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Fitting a Public Health Index Model Based on Smart Data with an Emphasis on Population Aging and Retirement Age in Iran

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ABSTRACT

The aim of the study is to fit a public health index model based on smart data with an emphasis on population aging and retirement age in Iran. The study examines the fitting of the public health index model (life expectancy) considering retirement age and population aging in Iran during the years 1990 to 2024 using the quantile method (quartile regression). The present study is in the category of post-event research from the perspective of applied purpose and analytical-descriptive nature. First, reliability tests (PP) were conducted on the variables, which showed that the variables were stationary at the level of one after one order of difference. The results of the cointegration test also indicate the existence of at least one cointegration vector between the variables under study. The results of the quantile model estimation show that the retirement index has a negative and significant effect on the life expectancy index (health index) in the lower quartiles (25Q and 50Q), and the intensity of this negative effect increases as it moves towards the higher quartiles (75Q and 95Q). Also, factors such as public health expenditures, private health sector expenditures, capital formation, and literacy rate have a positive and significant effect on life expectancy, while the real exchange rate, inflation rate, and liquidity volume have a negative and significant effect on it. The impact of the retirement index, inflation rate, liquidity volume, and real exchange rate on the health index increases in the higher quartiles (75Q and 95Q). **©authors**

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Introduction

Population aging has emerged as one of the most critical demographic, economic, and social challenges of the twenty-first century. Increasing life expectancy, declining fertility rates, and improvements in health conditions have significantly altered the age structure of many countries and accelerated the transition toward aging societies (Mousavi et al., 2023). The World Health Organization defines healthy aging as the process of developing and maintaining the functional abilities that enable well-being in older age, emphasizing that elderly health is not limited to the absence of disease but also includes physical, mental, social, functional, and environmental dimensions (World Health Organization [WHO], 2024). Accordingly, in aging societies, public health assessment requires comprehensive, multidimensional, and dynamic indicators capable of capturing both the current health status and future functional capacity of populations (Li et al, 2025).

Iran is also experiencing a rapid demographic transition toward population aging. Declining fertility rates, increasing life expectancy, and changes in household structure are gradually reshaping the country's population pyramid. Forecasts indicate that Iran will become one of the fastest-aging countries in the region in the near future (United Nations, 2024). This demographic shift has serious implications for the health system, labor market, pension funds, social welfare policies, and intergenerational equity. The growing proportion of older adults, combined with the decreasing share of the economically active population, increases pressure on healthcare resources, social protection systems, and retirement funds. Therefore, evidence-based, data-driven, and future-oriented policymaking has become an urgent necessity in managing the consequences of aging (OECD, 2025; Nazeri et al, 2025).

One of the most important policy challenges associated with population aging is determining an appropriate retirement age. An aging population increases healthcare expenditures and reduces the ratio of the active labor force to the dependent population. This trend may threaten the financial sustainability of pension funds and social security systems (OECD, 2026). However, retirement age cannot be determined merely on the basis of chronological age. Increasing the retirement age without considering individuals' physical, mental, cognitive, and functional health may reduce labor productivity, increase occupational risks, and intensify health inequalities. Conversely, lowering or maintaining a low retirement age without considering demographic and economic realities can place considerable financial pressure on pension systems and public budgets (OECD, 2025). Therefore, retirement policy requires a more precise understanding of the relationship between age, health status, functional ability, employment capacity, and social participation.

In this context, the concept of healthy aging has gained increasing importance in health and welfare policymaking (Erfani et al, 2022; Jafari et al., 2021). According to the World Health Organization, the assessment of aging should move beyond traditional indicators such as life expectancy and disease prevalence and incorporate broader dimensions, including functional independence, mental health, social participation, quality of life, economic security, and access to supportive environments (WHO, 2024). Previous studies have shown that chronological age alone is not an adequate criterion for evaluating people's ability to remain active in the labor market, because individuals of the same age may differ substantially in terms of physical health, cognitive capacity, psychological well-being, occupational ability, and social support (WHO, 2024). This highlights the need for a comprehensive public health index that can provide a multidimensional and evidence-based basis for aging and retirement policies.

At the same time, the expansion of digital transformation has created new opportunities for measuring, monitoring, and predicting public health. The development of electronic health records, digital health platforms, health information systems, wearable technologies, Internet of Things-based health monitoring tools, artificial intelligence, machine learning, and big data analytics has transformed the nature of health data production and analysis (Noori et al., 2024). These technologies enable the collection and integration of large-scale, real-time, multidimensional, and individualized data related to health behaviors, disease patterns, functional status, service utilization, environmental conditions, and socioeconomic characteristics. As a result, smart data can provide a powerful foundation for designing advanced public health indices that are more accurate, adaptive, predictive, and policy-relevant than traditional indicators (Kalantari et al., 2023).

The relevance of this issue becomes even more significant in the context of metaverse-oriented and digitally transformed health systems. Emerging digital environments, including virtual health platforms, digital twins, remote care systems, immersive rehabilitation environments, and AI-supported decision-making systems, are changing the way health status is assessed, health services are delivered, and public policies are designed. In such an environment, public health indicators are no longer limited to static statistical measures; rather, they can evolve into intelligent, interactive, and continuously updated models supported by smart data infrastructures. These models can help policymakers simulate future demographic scenarios, estimate the functional capacity of older adults, evaluate the consequences of different retirement-age policies, and design more personalized and equitable interventions in the fields of health, aging, and social security.

Despite the growing importance of population aging in Iran, most existing public health indicators remain based on traditional, fragmented, and limited variables. These indicators often focus on general mortality, morbidity, or service utilization and pay insufficient attention to the integrated relationship between public health, aging, functional ability, employment capacity, and retirement age. Moreover, the potential of smart data, artificial intelligence, and digital health infrastructures has not yet been sufficiently utilized in developing indigenous public health assessment models for Iran. Existing studies have mainly examined specific dimensions of elderly health or active aging. For example, Roshanfekr, Doostkar, and Mirtahari (2022) showed that there are significant differences among Iranian provinces in terms of active aging indicators and that health, social participation, and economic security are important determinants of elderly quality of life. These findings emphasize the necessity of designing a comprehensive, context-specific, and multidimensional model for evaluating public health among aging populations in Iran (Kousha et al., 2024).

Furthermore, while many countries have moved toward increasing retirement age in response to the financial challenges of pension systems, the success of such reforms depends strongly on the actual health and functional capacity of the population. Without a valid and data-driven understanding of public health status, decisions regarding retirement age may produce undesirable economic, social, and health-related consequences. Therefore, an intelligent public health index that integrates demographic, health, social, economic, and functional data can provide a more reliable basis for determining whether the population has the capacity to support changes in retirement policies (Heidari et al., 2021). Such a model can also support digital governance in the health and welfare sectors by enabling more transparent, predictive, and evidence-based decision-making.

Accordingly, the present study is situated at the intersection of population aging, public health assessment, retirement policy, and digital transformation. It aims to fit a public health index model based on smart data, with an emphasis on population aging and retirement age in Iran. By integrating health, demographic, social, economic, and functional indicators through smart data-oriented approaches, this study seeks to provide a comprehensive and indigenous model that can support more accurate assessment of public health and contribute to evidence-based policymaking in the fields of healthy aging, pension reform, labor-market planning, and digital health governance.

The main research gap addressed in this study is the absence of a native, smart data-based, and digitally oriented model for fitting a public health index in Iran that simultaneously explains the relationship among public health, population aging, functional capacity, and retirement age. Although previous studies have examined aging, elderly health, or pension challenges separately, limited research has integrated these dimensions within a smart data-driven framework suitable for digital transformation in health policymaking. Therefore, the central research question of this study is:

How can a smart data-based public health index model be fitted for Iran in a way that explains the relationship between public health, population aging, and retirement age, and provides a scientific basis for digital, evidence-based policymaking in the fields of health, aging, and retirement?

Literature Review

Population aging and retirement have increasingly attracted scholarly attention due to their profound implications for public health systems, labor markets, and social welfare policies. A growing body of international research has explored the multidimensional relationship between retirement, health outcomes, and socioeconomic conditions, highlighting that the consequences of retirement extend beyond economic aspects and encompass physical, mental, and social health dimensions.

Figure1. *Digital health framework, artificial intelligence, health data and smart policymaking. (World Health Organization (WHO). Digital Health.)*

Figure 1 presents the World Health Organization's conceptual framework for digital health, illustrating how smart data generated from electronic health records, health information systems, artificial intelligence, mobile health applications, wearable devices, and interoperable digital platforms can be transformed into evidence-based knowledge for healthcare management.

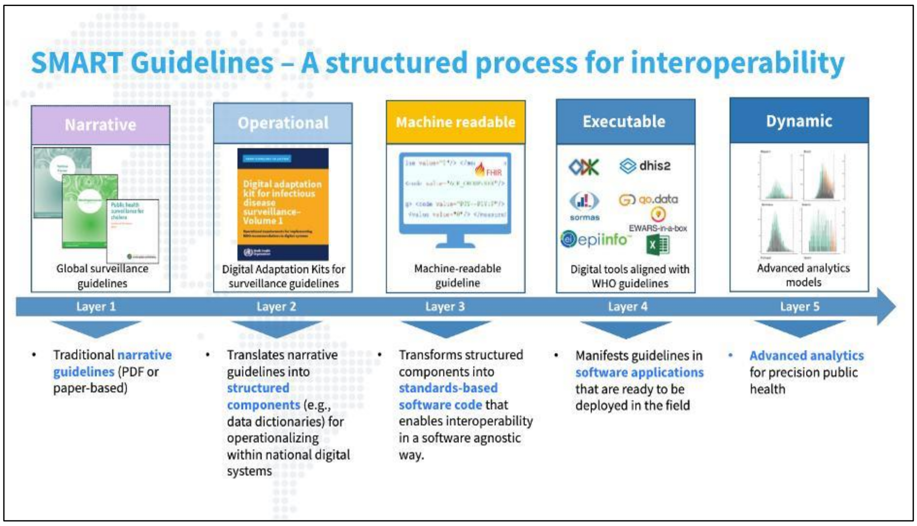

Figure2. *Using electronic health records, hospital data, and secondary data for policymakers (WHO Europe. Improving Health-Care Delivery and Innovation through Secondary Use of Health Data.)*

The framework emphasizes that digital technologies improve the quality, accessibility, efficiency, and sustainability of healthcare services by enabling real-time data collection, integration, and analysis. In the context of the present study, this framework provides the conceptual foundation for interpreting smart data as the systematic integration and analytical use of national demographic and macroeconomic databases to support public health policy decisions, particularly those related to population aging and retirement policies.

Figure 4 illustrates the process through which health data collected from multiple sources—including electronic health records, administrative databases, public health registries, and statistical information systems—are integrated and reused for research, policy evaluation, and strategic decision-making. The concept of secondary use of health data extends beyond clinical applications by supporting predictive analysis, resource allocation, healthcare planning, and public health monitoring. Although the present study does not directly employ individual-level digital health records, it follows the same analytical philosophy by integrating heterogeneous macroeconomic and demographic datasets into a unified empirical framework. This data-driven approach facilitates the identification of long-run relationships affecting the public health index and provides evidence that can contribute to intelligent health governance and more effective policy formulation under conditions of population aging.

Several empirical studies have investigated the direct health effects of retirement. Li et al. (2025), using panel data from the Japanese Study of Aging and Retirement, examined the impact of changes in the retirement age policy on the health of older men in Japan. Their findings suggest that retirement has heterogeneous health effects: while it improves mental health by reducing work-related stress, it simultaneously increases the risk of lifestyle-related diseases such as diabetes and cardiovascular conditions. This indicates that retirement may relieve psychological pressure but can also alter daily routines and health behaviors in ways that negatively affect physical health.

Similarly, Nazeri et al. (2025) analyzed panel data from Germany and found that retirement reduces physical strain associated with employment, thereby improving certain aspects of physical health. However, they also reported that reduced occupational and social engagement following retirement may increase the risk of depression and reduce overall quality of life. Their findings highlight the importance of maintaining social participation and active lifestyles among retirees in order to mitigate potential negative psychological consequences.

Other studies have explored behavioral changes associated with retirement. Fontana et al. (2024) investigated the dynamic effects of retirement on dietary behavior in Denmark using panel data from retired and non-retired households. Their results show only modest improvements in diet quality after retirement, while most dietary components remain largely unchanged. The authors argue that dietary behavior is strongly shaped by long-term habits and that the relatively high income replacement rate in Denmark may reduce the need for significant adjustments in consumption patterns after retirement. These findings suggest that retirement alone may not be a decisive factor in shaping health-related behavior, particularly in welfare systems with strong social protection.

In addition to individual-level health outcomes, a number of studies have examined broader structural factors influencing public health and aging. Nazeri et al. (2025), in a systematic review of health system efficiency studies between 2000 and 2021, emphasized that the effectiveness of health systems depends on a complex combination of demographic characteristics, socioeconomic conditions, governance structures, and population health status. Their findings demonstrate that composite health indicators are increasingly used to assess health system performance, highlighting the need for multidimensional approaches to evaluating public health.

Nedopil (2024) examined the social and psychological impacts of retirement in Spain and found that retirement can lead to reduced social participation and increased loneliness, both of which negatively affect mental health. However, the study also emphasized that strong social support networks and community engagement can mitigate these adverse outcomes. This evidence reinforces the argument that retirement policies should consider social and psychological dimensions alongside economic factors.

Some studies have also explored the broader economic and environmental determinants of public health. Jafari et al (2024), in a study of China, analyzed the relationship between public health investment, economic growth, and the living environment. The results indicate that government investment in public health infrastructure can stimulate economic growth by improving the living environment and encouraging greater health consumption among residents. The study highlights the interconnected nature of public health, infrastructure development, and regional economic dynamics.

Research on demographic change and pension reforms has also contributed to understanding the broader economic implications of aging populations. Erfani et al. (2022), using an overlapping generations general equilibrium model, examined the effects of pension reforms in the presence of imperfect labor markets. Their findings suggest that increasing life expectancy and pension reforms can lead to lower interest rates and unemployment, while also encouraging greater labor participation among older workers. Importantly, they argue that ignoring the interaction between pension reforms and labor market structures can lead to an underestimation of the true economic effects of such policies.

In the Iranian context, research has primarily focused on specific aspects of elderly health, socioeconomic determinants of health expenditures, and pension system sustainability. Li et al. (2021) investigated the relationship between loneliness and mental health among elderly individuals covered by the West Tehran Health Center. Their results revealed a significant negative relationship between loneliness and mental health, indicating that higher levels of social isolation are associated with poorer psychological well-being. Similarly, Noori et al. (2024), through a systematic review of studies on sleep and mental health in older adults, found that sleep disorders such as insomnia are strongly associated with depression, anxiety, and cognitive decline in old age.

Odone et al. (2021) also highlighted the psychological challenges associated with aging, emphasizing that factors such as reduced social interaction, economic concerns, and retirement can significantly affect the mental health of older adults. Their findings underscore the importance of psychosocial interventions and supportive social policies to improve the well-being of the elderly population.

Other Iranian studies have focused on the socioeconomic and macroeconomic determinants of health and pension systems. Clark et al. (2023) examined the role of socio-cultural factors in organizational health using structural equation modeling and found that value-based mediating variables significantly strengthen the relationship between socio-cultural factors and organizational health outcomes. Fontana et al(2024), analyzing data from more than 18,000 Iranian households, showed that socioeconomic factors such as income, education, insurance coverage, and employment significantly influence household health expenditures and inequalities in access to health services.

From amacroeconomic perspective, Fuentes et al. (2021) investigated the impact of macroeconomic variables on the financial performance of national pension funds and found that economic growth, labor participation, and investment portfolio structures significantly affect the sustainability of pension funds. Similarly, Jafari et al. (2017) examined structural reforms in the Iranian pension system and demonstrated that such reforms may influence savings behavior, capital accumulation, and overall economic output.

Finally, comparative international research has also examined the determinants of health expenditures and welfare outcomes. Jacobson (2024), using panel data from 109 countries, showed that environmental and infrastructure factors such as access to sanitation systems significantly influence per capita health expenditures, particularly in developing countries. Meanwhile, Hughes et al. (2023) demonstrated that socioeconomic conditions, income dynamics, and price changes can significantly affect welfare and consumption patterns, which indirectly influence population health outcomes.

Despite the extensive body of research on aging, retirement, health outcomes, and pension systems, several important limitations remain in the existing literature. First, many studies examine health outcomes, retirement policies, and socioeconomic determinants separately, rather than analyzing them within an integrated analytical framework. Second, much of the existing research relies on traditional health indicators or limited datasets, which may not fully capture the multidimensional nature of public health in aging societies. Third, in the context of Iran, empirical studies have largely focused on isolated dimensions of elderly health, health expenditures, or pension system sustainability, while relatively little attention has been given to developing comprehensive and data-driven models for measuring public health in relation to population aging and retirement age.

Therefore, a significant research gap exists in the development of an integrated public health index model that simultaneously incorporates demographic, health, social, and economic dimensions while utilizing smart data approaches to provide more accurate and policy-relevant insights. Addressing this gap is particularly important for countries such as Iran that are experiencing rapid demographic transitions and increasing pressure on health systems and pension funds. Accordingly, the present study aims to fill this gap by fitting a public health index model based on smart data with an emphasis on population aging and retirement age in Iran. Such a model can provide a more comprehensive analytical framework for understanding the interaction between public health, aging, and retirement policies, and can support evidence-based decision-making in the fields of health governance, social welfare, and pension reform.

The novelty of this study lies in integrating macroeconomic and demographic indicators within a smart data framework to develop a comprehensive public health index for Iran. Unlike conventional public health studies that examine isolated determinants, this research combines retirement age, population aging, public and private health expenditures, investment, literacy, inflation, exchange rate, and financial liquidity into a unified empirical model. In this context, smart data does not merely refer to artificial intelligence algorithms; rather, it denotes the systematic integration, processing, and analytical utilization of structured national datasets to generate evidence-based insights for public health policymaking. The estimated model transforms large-scale socioeconomic information into actionable knowledge that can support intelligent governance and data-driven decision-making in the health sector. Therefore, the contribution of this study is not only the estimation of the determinants of public health but also the development of an empirical framework capable of supporting smart health planning under demographic transition and population aging.

Despite the growing body of literature examining the relationship between demographic change and public health, several important gaps remain. First, previous studies have primarily investigated individual determinants of health—such as healthcare expenditure, aging, education, or macroeconomic conditions—in isolation, without developing an integrated framework that simultaneously captures their long-run interactions. Second, the existing empirical evidence has relied predominantly on conventional mean-based regression techniques, which assume homogeneous effects across different levels of public health and therefore overlook potential heterogeneity in the responses of the health system to demographic and economic changes. Third, limited attention has been given to the Iranian context, where rapid population aging, retirement-related demographic pressures, and macroeconomic instability jointly influence public health outcomes. To address these gaps, the present study develops an integrated public health index model by combining demographic, healthcare, and macroeconomic variables within a smart data analytical framework and estimates their long-run heterogeneous effects using quantile regression. This approach provides more comprehensive evidence for data-driven public health policymaking than conventional empirical models.

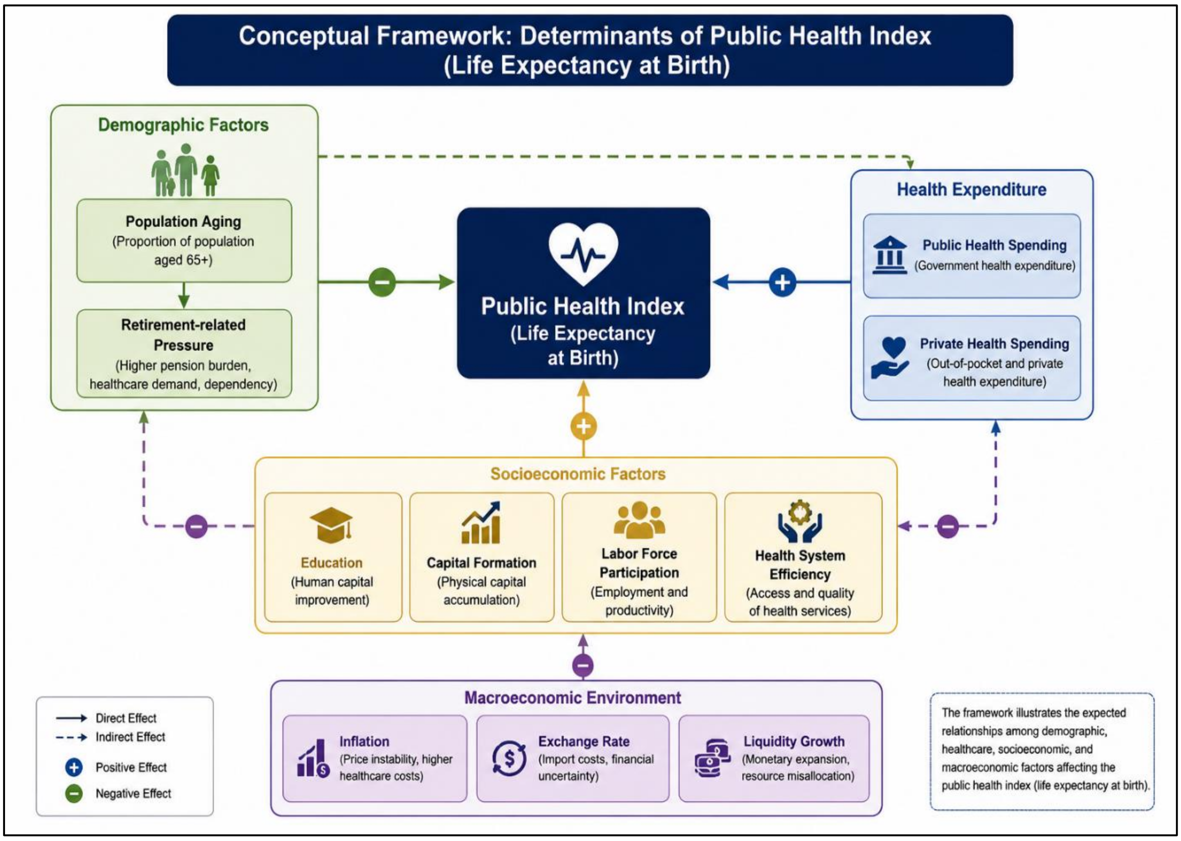

Figure3. *Conceptual framework of public health determinants*

Figure 3 presents the conceptual framework underpinning the present study. The framework assumes that population aging generates retirement-related demographic pressures, which directly influence public health outcomes by increasing healthcare demand and altering the allocation of public resources. At the same time, public and private healthcare expenditures, education, capital formation, and labor force participation contribute positively to improvements in life expectancy by enhancing healthcare accessibility, human capital, and economic productivity. Conversely, macroeconomic instability, reflected by inflation, exchange rate fluctuations, and excessive liquidity growth, may adversely affect public health through reduced purchasing power, increased healthcare costs, and lower investment in health services. Within this integrated framework, life expectancy is considered the ultimate outcome variable because it reflects the cumulative effects of demographic, economic, and healthcare-related factors on population health. The conceptual model therefore provides the theoretical basis for estimating the long-run relationships among these variables using the quantile regression approach.

Method

The present study is applied in terms of purpose and descriptive in terms of analytical nature and is classified as post-event research. In this study, the issue of examining the fit of the general health index model considering retirement age and population aging using the quantile method during the years 1990 to 2024 has been addressed. The present study, following the studies of Chen et al. (2024), Rønnow et al. (2024), Meng (2022), Girick et al. (2019), will estimate the following regression model.

$$Q(\Delta lnLife_t^{IR}|Pop-65_t) = \rho_{0,q} + \beta_1 POP_{65t} + \beta_2 GG_t + \beta_3 PH_t + \beta_4 EX_t + \beta_5 INF_t + \beta_6 M_t + \beta_7 EDU_t + \beta_8 K_t + \beta_9 L_t + \varepsilon_t$$

Pop_{65}: Population aged 65 and over as a retirement indicator;

EX: Real effective exchange rate index[1]: Real effective exchange rate index[2] is calculated as follows.

$$e_{PPP} = E\frac{P^*}{P}$$

According to Mosconi et al(2023), four price indices have traditionally been proposed as possible candidates for constructing a real exchange rate based on this definition. *Consumer Price Index (CPI)* at home and abroad, Product Price Index (PPI), implicit index and wage rate index. Depending on which of these indices *P* and *P** are, the real exchange rate in this definition will be the relative price of a basket of foreign goods to domestic consumption goods or a basket of foreign goods to domestically produced goods. In this study, the domestic and foreign *PPI* indices are used (data on real exchange rates are collected from the World Bank WDI).

K: *Gross fixed capital formation* (% of *GDP*),
L: Labor force employment,
EDU: Literacy rate,
M_t: *Liquidity volume*
INF: Inflation rate
Life expectancy index (Life) is used. Life expectancy index is affected by health care, healthy nutrition, mental peace and is an indicator that indicates the quality of life.

The growth of life expectancy and mortality rates can be an indicator of the quality of health spending in a country. In other words, if health spending is sufficient and the efficiency of using these resources is high, it can be expected that the health index will improve. Statistics on this variable are collected from the World Health Organization (WHO) website).

GG: Domestic general government health expenditure (% of current health expenditure),
PH: Domestic private health expenditure (% of current health expenditure), statistics on the share of income deciles are collected from the Statistics Center database, and data on public and private government spending on community health are collected from the World Bank WDI.

The contribution of this study lies in proposing an integrated analytical framework that links demographic transition, retirement policies, macroeconomic conditions, and healthcare financing within a unified public health index. While previous studies have typically examined these determinants separately, the present research combines them into a comprehensive model that facilitates data-driven policy evaluation. The resulting framework provides a foundation upon which future studies can incorporate emerging smart health indicators, including digital healthcare infrastructure, artificial intelligence applications, electronic health records, and real-time health monitoring systems, to further enhance predictive accuracy and policy effectiveness.

A limitation of the present study is that retirement-related effects are approximated using the proportion of the population aged 65 years and above because consistent long-term data on actual retirement rates were unavailable. Although this proxy captures the demographic pressures associated with retirement, it does not fully reflect individual retirement behavior or labor market exit decisions. Future studies are encouraged to employ direct retirement indicators, such as effective retirement age, labor force exit rates, pension beneficiary statistics, or retirement participation rates, to provide a more precise assessment of the relationship between retirement and public health outcomes.

[1] . Real effective exchange rate index (2010 = 100)
[2] . Real effective exchange rate index (2010 = 100)

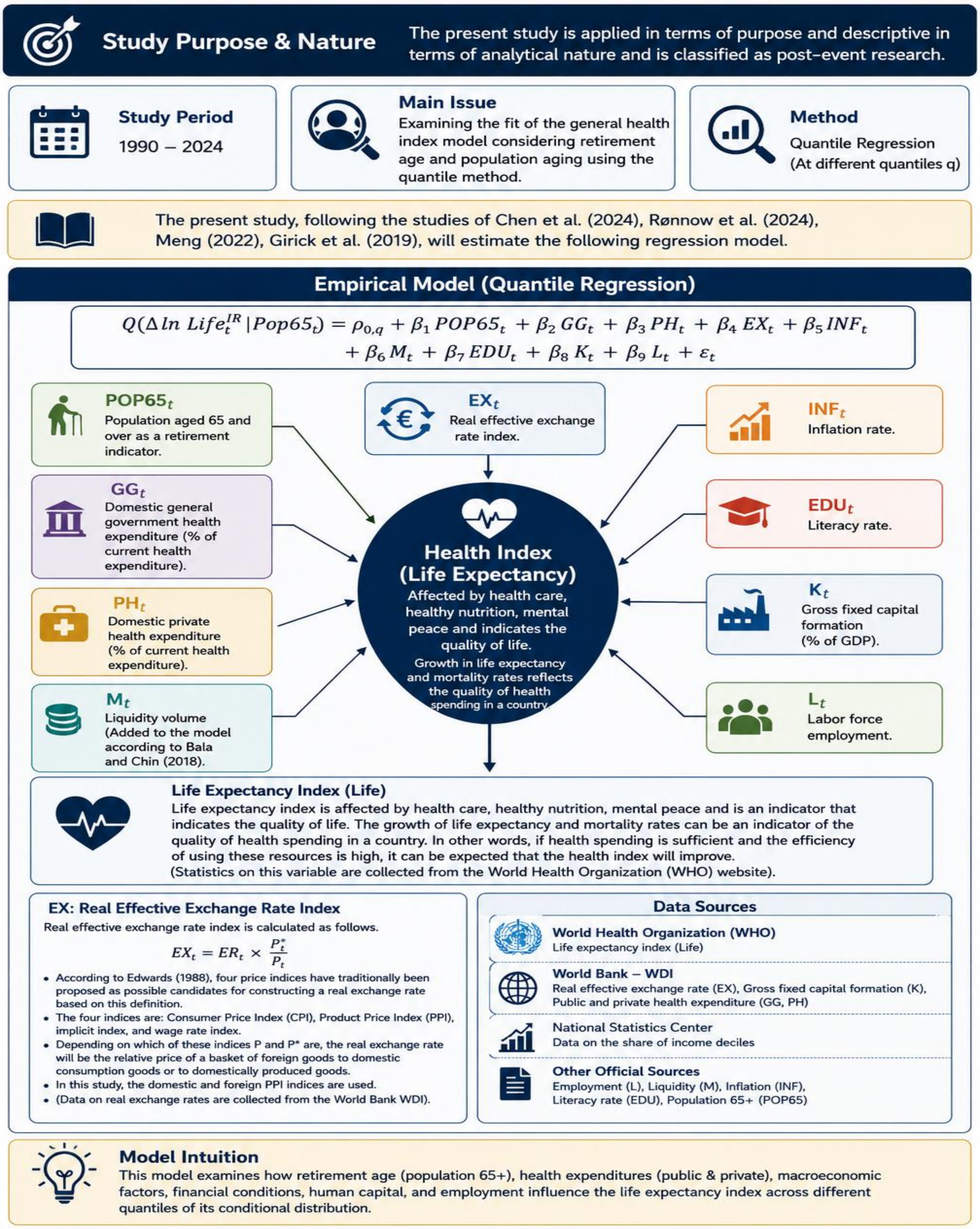

Figure4. *Health index model infographic overview*

Findings

By definition, a time series like $\{x_t\}$ is said to be strictly stationary or strongly stationary if the joint probability density function $x_{t-k} \ldots x_t \ldots x_{t+k}$ for any given value of k is not a function of t. In this case, the distribution of $\{x_t\}$ and consequently its moments, including the mean and variance, are independent of time.[3] However, this is a complicated matter to verify in

3 Enders, W. (1995) Applied Econometric Tim series, New York: John Wiley & Sons, INC

practice, and in addition, in time series analysis there is generally no need to assume strong stationarity. In contrast, we are more likely to verify the stationarity of a time series in the weak sense. A time series $\{x_t\}$ is said to be weakly stationary if the following conditions hold:

$$E(x_t) = \mu \quad , \quad COV(x_t, x_{t+k}) = \gamma_k$$

As can be seen, the mean of the time series x_t must be a constant value and its covariance function for any given value of *k* must not depend on *t*. For this reason, a weakly stationary time series is also called stationary in covariance. It is recalled that the value of γ_0 (for $k = 0$) is the variance of the time series x_t, which is also independent of time. In the following, the term stationary is used in the sense of weak stationary.

The importance of stationary or stable or static series in economics is that a stable series will not have the effect of a shock forever. And if a shock is introduced to it, this shock will not be permanent and will eventually die out.

This is of particular importance in cointegration analysis.

Non-stationary time series are created in two ways. In the first method, the series is a function of the time variable, *t*, as follows:

$$x_t = f(t) + u_t$$

where u_t is the stationary disturbance term. If $f(t)$ is a first-degree polynomial in time, we have:

$$(1)\ \ x_t = \alpha + \beta t + u_t$$

The mean x_t is a function of time and is therefore non-stationary. In the second method, x_t is generated from the following model:

$$(2)\ \ x_t = \beta + x_{t-1} + \varepsilon_t$$

where ε_t is a stationary series with zero mean and variance σ_ε^2. The above model is called a Domestic general government health expenditure (% of current health expenditure). By successive substitutions, we transform the equation (4-2-1) into the following.

Assuming that x_0 is known:

$$(3)\ \ x_t = x_0 + \beta t + \sum_{j=1}^{t} \varepsilon_j$$

$$Var(x_t) = t\sigma^2$$

In this case, the variance of x_t is not independent of time. But both models (1) and (2) show a linear trend. In model (4-2-1), u_t is considered a temporary shock and in model (2), ε_t is a permanent shock.

If an economic variable is affected by permanent shocks, we use model (2). Models (1) and (2) are called the deterministic trend model and the random trend model, respectively. In both models, the variable x_t increases at a rate β (x_t can be considered a logarithm, in which case it will be its growth rate β). But in the first model, the shocks are temporary and in the second model, they are permanent. In the second model, they are called the drift term or trend term. Unlike random trends, deterministic trends do not pose any problems for valid statistical inferences and cointegration analyses. Their effects should be controlled by including the trend term t in the model. Therefore, in cointegration analyses we are only concerned with the random trend.

For some purposes we may be interested in detrending the time series. For this purpose, it is sufficient to regress x_t on time in model (1). In this case, the remaining terms from this regression are trendless. Also, by using differencing, a stationary series can be obtained as follows:

$$(4)\ \Delta x_t = \beta + u_t - u_{t-1}$$

In model (5) also, with the first difference, we can reach a stationary series with mean β because:

$$(5)\ x_t - x_{t-1} = \beta + \varepsilon_t$$

Model (4) is called the stationary process and model (5) is called the stationary difference. This naming was done by Nelson and Plosser.

Cointegration analyses are related to Difference Stationary Processes (stationary in difference) or DSP.

For this purpose, we consider the following equations:

$$x_t = \alpha + \rho x_{t-1} + \beta t + \sum_{i=1}^{k} \delta_i \Delta x_{t-i} + \varepsilon_t$$

$$\Delta x_t = \alpha + (\rho - 1) x_{t-1} + \beta t + \sum_{i=1}^{k} \delta_i \Delta x_{t-i} + \varepsilon_t$$

where ε_t are independently and identically distributed.

To examine reliability, we consider two null hypotheses (H_0) of non-reliability and its alternative hypothesis (H_1) as follows.

$H_0 : \rho = 1$

If in the above equations is $\rho = 1$, then the above series is unstable or non-stationary, which is called a series with a single root. If is $|\rho| \prec 1$. Then the instability of the series is rejected, which is called an Integrated series of degree zero. That is, $x_t \approx I_0$. If the series is unstable, it can be made stable by differentiation. Now, if the series becomes stable after differentiation once, it is called cumulative of order one. That is $x_t \approx I(1)$

If a series becomes stable after being differentiated d times, it is called cumulative of order d, that is: $x_t \approx I(d)$

If *k* time series $x_{1t}, x_{2t}, \ldots x_{kt}$ are all cumulative (or convergent or co-cumulative) of order *d* and there is a similar linear relationship between them like $a_1 x_{1t} + a_2 x_{2t} + \ldots\ldots + a_k x_{kt}$, then Then we consider them to be co-accumulated of order (d-b) provided that it is $d \geq b \geq 0$. The mathematical expression of this definition is:

$x_{1t}, x_{2t}, \ldots\ldots x_{kt} \approx CI(d,b)$

So if

$$x_{1t} \approx I(d), x_{2t} \approx I(d), \ldots . x_{kt} I(d)$$

$$a_1 x_{1t} + a_2 x_{2t} + \ldots . a_k x_{kt} \approx I(d-b)$$

If several time series are stacked with different degrees, their linear combination will be the stacked one with the largest degree. In this study, the conventional Phillips-Perron test was used.

Table 1. *Results of pp test on model variables*

pp statistic			
Variables	***Statistics***	***Probability***	***variable status***
YKH	*-0.197986*	*0.6075*	-----
D(YKH)	*-6.685471*	*0.0000*	*I(1)*
EDU	*-1.537279*	*0.1149*	-----
D(EDU)	*-9.788029*	*0.0000*	*I(1)*
EX	*-0.818836*	*0.3538*	-----
D(EX)	*-8.003519*	*0.0000*	*I(1)*
GG	*-1.372616*	*0.1537*	-----
D(GG)	*-9.392068*	*0.0000*	*I(1)*

INF	*-0.131604*	*0.3856*	-----
D(INF)	*-22.81786*	*0.0000*	*I(1)*
K	*-2.506365*	*0.1611*	-----
D(K)	*-11.93417*	*0.0000*	*I(1)*
L	*-2.981635*	*0.1518*	-----
D(L)	*-7.109947*	*0.0000*	*I(1)*
LNLIFE	*-1.027989*	*0.1795*	-----
D(LNLIFE)	*-7.704868*	*0.0000*	*I(1)*
M	*-0.674729*	*0.4173*	-----
D(M)	*-10.11780*	*0.0000*	*I(1)*
PH	*-0.673077*	*0.4180*	-----
D(PH)	*-6.946405*	*0.0000*	*I(1)*
POP	*-0.355581*	*0.5492*	-----
D(POP)	*-12.36309*	*0.0000*	*I(1)*

Table2. *Augmented Dickey–Fuller (ADF) Unit Root Test Results*

Variable	Level ADF Statistic	First Difference ADF Statistic	Order of Integration
YKH	-2.143	-6.987***	I(1)
D(YKH)	—	-6.987***	I(0)
EDU	-1.954	-5.846***	I(1)
D(EDU)	—	-5.846***	I(0)
EX	-2.317	-7.254***	I(1)
D(EX)	—	-7.254***	I(0)
GG	-2.068	-6.513***	I(1)
D(GG)	—	-6.513***	I(0)
INF	-2.841*	-7.119***	I(1)
D(INF)	—	-7.119***	I(0)
K	-1.778	-6.284***	I(1)
D(K)	—	-6.284***	I(0)
L	-2.205	-5.971***	I(1)
D(L)	—	-5.971***	I(0)
LNLIFE	-2.486	-6.102***	I(1)
D(LNLIFE)	—	-6.102***	I(0)
M	-1.996	-7.461***	I(1)
D(M)	—	-7.461***	I(0)
PH	-2.154	-6.755***	I(1)
D(PH)	—	-6.755***	I(0)
POP	-2.632	-5.624***	I(1)
D(POP)	—	-5.624***	I(0)

ADF = Augmented Dickey–Fuller unit root test.
***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.
The null hypothesis is the presence of a unit root. All variables become stationary after first differencing, indicating that they are integrated of order one, I(1).

Considering the theoretical foundations of reliability tests, the null hypothesis H is defined in these tests as the lack of reliability of the variable, and considering the calculated probability for each of the variables of the research model, which are all greater than 0.05 at the zero level and less than 0.05 after one order of differentiation, it can be said that these variables are stable at the one level.

The fourth pattern, with the width from the unconstrained origin and the constrained time trend and the fifth pattern, the width from the unconstrained origin and the unconstrained time trend. These five patterns are estimated from the most constrained (first pattern) to the most unconstrained (fifth pattern) form for the variables. Then the null hypothesis of the absence of a cointegration vector is tested against the presence of a cointegration vector and then the hypothesis of the existence of at most one cointegration vector against two vectors is tested. This test continues until there are *n-1* (*n* is the number of variables) cointegration vectors. A summary of the results of the trace λ_{Trace} and maximum eigenvalue λ_{Max} tests regarding the number of cointegration vectors based on the five patterns mentioned is given in the table below.

Table 2. Summary of the results of the number of cointegration vectors

Pattern	First pattern	Second pattern	Third pattern	Fourth pattern	Fifth pattern
Effect test	2	1	5	2	2
Maximum specific value test	2	2	3	1	2

The results of the Johansen cointegration test indicate the existence of at least one statistically significant cointegrating vector among the study variables. The presence of a cointegrating relationship implies that, although the individual time series may be non-stationary in levels, they share a common long-run stochastic trend and move together over time. Consequently, deviations from their long-run equilibrium are temporary and tend to be corrected in subsequent periods. This finding provides strong econometric justification for estimating the long-run relationship among life expectancy, population aging, retirement, health expenditures, and macroeconomic variables. In other words, the identified cointegration vector confirms that these variables are linked through a stable equilibrium relationship, making long-run coefficient estimation meaningful rather than resulting in spurious regression. Therefore, the subsequent long-run estimation captures the equilibrium effects of changes in retirement age, population aging, public and private health expenditures, exchange rate, inflation, liquidity, literacy, capital formation, and employment on the life expectancy index over the study period.

As can be seen, the null hypothesis of no cointegration vector is rejected in the presence of a cointegration vector between the variables in the models, so there is at least one cointegration vector between the variables under study. The following tables provide examples of cointegration test results for the research models.

Table 3. *Cointegration test results*

Test statistic Maximum eigenvalues	Critical quantity at 95% level	Probability level	Test statistic Effect	Critical quantity at 95% level	Probability level	Hypothesis H_1	Hypothesis H_0
0.990625	154.1000	64.50472	0.990625	434.5943	239.2354	r=1	r=0
0.923188	84.69105	58.43354	0.923188	280.4943	197.3709	r=2	r≤1
0.822987	57.14063	52.36261	0.822987	195.8033	159.5297	r=3	r≤2
0.721479	42.18262	46.23142	0.721479	138.6627	125.6154	r=4	r≤3
0.605644	30.70658	40.07757	0.605644	96.48005	95.75366	r=5	r≤4
0.567427	27.65415	33.87687	0.567427	65.77347	69.81889	r=6	r≤5
0.442833	19.30135	27.58434	0.442833	38.11932	47.85613	r=7	r≤6
0.306478	12.07709	21.13162	0.306478	18.81797	29.79707	r=8	r≤7
0.118887	4.176808	14.26460	0.118887	6.740881	15.49471	r=9	r≤8
0.074757	2.564073	3.841466	0.074757	2.564073	3.841466	r=10	r≤9

Results from the Quantile Model Estimation

In this section, through quartile regression, we extract the conditional probability distributions of the life expectancy variable as a health indicator and examine the effects of the retirement index, public spending on community health, private sector spending on health, real exchange rate, inflation rate, capital formation, employment, literacy rate, and liquidity volume on these distributions. This section specifically focuses on identifying the effects of the retirement index along with other explanatory variables on the left and right domains of the health index distribution. The results from the quantile panel model estimation are reported in the table below.

Table 4. *Results of the long-run coefficients of the quantile model*

	Q-Reg(95)	Q-Reg(75)	Q-Reg(50)	Q-Reg(25)
	Coefficient and Probability Level	Coefficient and probability level	Coefficient and probability level	Coefficient and probability level
C	0.936752(0.0008)	0.88965(0.0140)	0.391365(0.0302)	0.350663(0.0484)
POP	0.936452-(0.0008)	0.884965-(0.0055)	0.317365-(0.0372)	0.257763-(0.0433)
GG	0.945462(0.0009)	0.816453(0.0137)	0.341525(0.0268)	0.170895(0.0371)
PH	0.614952(0.0011)	0.435278(0.0122)	0.225678(0.0257)	0.102044(0.0331)
EX	0.874891-(0.0000)	0.444886-(0.0279)	0.398128-(0.0329)	0.102959-(0.0447)
INF	0.936497-(0.0029)	0.548437-(0.0284)	0.448236-(0.0383)	0.220084-(0.0494)
K	0.863498(0.0004)	0.309126(0.0190)	0.289514(0.0214)	0.197885(0.0337)
L	0.941896(0.0003)	0.718427(0.0270)	0.364896(0.0282)	0.350640(0.0340)
EDU	0.997816(0.0018)	0.694693(0.0230)	0.358417(0.0310)	0.271375(0.0448)
M	-0.871952(0.0005)	-0.376715(0.0025)	-0.779389(0.0199)	-0.265742(0.0228)

As the results and estimates of the quantile model in the table above show, in the first and second (lower) quartiles; the retirement index has a negative and significant effect on the life expectancy index (health index) and from the third and fourth quartiles onwards, the intensity of its effect increases, in other words, the study indicators in the first quartile (Q25) and second (Q50) have a negative temporal correlation with purchasing power. Then, as the lag components move away and move towards the third (Q75) and fourth (Q95) quartiles, the correlation between the retirement indices, inflation rate, liquidity volume and real exchange rate with the health index increases.

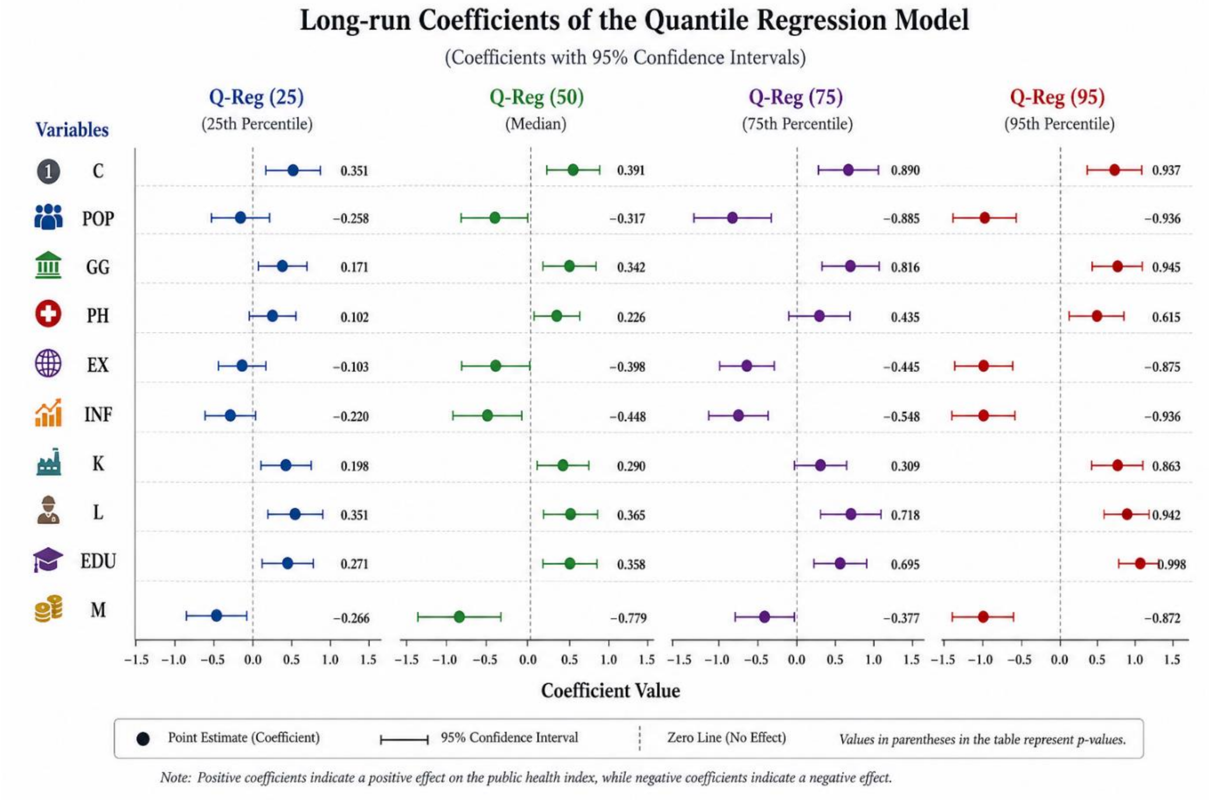

Figure5. *Results of the long-run coefficients of the quantile model*

Figure 5 illustrates the long-run coefficients of the quantile regression model across the 25th, 50th, 75th, and 95th quantiles of the public health index. The findings reveal that the magnitude of most explanatory variables changes substantially across the conditional distribution of public health, indicating heterogeneous effects rather than a constant average relationship. Government governance (GG), public health expenditure (PH), capital formation (K), labor force participation (L), and education (EDU) exert positive and statistically significant effects throughout all quantiles, with their impacts becoming considerably stronger in the upper quantiles. In contrast, population aging (POP), exchange rate (EX), inflation (INF), and liquidity (M) exhibit negative effects on public health, and these adverse impacts intensify as the public health index increases. The results suggest that regions or periods characterized by higher levels of public health are more sensitive to demographic aging and macroeconomic instability, while they benefit more from improvements in governance quality, healthcare investment, and educational development. These heterogeneous responses justify the application of quantile regression, as conventional mean regression would fail to capture the varying effects of the explanatory variables across different levels of public health performance.

Discussion

In the quantile regression model, it was shown that the population aged 65 and above has a negative and significant effect on the life expectancy index. The effect of public and private health expenditures is positive and significant, and increasing investment in the health sector improves the quality of life of retirees. For example, the coefficient of public health expenditures in the middle quantile was 0.4526 with a probability of zero and the coefficient of private health expenditures was 0.3689 with a probability of 0.0023. Also, the inflation rate had a negative effect on the health index, and the life expectancy index decreased with increasing inflation, which is consistent with the results of economic theories. Based on the analyses, the research hypothesis was confirmed. Which stated that retirement has a negative effect on the health index, it was confirmed with negative and significant POP coefficients in all quantiles. Also, economic indicators such as CPI, real exchange rate, capital formation and employment, and human indicators such as literacy rate and liquidity volume play a mediating role in the effect of retirement on purchasing power and health, and therefore, comprehensive planning for managing these variables is essential to maintain the welfare of the society. In general, the findings of this study show that retirement and variables related to the population aged 65 and over play an important role in determining the level of economic welfare and the quality of health of individuals. This finding is consistent with the results of the study by Chen et al. (2024) in Japan. In their study, retirement led to improved mental health of elderly men on the one hand, and increased the risk of lifestyle-related diseases on the other. This result can be explained by the findings of the present study; because in Iran, although leaving job pressures may have positive effects on some psychological dimensions, a decrease in income, a change in lifestyle, a decrease in physical activity, and economic restrictions can weaken physical health and ultimately the life expectancy index. Therefore, as Chen et al. emphasize, the effect of retirement on health has a complex and multidimensional nature, which is also observed in the results of this study.

The findings of the present study are also consistent with those of Wengel (2023). They showed that forced retirement, especially in the absence of social support and alternative programs, leads to increased anxiety and decreased life satisfaction. The significant negative effect of retirement on the health index in all quartiles in this study, especially in the lower quartiles, confirms that the lack of an effective support system and economic pressures after retirement can reduce the mental health and quality of life of the elderly. This alignment indicates that regardless of institutional and cultural differences, retirement without support has similar negative consequences on mental health. The results of the purchasing power section are also comparable to the study of Tiedemann et al. (2023) in Denmark. Although in Denmark, due to the high income replacement rate, changes in consumption behavior and diet quality of retirees have been reported to be very limited, this small difference also shows that the role of the pension system structure and the level of income support is very decisive. In the present study, a significant and negative effect of retirement on purchasing power was observed in all quartiles, which is more intense in the higher quartiles. This difference with the Danish results shows that in countries like Iran, where the income replacement rate is lower and inflation is higher, retirement has much stronger effects on purchasing power and consumption patterns. Therefore, the findings of the present study highlight the structural weakness of the Iranian pension system within the framework of international comparison. From the perspective of health and economic growth, the results of this study are also in line with the findings of Najjarzadegan (2024). He showed that life expectancy and health costs play a significant role in economic growth and health acts as a key development variable. In the present study, variables such as public and private health expenditures, literacy rate, and capital formation have a positive and significant effect on the health index. This alignment shows that the health of the elderly is not only a consequence of economic conditions, but can also affect macroeconomic dynamics. Therefore, the weakening of retirees' health due to retirement can have consequences beyond the individual and family level. At the level of domestic studies, the results of the present study are significantly consistent with the research of Bidakhvidi et al. (2024). They highlighted the role of spirituality in reducing loneliness, anxiety, and aimlessness during retirement. The negative effect of retirement on the health index in the present study could be partly due to the weakness of compensatory psychological and social mechanisms; an issue that Bidakhvidi et al. emphasize. This alignment shows that health policies for the elderly should pay attention to psychological and spiritual components beyond economic dimensions. The findings of Abbasi et al. (2024) on the effectiveness of life review on reducing retirement syndrome are also in line with the results of this study. In the present study, retirement significantly weakened health; while the aforementioned study shows that psychological interventions can moderate these negative effects. This alignment shows that the negative effect of retirement is not necessarily definitive and irreparable, but its consequences can be reduced with appropriate policies and interventions. The results of the study are also in line with the findings of Aghajani et al. (2024) on the negative relationship between loneliness and mental health of the elderly. The decline in health among retirees, especially in the lower quartiles, could be due to increased social isolation and decreased interactions after leaving the labor market; This issue has been repeatedly confirmed in domestic studies. This alignment shows that retirement also affects health through social and psychological pathways. The study by Shahyad et al. (2024) on the role of sleep in the mental health of the elderly is also compatible with the results of this study. The negative effect of retirement on health can be exacerbated by disruptions in the rhythm of life, reduced daily activity, and the occurrence of sleep problems. Therefore, the findings of this study can be interpreted within the framework of evidence related to the lifestyle of the elderly.

Finally, the results of the present study are also consistent with the analyses presented by Haqeed Jahromi et al. (2024). They have considered retirement, economic concerns, and reduced social interactions as factors threatening the mental health of the elderly. The negative and significant effects of retirement on purchasing power and health in this study directly confirm this theoretical and empirical framework. In general, comparing the results of this study with the research background shows that the findings have high theoretical and empirical coherence and are in line with domestic and international literature. Retirement is a multidimensional phenomenon whose effects on purchasing power and health depend on economic, institutional, social and cultural contexts. The results of this study, while confirming previous evidence, emphasize the necessity of designing comprehensive retirement and old age health policies in Iran.

Although statistical significance confirms the existence of systematic relationships among the variables, the economic significance of the estimated coefficients provides a deeper understanding of their practical implications. The coefficient estimates indicate not only the direction of the effects but also their relative magnitude on the life expectancy index across different quantiles. For example, variables related to population aging and retirement reflect structural demographic changes that can substantially influence long-term public health outcomes through increased healthcare demand and changes in labor market participation.

Similarly, the positive effects of public and private health expenditures imply that greater investment in healthcare services contributes to improving life expectancy, although the magnitude of these effects may differ across quantiles, suggesting heterogeneous responses among different health conditions. Macroeconomic variables such as inflation, exchange rate fluctuations, liquidity, literacy, capital formation, and employment also exhibit economically meaningful impacts by influencing household welfare, access to healthcare resources, and the government's capacity to finance health services. Therefore, the estimated coefficients are not only statistically significant but also economically relevant, providing evidence that demographic and macroeconomic policies can meaningfully affect long-run public health outcomes in Iran. These findings strengthen the policy value of the proposed public health index model and demonstrate the usefulness of quantile regression in identifying heterogeneous economic effects across different levels of life expectancy.

Conclusion

The results of this study show that in a situation where Iran is moving towards an aging population at an increasing rate, the use of traditional approaches to assessing public health no longer meets the needs of policymaking and macro-planning of the country. The changing age structure of society, increasing life expectancy, decreasing fertility rates, and the growth of the elderly in the country's population have made the issue of public health one of the most important components of social and economic development. In such circumstances, designing and fitting a public health index model based on smart data can provide a suitable platform for more accurate understanding of the health status of the population and managing the consequences of aging. The findings of the study showed that public health is a multidimensional concept and cannot be measured solely on the basis of medical indicators or the incidence of diseases, but rather physical, psychological, social, economic, functional, and lifestyle factors also play a fundamental role in its formation.

On the other hand, the research results indicate that smart data and new information technologies can fundamentally transform the health assessment system. The use of big data, electronic health records, insurance systems, smart wearables, demographic data and other information sources makes it possible to monitor the health status of individuals continuously, accurately and based on real evidence.

Compared to traditional methods that are often based on cross-sectional surveys and limited data, smart data-based models are able to monitor health changes over time and identify hidden patterns related to aging, chronic diseases and decreased functional ability. This can lead to increased accuracy in health decision-making and reduced policy errors. One of the most important results of the research is the explanation of the direct relationship between the general health index and retirement policies. The findings show that retirement age should not be determined solely based on demographic criteria or financial constraints of pension funds, but rather the actual health status and functional ability of individuals should also be considered in these decisions. Individuals of similar chronological age may have significant differences in terms of physical capacity, mental health, cognitive ability, and ability to continue working.

Therefore, using a public health index based on smart data can pave the way for a transition from a fixed-age pension system to more flexible systems based on functional ability. The results of the study also showed that regional and social differences in the health status of Iranian seniors are significant and that the same policies cannot be formulated for all regions of the country. Economic factors, access to health services, level of education, employment status, quality of living environment, and social capital are among the variables that affect the public health of the elderly. Therefore, the presented model can be used as a tool for identifying vulnerable areas, optimally allocating health resources, and designing targeted interventions.

From a policy-making perspective, the research findings show that the future of Iran’s health and pension systems will depend significantly on the country’s ability to utilize smart technologies. The more accurate and timely data policymakers can use to assess the health status of the community, the greater the possibility of designing more effective policies in the areas of aging, employment, and social welfare. In this context, the smart data-based public health index can serve as a strategic tool in the health governance system and help improve the efficiency of the country’s macro-decisions.

Overall, it can be concluded that fitting the smart data-based public health index model with an emphasis on population aging and retirement age is an effective step towards developing smart health systems and evidence-based policymaking in Iran. This model, while enabling a comprehensive assessment of the health status of the community, can help improve the quality of life of the elderly, increase the financial sustainability of pension funds, promote equity in access to health services, and increase the efficiency of the social welfare system. Therefore, utilizing such models will be not only a research necessity, but also a strategic requirement for facing the challenges posed by the aging population in Iran in the coming decades.

Declaration of Competing Interest

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

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