Criterion	−3.4294	−2.6699	−3.8981
Schwarz Criterion	−3.0046	−2.2451	−3.4499
Mean dependent	3.1747	3.3209	4.4836
Standard deviation dependent	0.1515	0.1967	0.1358

Note: Vector autoregression estimation, sample (adjusted): 2008 – 2022, included observations: 15 after adjustments. Coefficients are given first without parentheses, standard errors in ( ), and z-statistic in [ ]. Abbreviations: GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

Figures 1-6 depict the standard 10-period impulse responses for adult mortality, HDI, GII, and NEETs

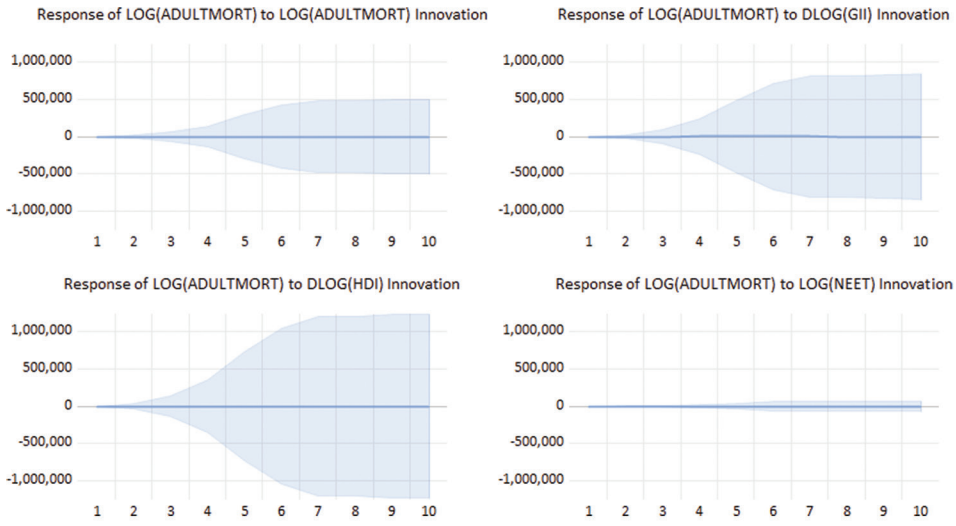

Figure 1. Impulse response (joint local projection) of Bosnia and Herzegovina to Cholesky one standard deviation (degrees of freedom adjusted) innovations. A 95% confidence interval using analytic asymptotic standard errors was employed. Local projection band type: marginal.
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

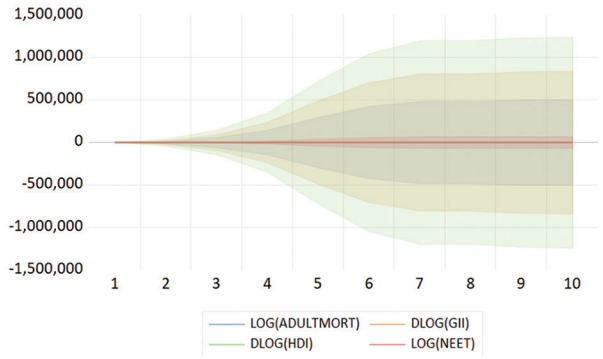

Figure 2. Response of adult mortality to innovations in Bosnia and Herzegovina, to Cholesky one standard deviation (degrees of freedom adjusted) innovations. A 95% confidence interval using analytic asymptotic standard errors was employed.
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender Inequality Index; HDI: Human Development Index; NEET: Not in employment, education, or training.

across the three countries. For Bosnia and Herzegovina (Figures 1 and 2), adult mortality exhibits a gradual response to shocks in both GII and HDI, with the influence of HDI peaking around the mid-period. In contrast, the effect of NEET rates is very minimal and insignificant throughout the period, with its impact diminishing almost entirely by the end of the period.

For North Macedonia (Figures 3 and 4), adult mortality begins to respond to shocks in GII and HDI just before the midpoint of the period. The effect gradually increases over time, with GII demonstrating a slightly stronger influence than HDI. The response of adult mortality to NEET shocks also increases gradually but proceeds at a slower pace compared with HDI and GII.

For Moldova (Figures 5 and 6), the response of adult mortality to the shock of GII is the most pronounced, persisting throughout the entire period. The impact peaks around the midpoint, before a slight decrease. Similarly, adult mortality responds consistently to HDI shocks across the period, with the greatest effect also occurring in the middle. However, the effect is lower than that of GII. The response of adult mortality to NEET shocks shows a gradual increase, stabilizing from the midpoint to the end of the period, and remains the weakest among the three indicators.

One of the objectives of using VAR models is to predict future outcomes, as the interdependencies among variables in the system facilitate inferences about the predictive adequacy of other variables. The Granger causality test was used to determine the causal relationship between two or more variables. The Granger causality concept is increasingly being applied for the specification of directional relationships in different implementations, as understanding the direction of information flow in pairs of systems is of central importance (Papana *et al.*, 2021). Hence, methods applying the concept of Granger causality have a wide practical use for estimating the direction of causal effects in a time series analysis. According to the results of the Granger causality analysis, a one-way directional causality was found between adult mortality and GII for Bosnia and Herzegovina. In Moldova, a one-way causal relationship was found between HDI and adult

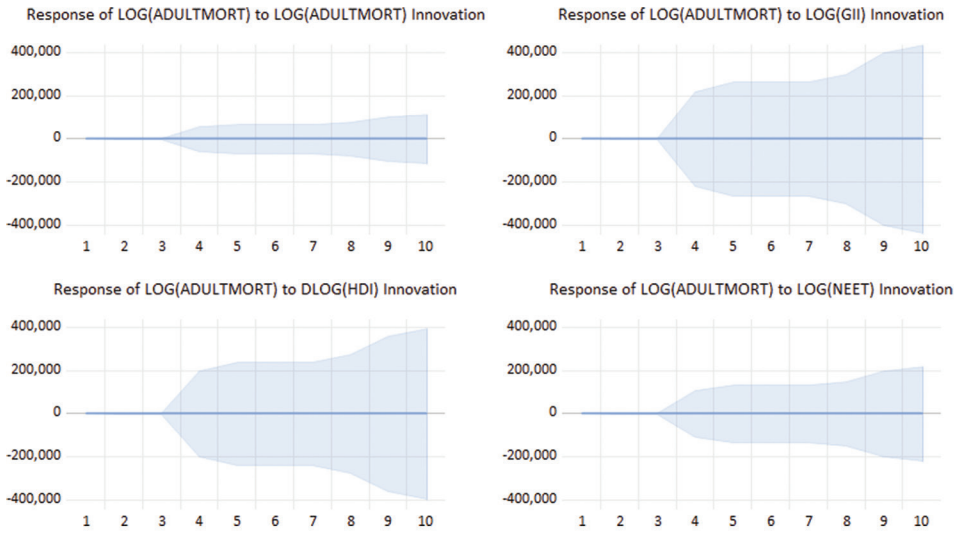

Figure 3. Impulse response (joint local projection) of North Macedonia to Cholesky one standard deviation (degrees of freedom adjusted) innovations. A 95% confidence interval using analytic asymptotic standard errors was employed. Local projection band type: marginal.
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

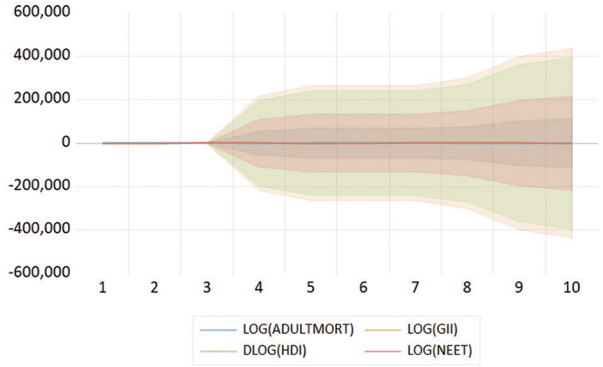

Figure 4. Response of adult mortality to innovations in North Macedonia, to Cholesky one standard deviation (degrees of freedom adjusted) innovations. A 95% confidence interval using analytic asymptotic standard errors was employed.
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

mortality and between adult mortality and NEET (Table 2). For North Macedonia, a one-way directional causality was found between adult mortality and GII, HDI and adult mortality, and NEET and adult mortality.

The GII is an important instrument for measuring gender inequality in three dimensions: reproductive health, empowerment, and labor market participation. Gender differences are consistent and continue to be a key challenge for sustainable development in developed and developing countries (Ansar, 2023; Perrin *et al.*, 2023), including Bosnia and Herzegovina and North Macedonia. Furthermore, the causal relationship found between HDI and adult mortality reveals that the specific historical socioeconomic context, such as the overall standard of living and well-being of North Macedonia and Moldova, as well as long-term unemployment and social exclusion, has a substantial effect on the adult mortality rate in these two countries. The historical decomposition method was applied for the observation period 2004 – 2022. Historical decomposition is a standard tool within the VAR model, allowing an interpretation of historical variations in time series models by attributing them to related structural shocks (Figures A5-A7).

4. Discussion

Concerns regarding inequalities in emerging countries have become prominent in public discourse (Ferreira *et al.*, 2022; Shen & Zhao, 2022). Understanding and dealing with the negative impacts of social inequality is a complex and continuing challenge, especially in less developed countries and, to a certain degree, in some developed societies. Despite the existing efforts, issues emerging from inequality persist to impact society. Previous literature on inequality mainly relied on income as a social inequality measure, and this practice, in a way, has limited the understanding of the problem. Certain types of inequality deserve more attention, while others may not, as they are not recognized as pressing social issues. Income alone cannot capture all nuances of inequality. Nonetheless, the literature has established a robust inverse relationship between income inequality and population health. This research presents

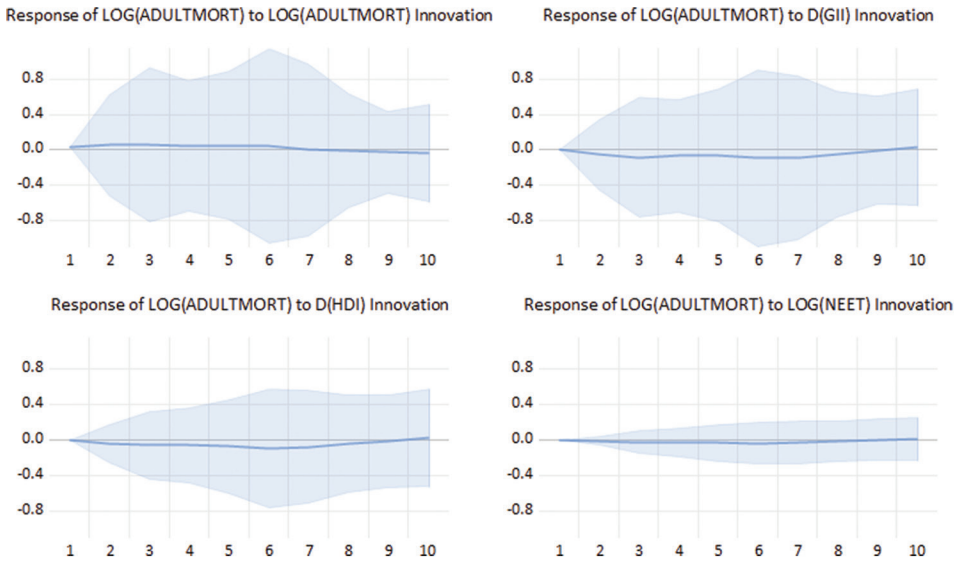

Figure 5. Impulse response (joint local projection) of Moldova to Cholesky one standard deviation (degrees of freedom adjusted) innovations. A 95% confidence interval using analytic asymptotic standard errors was employed. Local projection band type: marginal.
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender Inequality Index; HDI: Human Development Index; NEET: Not in employment, education, or training.

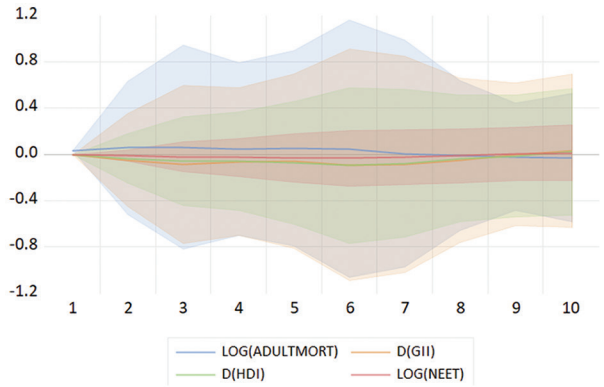

Figure 6. Response of adult mortality to innovations in Moldova, to Cholesky one standard deviation (degrees of freedom adjusted) innovations. A 95% confidence interval using analytic asymptotic standard errors was employed.
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

several relevant and original findings (Barboza-Solis *et al.*, 2024; Ferreira *et al.*, 2022; Wu, 2022). A VAR regression model was run separately for each of the three European countries (Bosnia and Herzegovina, North Macedonia, and Moldova), over the period 2004 – 2022. This study contributes innovative evidence by investigating whether impulse-response shocks, measured by different inequality indicators (HDI, GII, and NEET), affect adult mortality rates in these countries. To the extent that inequalities have widened across countries, one might reasonably infer that there could be reasons for concern about how inequality issues further impact population health.

The Granger causality tests revealed consistent and significant patterns. More specifically, one-way directional causality was established from HDI to the adult mortality rate in Moldova (at 1% significance level) and North Macedonia (at 5% significance level). The same causal pattern was also observed from NEET to the adult mortality rate in North Macedonia at a 10% significance level. Conversely, a one-way causal dimension was found from adult mortality to GII in North Macedonia and Bosnia and Herzegovina, as well as from adult mortality to NEET in Moldova. Therefore, particularly HDI and, to some extent, NEET are identified as the most important measures of inequality concerning adult mortality rate in two out of the three countries examined. The negative relationship between HDI and adult mortality, as found from the VAR model in North Macedonia and Moldova, indicates that adult mortality rates increase as the HDI decreases. This is in line with the study by Piketty (2014), who concluded that the large income differences, resulting from lower levels of human development and socioeconomic development and diminished social well-being in a country, have damaging and strong health consequences. Piketty (2014) emphasizes that inequality manifests in different ways across societies and evolves in the same societies over time. He asserts that inequality has followed diverse paths – socioeconomic, political, civilizational, cultural, and religious. One of the most drastic actions

Table 2. Granger causality test results

Pairwise Granger causality tests	Observations	*F*-statistic	Probability
Null hypothesis: Bosnia and Herzegovina			
GII does not Granger-cause adult mortality	20	0.2044	0.8174
Adult mortality does not Granger-cause GII		6.8171	0.0000
Null hypothesis: North Macedonia			
GII does not Granger-cause adult mortality	21	0.2703	0.7665
Adult mortality does not Granger-cause GII		9.9615	0.0015
HDI does not Granger-cause adult mortality	21	3.7412	0.0465
Adult mortality does not Granger-cause HDI		0.0830	0.9208
NEET does not Granger-cause adult mortality	15	3.0653	0.0916
Adult mortality does not Granger-cause NEET		1.2710	0.3222
Null hypothesis: Moldova			
HDI does not Granger-cause adult mortality	21	11.312	0.0009
Adult mortality does not Granger-cause HDI		0.6413	0.5396
NEET does not Granger Cause Adult mortality	21	1.0644	0.3681
Adult mortality does not Granger-cause NEET		3.3531	0.0608

Abbreviations: GII: Gender inequality index; HDI: Human Development Index; NEET: Not in employment, education, or training.

of intervening against inequality, according to Piketty (2014), was the development of the welfare state, marked by increased public spending on pensions, healthcare, and education. These were significant steps in reducing inequality. Spending on welfare, education, and healthcare is supported broadly in most countries, including by the wealthiest individuals who are often willing to pay more in taxes. Piketty (2014) states that the abrupt tenfold increase in public spending during the last century was a major factor in developing individual freedom, reducing inequality, and raising living standards and productivity. He claims that political mobilization to drive policy change is the key to understanding and reducing inequality, and it is intrinsically linked to a country's political culture and institutions. The Kuznets hypothesis proposes that nothing can or should be done about inequality, as it is a necessary part of economic development and will naturally decline as economies mature and as education, skills, and technology expand. On the contrary, the Piketty hypothesis argues that inequality will increase in modern economies, necessitating government intervention to counteract this process (Piketty, 2014). Piketty (2014) argues that wealth will become increasingly concentrated and recommends an annual tax on the top 1% of wealth owners, progressive income taxation, an end to tax evasion schemes, the closure of tax havens, and a global minimum corporate tax. Economic inequality frequently underlies other forms of social inequality. Poverty and inequality are connected (Roberts, 2023), both being consequences of the exploitation of labor by capital at both national and global levels.

The findings of our study align with previous research by the International Monetary Fund (2017), which highlights that gaps in education and health are still significant in many countries, including the three examined in this study. The IMF emphasizes that addressing these gaps through better allocation decisions of public spending would effectively reduce inequality. Understanding that income inequality negatively affects health has sparked extensive research in economics and public health (Ferreira *et al.*, 2022). Notably, greater income equality has been linked to improved health outcomes in developed economies (Wu, 2022). Ferreira *et al.* (2022) argued that there is no strong evidence indicating that income inequality is an important determinant of population health, although it does affect health through poverty. Our empirical findings resonate with Barboza-Solis *et al.* (2024), claiming that health is determined by the circumstances in which people are born, grow up, live, work, and age – conditions shaped by social, political, and economic factors. These insights are consistent with the observations in the three countries examined and align with the broader perspectives of this study.

Regarding human development, North Macedonia and Moldova registered relatively high HDI rankings in 2022, placing 83rd and 86th, respectively, out of 193 countries and territories (UNDP, 2024). However, the association between human development and the influence of inequality has severely widened within these two countries, demonstrating a strong impact of inequality on the human dimension. In addition, this suggests the importance of adopting a comprehensive perspective that considers not only macroeconomic variables but also other aspects of the country's stage of economic development, such as poverty reduction, quality of life improvements, and education system enhancements (Cigdem *et al.*, 2023). As established, population health is determined by income inequality and mostly through the effects of poverty as an intermediate variable (Barboza-Solis *et al.*, 2024; Ferreira *et al.*, 2022). In addition to reducing inequality, it is also important

to develop and implement proper policies. In particular, policies for empowerment and greater labor market participation of females should be strengthened in Bosnia and Herzegovina and North Macedonia. Furthermore, policies toward young people regarding the reduction of long-term unemployment and social exclusion should be developed in North Macedonia. For Moldova, specific policy interventions are needed to improve the overall standard of living and well-being.

One of the limitations of this study was the decision not to use the Gini coefficient as a measure of income inequality, despite its widespread recognition for accuracy and comparability. The Gini index is primarily used to measure both income and wealth inequality within a country (Roberts, 2023), and is the most common index of measuring income inequality (Clementi, 2023; Gornick, 2024; Qiu & Sun, 2024; Vella & Camilleri, 2021). Since this research did not focus exclusively on the impact of income inequality on adult mortality, excluding the Gini coefficient was justified. The Gini coefficient, GII, HDI, and NEET rates reflect aspects of societal welfare, but concentrate on different dimensions (Mandegar & Olsson, 2023). While these indicators can be related, they measure different aspects of societal development and offer different perspectives on societal well-being. The Gini coefficient focuses on income inequality, while the focal point of GII is on gender inequalities. The HDI focuses on overall human development, and NEET rates reflect the employment and educational status of young people. The second limitation is that the VAR model is sensitive to lag length; therefore, the results may be sensitive to the selected lag length, potentially minimizing the reliability of the model's forecasts. In addition, the study's use of only three European countries may limit the generalizability of the findings. Other limitations include the exclusion of important contextual variables such as the specific environmental, cultural, and physical factors unique to these countries.

To address concerns about lag length sensitivity, this study examined the sensitivity of forecasts from the VAR model using different lag structures, while keeping the same variables and study period. Sensitivity analyses were conducted by varying the lag order and checking the stability of the model. The results showed that the accuracy of the VAR forecasts did not vary significantly across alternative lag structures, indicating that the conclusions are not sensitive to (possibly arbitrary) lag structures. Moreover, on average, models with relatively short lags are more accurate than specifications with longer lags. When the lag length was too short, the model was misspecified, and when the lag length was too long, the degrees of freedom were unnecessarily consumed.

5. Conclusion

The pragmatic goal of this study is to achieve social cohesion, reduce the negative impacts of inequalities, and, most importantly, protect human dignity, particularly among marginalized groups within society. The existence of social inequalities in adult health and mortality in these three countries is not surprising. Future research is needed to understand the mechanisms underlying the growing social inequalities in health that were observed in these three countries. The causal relationship found between adult mortality and GII in Bosnia and Herzegovina and North Macedonia indicates that the past values of adult mortality rates are influenced by gender inequalities. This underscores that persistent gender differences remain a key challenge for sustainable development in these countries. In addition, the causal relationship found between HDI and adult mortality in North Macedonia and Moldova reveals that the specific historical socioeconomic context, such as the overall standard of living and well-being, has a substantial effect on the adult mortality rate. These findings highlight the significance of targeted policies to reduce social inequalities and the related health consequences within these three European countries. The insights gained from this research contribute to a better understanding of these relationships and provide a basis for robust, sustainable development. The practical recommendations for policymakers based on the findings would be aimed at improving youth employment policies to reduce social inequalities and increase investment in education and health, fostering social and human development. Finally, it is worth reiterating Piketty's (2014) policy recommendation: one of the most drastic actions of intervening against inequality is the development of the welfare state with increased public spending on pensions, healthcare, and education.

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Conflict of interest

The author declares no competing interest.

Author contributions

This is a single-authored article.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

All data analyzed have been presented in the paper.

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Appendices

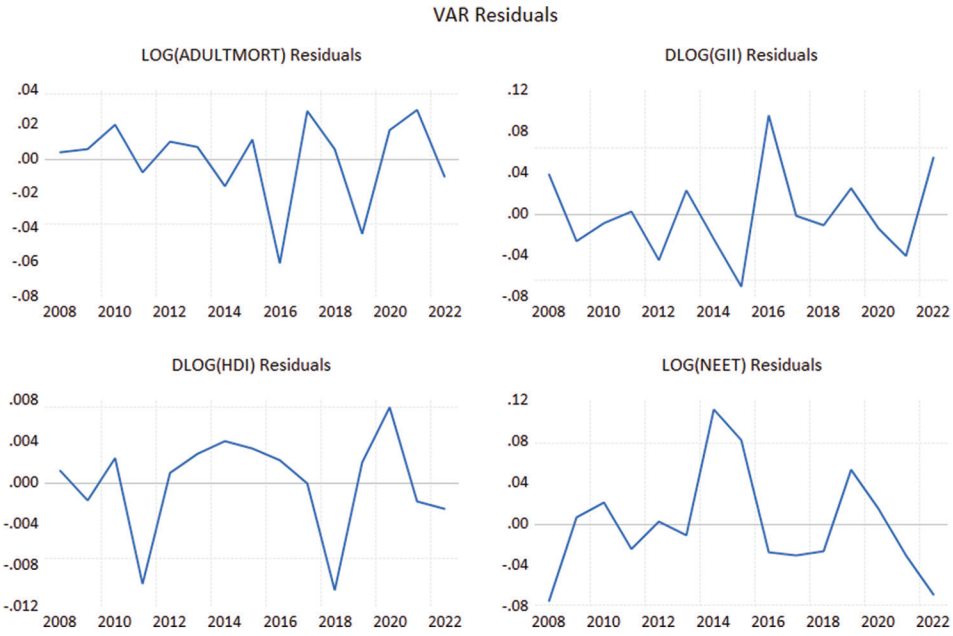

Figure A1. Vector autoregression residuals of Bosnia and Herzegovina
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

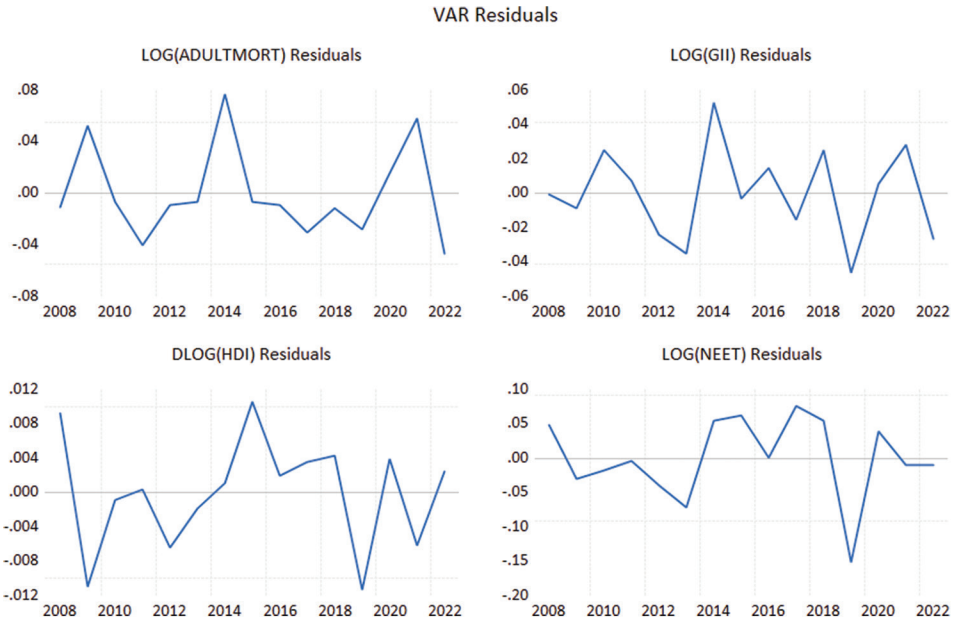

Figure A2. Vector autoregression residuals of North Macedonia
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

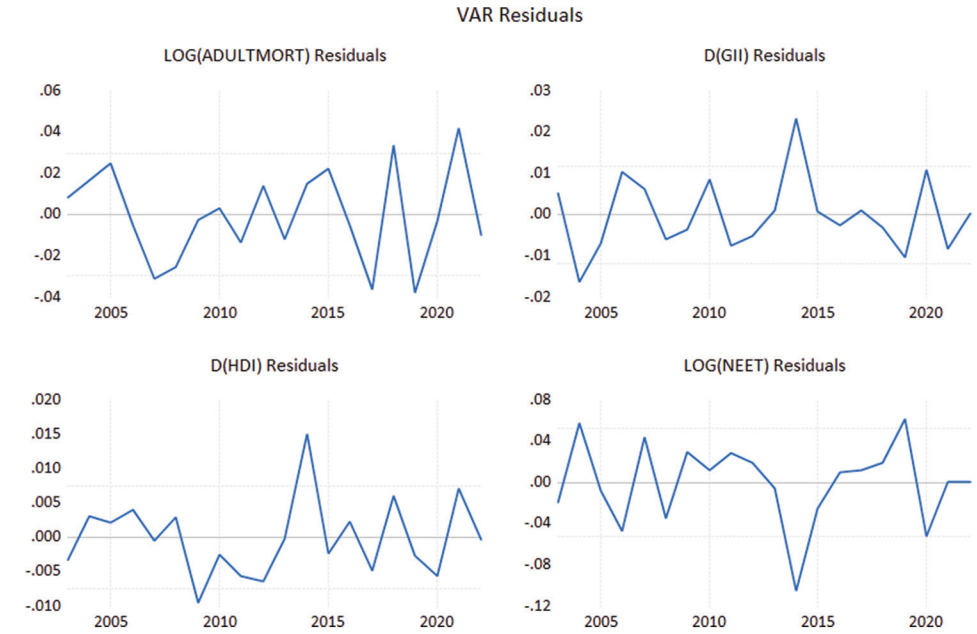

Figure A3. Vector autoregression residuals of Moldova
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

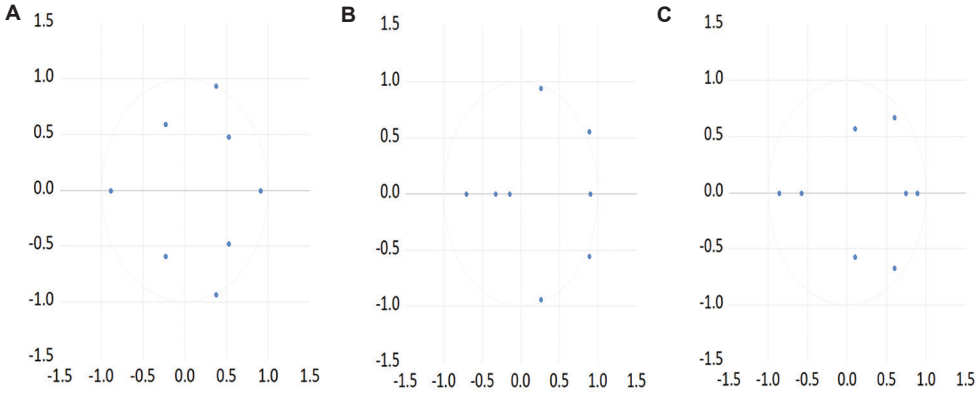

Figure A4. Inverse roots of the characteristic equation. (A) Bosnia and Herzegovina. (B) North Macedonia. (C) Moldova.

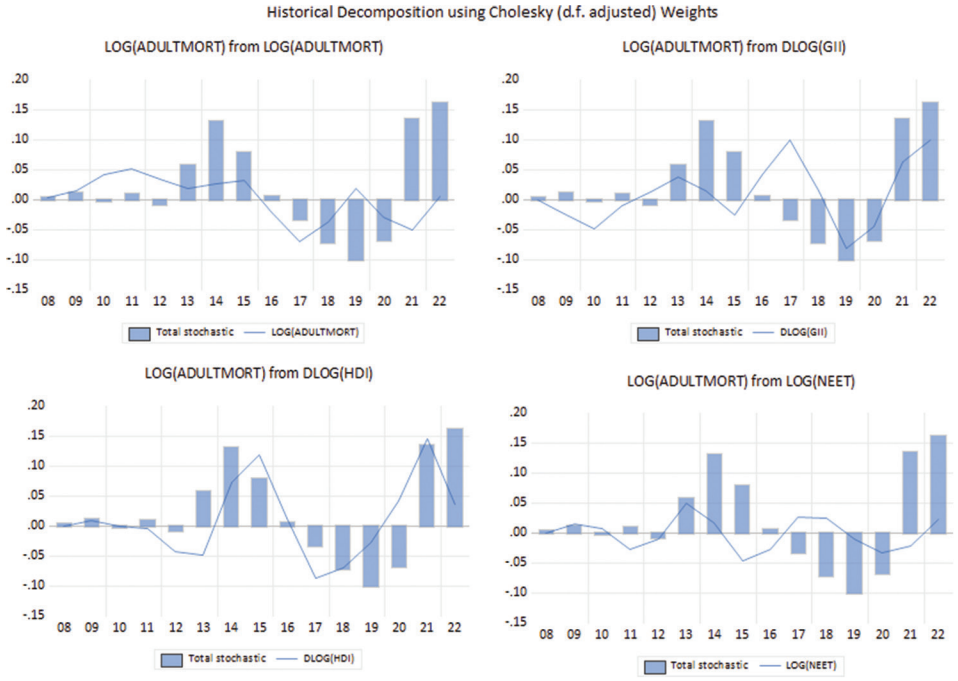

Figure A5. Vector autoregression historical decomposition of Bosnia and Herzegovina using Cholesky (degrees of freedom adjusted) weights
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

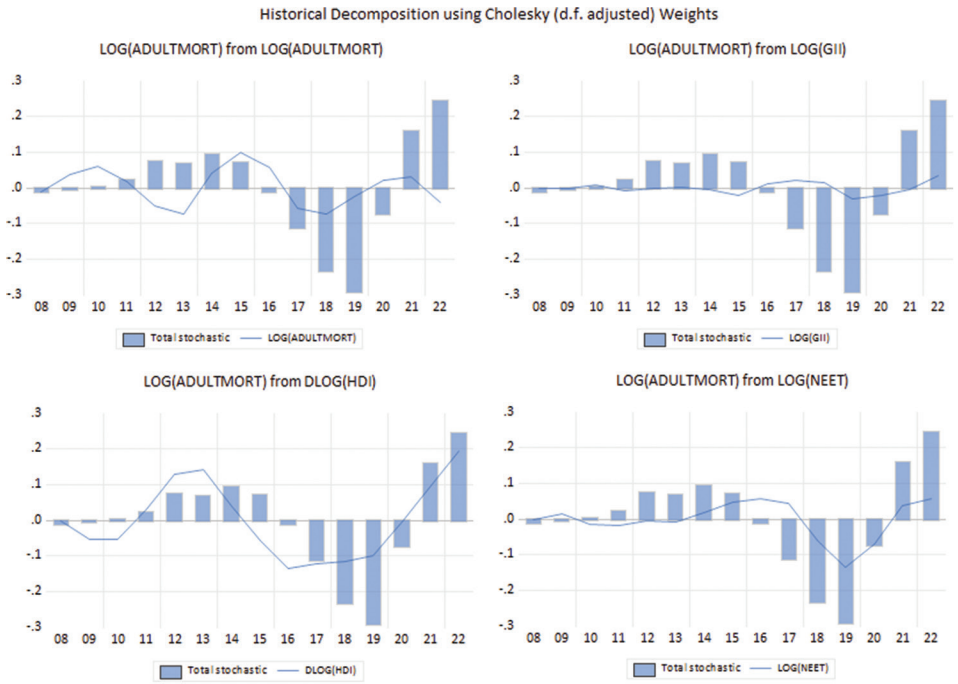

Figure A6. Vector autoregression historical decomposition of North Macedonia using Cholesky (degrees of freedom adjusted) weights
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

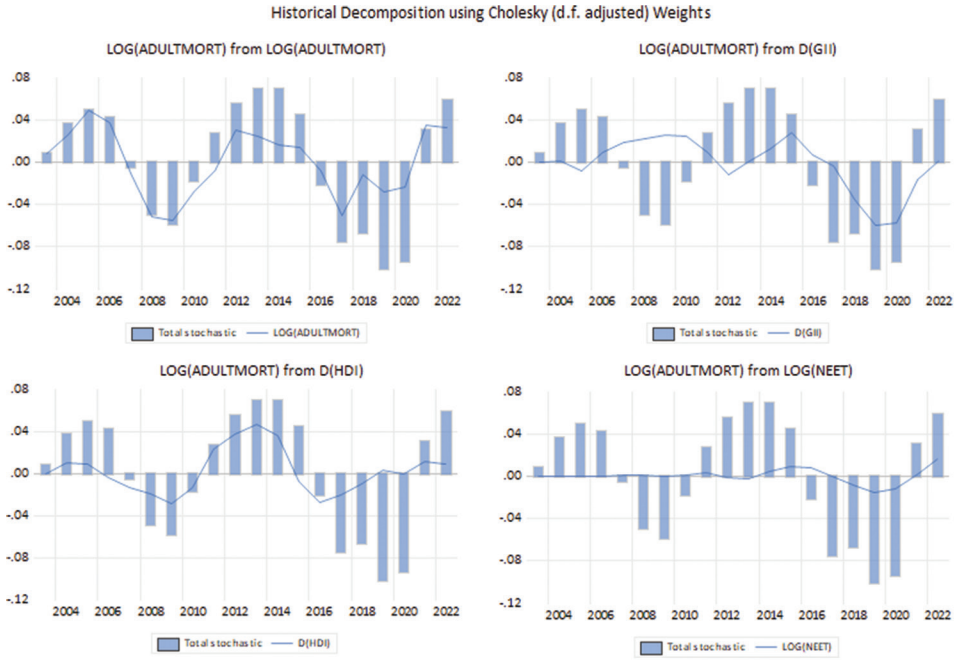

Figure A7. Vector autoregression historical decomposition of Moldova using Cholesky (degrees of freedom adjusted) weights
Abbreviations: ADULTMORT: Adult mortality rate; GII: Gender inequality index; HDI: Human development index; NEET: Not in employment, education, or training.

Table A1. Vector autoregression residual portmanteau tests for autocorrelations

Country	Lags	*Q*-statistic	Probability[a]	Adjusted *Q*-statistic	Probability[a]	Degrees of freedom
Bosnia and Herzegovina	1	21.117	---	22.625	---	---
	2	37.362	---	41.369	---	---
	3	53.308	0.000	61.303	0.000	16
North Macedonia	1	16.202	---	17.360	---	---
	2	29.493	---	32.695	---	---
	3	48.180	0.000	56.054	0.000	16
Moldova	1	14.276	---	15.028	---	---
	2	27.471	---	29.689	---	---
	3	41.800	0.000	46.546	0.000	16

Null hypothesis: No residual autocorrelations up to lag h

Note: [a]Test is valid only for lags larger than the vector autoregression model lag order.