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Association between healthcare resources, healthcare systems, and population health in European countries

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Abstract

Background Recently, the demand for care has risen, while in contrast, healthcare resources remain limited. These resources include health expenditure, the number of physicians, nurses, and hospital beds. Many studies have revealed that healthcare resources are one of the most critical factors contributing to a population's health status. The healthcare system plays a key role in transforming these resources into health outcomes, which are widely used as indicators to measure population health and the performance of healthcare systems. Previous work has primarily investigated the relationship between health expenditure or the number of doctors and population health. However, the association between healthcare resources as a whole has yet to be widely examined.

Methods This study utilized multilevel regression analysis to explore the association between healthcare resources, healthcare systems, and population health outcomes across 25 European countries. The healthcare systems in these countries are primarily categorized into two types: Beveridge-type and Bismarck-type. In addition to regression analysis, descriptive statistics were used to analyze the allocation patterns of healthcare resources. Welch's t-test was employed to compare the performance metrics of the Beveridge-type and Bismarck-type healthcare systems, providing a statistical basis for understanding differences in their effectiveness.

Results The regression analysis revealed positive correlations between health expenditure per capita, the number of physicians, and nurses, and life expectancy at birth, while the number of hospital beds showed a negative correlation. Conversely, infant mortality was negatively correlated with health expenditure per capita and the number of physicians and nurses, and positively correlated with the number of hospital beds. The models did not find statistical significance in the effects of healthcare system type (Beveridge-type or Bismarck-type) on life expectancy at birth or infant mortality rates. Additionally, Welch's t-test indicated that the Beveridge-type healthcare system generally showed better performance outcomes compared to the Bismarck-type system.

Conclusions The findings indicate that higher allocations of certain healthcare resources, such as hospital beds, are associated with poorer health outcomes, which suggests potential inefficiencies in resource utilization. Observations also show that countries using the same healthcare systems tend to have similar patterns of resource allocation, which may influence the performance of these systems. Policymakers should consider these associations when planning resource allocation and when selecting or modifying healthcare system models in their countries.

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Keywords Resource allocation, Population health, Healthcare system performance, Healthcare resources, Health outcomes, Multilevel regression model

Background

The global population is noticeably aging, with people living longer lives than ever before. Advancements in medical care, better nutrition, and overall improvements in living conditions fuel this significant change [1]. As a result, the proportion of older individuals within the global demographic is increasing. This shift is reshaping various aspects of society, from healthcare provision and pension schemes to labor markets and family dynamics. Adapting to this new reality is essential, as it will deeply influence future economic and social policies, ensuring that an aging population's needs are met sustainably. According to data from the World Bank, in 2020, there were 724,484,054 persons aged 65 and above, accounting for 9% of the world population [2]. In 2021, Europe had the highest percentage of its population within this age group at 19%, followed by North America at 17%, Oceania at 13%, Asia and Latin America and the Caribbean at 9%, and Africa at 4% [3]. This demographic shift is prompting policymakers to pay more attention to healthcare systems. Healthcare systems translate resources into health outcomes. Healthcare resources refer to financial resources (health expenditure), human resources (physicians and nurses), facilities (hospital beds), equipment, and supplies [4, 5]. Health expenditure includes aggregate healthcare spending on health services, family planning activities, nutrition activities, and emergency aid designated for health [6]. In 2019, world health expenditure accounted for approximately 9.84% of GDP, with the European Union's spending slightly higher at 9.92% [7].

The rapid growth of health expenditure has become a significant concern for households and governments. The World Health Organization (WHO) revealed that between 2000 and 2017, global health expenditure grew by 3.9%, outpacing global GDP growth, which was 3% [8]. The allocation of healthcare resources becomes problematic due to their limited nature [9]. Thus, examining how these allocations affect health outcomes is vital. These findings assist policymakers in planning the allocation of funding for healthcare resources. Recently, health policymakers have increasingly focused on the performance of healthcare systems. Life expectancy at birth and infant mortality are often used to assess this performance [10–14]. Evaluating the performance of healthcare systems could help policymakers secure quality improvements and manage systems effectively [11]. Moreover, international comparisons of healthcare systems could also guide health policy [15].

Population health is key to economic development [16, 17]. A healthy society boosts economic productivity. Thus, maintaining a strong workforce is essential. Population health can be defined as the health outcomes of a group of individuals, including the distribution of such outcomes within the group [18]. Common measures of population health include life expectancy at birth and infant mortality rates [19–22]. Previous studies have demonstrated associations between healthcare resources and population health outcomes [23–28]. Extensive research has documented associations between healthcare resources and population health outcomes, mainly focusing on health expenditure and the number of physicians [24, 29–33]. Despite the breadth of research, comprehensive investigations into how a broader range of healthcare resources—including health expenditure, the number of physicians, nurses, and hospital beds—affect health outcomes on both national and international scales remain relatively limited.

In health service research, it is common to categorize healthcare systems based on the model that a country uses [34, 35]. Healthcare models outline the methods by which countries finance, organize, and deliver health services to their populations [36]. These models vary globally due to differences in funding, administration, and the roles of the public and private sectors. Generally, healthcare systems fall into four main categories: Beveridge, Bismarck, national health insurance, and out-of-pocket models [34, 37]. Previous studies have suggested that healthcare systems are associated with health outcomes [38, 39]. Much research has focused on evaluating the performance, efficiency, and effectiveness of healthcare systems [40, 41]. Yet, there remains no consensus on which healthcare system model is superior in terms of performance or efficiency. The Beveridge and Bismarck models are the most common healthcare models widely used in Europe [42]. They have been compared over the past two decades to determine which performs better and is more effective [35, 43]. However, comprehensive studies that explore the associations between these models and population health outcomes, specifically comparing Beveridge-type and Bismarck-type systems, are lacking.

In 1972, Michael Grossman introduced Grossman's Health Capital Model, which proposes how investments in health may influence individual well-being and economic productivity [44]. This approach has significantly influenced public health policy, healthcare management, and health economics research. In this model, health is considered a form of capital that depreciates over time but can be improved through investment [44]. To counteract this depreciation, individuals can invest in their health, similarly to how they might invest in the maintenance or upgrade of capital goods to enhance their longevity and performance. These health investments can take various forms, such as medical care, lifestyle choices, and other activities that improve health or slow its decline [44]. In empirical research, Grossman's model can be formulated into regression models to analyze the relationship between health investments and health outcomes [45].

This study aimed to address research gaps by utilizing the Grossman Health Capital Model to explore the associations between healthcare resources, healthcare systems, and population health in 25 European countries from 2000 to 2018. These countries were categorized into Beveridge-type and Bismarck-type healthcare systems. Accordingly, this research investigated the allocation patterns of healthcare resources in these systems, exploring how these allocations were associated with population health outcomes. To the best of my knowledge, no previous research has conducted a comprehensive comparative analysis of these specific healthcare systems' associations with population health. This study also assessed the performance of Beveridge-type and Bismarck-type healthcare systems. The findings provide insights into how healthcare resources and systems may relate to population health and offer considerations for policymakers in making informed decisions on allocating budgets for healthcare resources, shaping health policy, and selecting or adapting healthcare models.

Literature review

Healthcare systems: Bismarck and Beveridge

A healthcare system can be defined as the manner in which healthcare is financed, organized, and delivered to a population [37]. Healthcare systems can generally be categorized into four basic models: Bismarck, Beveridge, national health insurance, and out-of-pocket [34, 37]. The Beveridge model, also referred to as 'National Health Services,' was developed by Sir William Beveridge in the United Kingdom [46]. In this model, healthcare is provided and financed by the government through taxation; many hospitals and clinics providing care are owned by the government [47, 48]. The government acts as the sole payer, which eliminates market competition and helps keep costs low [42, 49]. The Beveridge system is used in the United Kingdom, Italy, Spain, Sweden, Denmark, Norway, and Finland [42].

Chancellor Otto von Bismarck introduced the Bismarck model (also referred to as 'social insurance systems') in the nineteenth century [42, 50]. Employers and employees jointly finance health insurance through sickness funds, which are created by compulsory payroll deductions and often supplemented by general tax revenue [42, 51]. Most hospitals and health service providers are privately owned [50]. Unlike the insurance industry, Bismarck health insurance plans do not permit insurers to make a profit, as the price of health services is tightly controlled by law [52]. This tight regulation allows the government to contain costs and operate in a manner similar to the Beveridge Model [52]. The model is employed by Germany, France, Austria, Switzerland, Belgium, the Netherlands, and Japan [42].

Previous research has extensively explored the relationship between healthcare system types and population health outcomes. Studies have shown that healthcare systems play a crucial role in determining health outcomes [53–55]. The Beveridge model, which is primarily funded through taxation and government control, has been linked to better access to universal healthcare services and improved health outcomes, such as increased life expectancy and reduced infant mortality [56]. On the other hand, the Bismarck model, characterized by social health insurance and private provision of care, has demonstrated effectiveness in ensuring broad health coverage and high-quality services, though with variations in access depending on income levels [57]. Comparative studies between these two models have revealed mixed results; while some research suggests that Beveridge systems perform better in terms of cost containment and public health metrics, others highlight the advantages of the Bismarck model in terms of individual care quality and system sustainability. However, there remains no consensus on which system consistently produces superior health outcomes.

The National Health Insurance model (NHI) incorporates elements from both the Bismarck and Beveridge models [58, 59]. In the NHI system, similar to the Beveridge model, the government acts as the sole payer for medical costs [58, 59]. However, like the Bismarck model, care is primarily provided by private actors [58]. Universal insurance under this model does not generate profits or deny claims [58]. Canada, South Korea, and Taiwan are examples of countries that use this model [42, 59]. The out-of-pocket model is most common in developing countries where governments lack the financial resources to provide widespread medical care [60, 61]. In the out-of-pocket model, individuals pay for healthcare procedures as needed [60, 61]. The United States, India, and China use this model [61].

Currently, the performance of healthcare systems is attracting more interest because the demand for care is growing and expected to rise, while public financing remains constrained. Life expectancy at birth and infant mortality have become primary indicators for evaluating a country's healthcare system performance [62–64]. Many researchers have tried to apply various methods to evaluate healthcare systems at local, regional, national, and international levels [14, 63, 65–68]. However, future studies are needed to determine which healthcare systems perform best and which determinants most significantly affect their performance.

Health outcomes indicators: life expectancy and infant mortality

Worldwide, healthcare systems face the challenge of controlling health spending while maximizing population health. Efficient healthcare systems can enable populations to live longer and healthier lives. Over the past decades, health outcome indicators have been extensively used to evaluate population health and the performance of healthcare systems [12, 69–71]. Life expectancy at birth and infant mortality are important health outcome indicators for measuring the population's health and assessing the performance of healthcare systems [70, 72].

In this study, life expectancy at birth and infant mortality are used as key indicators to examine the associations between different healthcare resources and healthcare system types, such as the Beveridge and Bismarck models. Prior research has shown that the structure and efficiency of healthcare systems are associated with these health outcomes [53–55]. The Beveridge and Bismarck systems, in particular, have been widely studied for their relationship with health indicators, with varying results depending on factors such as cost-effectiveness, access to healthcare services, and quality of care [54, 55]. Healthcare resources, such as health expenditure, the number of physicians, and hospital beds, are key components of these systems and are associated with life expectancy at birth and infant mortality by reflecting the availability and quality of healthcare services [23–28]. By analyzing these two indicators, this study aims to explore how different healthcare systems and resources in European countries are related to overall population health.

WHO defines life expectancy at birth as 'the average number of years a newborn could expect to live' [73]. Over the past decades, many researchers have explored factors associated with life expectancy [74–76]. Swift [77] utilized Johansen multivariate cointegration analysis to investigate the association between life expectancy and GDP for 13 Organization for Economic Cooperation and Development (OECD) countries over the last two centuries. The author reported that changes in total GDP and GDP per capita were significantly associated with changes in life expectancy. A 1% increase in life expectancy was associated with an average increase of 6% in total GDP and 5% in GDP per capita. Garcia et al. [78] examined the relationship between the inflation rate and life expectancy using data from 120 countries in 2017. Through binary logistic regression analysis, they found that the inflation rate was negatively correlated with life expectancy; life expectancy would decrease by about 20% for each unit increase in the inflation rate. Data from the Population Reference Bureau [79] indicate that female life expectancy at birth is generally higher than male life expectancy, suggesting that countries with a higher percentage of females tend to exhibit higher overall life expectancy.

The Centers for Disease Control and Prevention (CDC) defines infant mortality as 'the death of an infant before his or her first birthday' [80]. Research has shown that factors such as female literacy, participation in the labor force, fertility rates, unemployment, inflation, gross domestic product (GDP), and gross national income (GNI) are associated with infant mortality rates [81–89]. Siah and Lee [90] investigated the short-run and long-run relationships and causality between female labor force participation, infant mortality rates, and fertility in Malaysia. Their study indicated that higher infant mortality rates are associated with higher fertility in the long term, while women's childbearing decisions appeared to be unaffected by their employment status. Jiang and Liu [91] studied the relationship between inflation and infant mortality in China using a mixed frequency vector autoregressive model, impulse response analysis, and forecast error variance decomposition. Their findings suggested that inflation is positively correlated with infant mortality. Zakir and Wunnava [92] utilized a cross-sectional model including 117 countries in 1993 to explore factors influencing infant mortality rates. Their analysis showed significant correlations between infant mortality rates and factors such as fertility rates, female participation in the labor force, per capita GNI, and female literacy rates. Using panel data analysis techniques, Erdogan et al. [93] examined the relationship between economic growth and infant mortality in 25 high-income OECD countries from 1970 to 2007. They identified a significant inverse correlation between the infant mortality rate and real per capita GDP, indicating that infant mortality rates tend to decrease as countries' economies grow. Miladinov [94] analyzed the association between socioeconomic factors and infant mortality in Macedonia, Turkey, and Albania using macro aggregate level time-series data from 1991 to 2017. Their results demonstrated a significant negative correlation between infant mortality and variables such as the total unemployment rate, female employment in agriculture, the gender parity index for secondary school enrollment, and GNI per capita.

Methods

Research objectives

The main goal of this study was to explore how healthcare resources and healthcare systems were associated with population health in 25 European countries from 2000 to 2018. It utilized life expectancy at birth and infant mortality as health outcome indicators to represent population health and assess the performance of these healthcare systems. The 25 European countries in this study were primarily categorized into Beveridge-type and Bismarck-type systems. This research also investigated whether there were any differences in the allocation patterns of healthcare resources among countries using these two systems. Additionally, the study employed these health outcome indicators to compare the performance of the Beveridge-type and Bismarck-type systems. The research questions were formulated as follows:

- Q1: How were healthcare resources and healthcare systems associated with population health in 25 European countries from 2000 to 2018?
- Q2: How were healthcare resources allocated in 25 European countries with Beveridge-type and Bismarck-type healthcare systems over the past 19 years (2000 to 2018)?
- Q3:Was there statistical significance in the differences in the performance of Beveridge-type and Bismarck-type healthcare systems in 25 European countries from 2000 to 2018?

Life expectancy at birth and infant mortality were selected as measures of population health because they are widely recognized and commonly used in public health research as standard indicators of overall health system performance [70, 72]. Life expectancy reflects the overall longevity and health quality of a population, while infant mortality serves as a sensitive indicator of a country's healthcare quality, especially in relation to maternal and child health services [95]. Despite their widespread use, these indicators have limitations. Life expectancy at birth, for instance, does not account for disparities within subpopulations or provide information on the quality of life during those years [95]. Similarly, while infant mortality is a critical indicator of early life conditions, it may not capture the broader spectrum of health challenges faced by the population, such as non-communicable diseases or morbidity in later life [95]. Other potential population health indicators include disability-adjusted life years (DALYs), quality-adjusted life years (QALYs), and disease-specific mortality rates, which can provide a more nuanced understanding of the burden of disease and healthcare system performance [96]. These measures offer a broader perspective on both the quality and quantity of life, accounting for years lived in good health and the impact of specific diseases. However, such data were not consistently available for all the countries and years in this study, limiting their use in the present analysis.

Dataset

This research covered 25 European countries from 2000 to 2018, including Austria, Bulgaria, Czechia, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom. The 25 European countries selected for this study were chosen based on several factors. First, these countries were selected because they represent a mix of healthcare systems, specifically the Beveridge-type and Bismarck-type systems, which are the predominant models in Europe. This allowed for a comparative analysis of how different healthcare systems impact population health. Second, these countries have reliable and comprehensive data available from international databases such as the World Bank, Eurostat, and UN, ensuring consistency and accuracy in the analysis. Lastly, the selected countries cover a broad geographic and economic spectrum within Europe, providing a diverse representation of healthcare systems, resource allocation, and population health outcomes. Data were collected from 2000 to 2018 because this period provided consistent and comprehensive data for all required variables across the 25 European countries studied. This ensured that the analysis could be conducted using complete datasets, allowing for accurate comparisons and meaningful conclusions.

Data were collected from the World Bank, Eurostat, and UN databases to construct a dataset [97–99]. Data from the World Bank was used as the primary source, and where data were missing for certain countries in specific years, they were supplemented with data from Eurostat and UN databases. All sources (World Bank, Eurostat, and UN databases) provided observations for each year and each variable across the study period. The data from the World Bank, Eurostat, and UN databases are considered highly reliable due to the stringent standards these organizations adhere to during their data collection processes [100–102]. They employ various methods to gather information, including surveys, official records, and collaborations with national statistics offices. These data are consistently reviewed and updated to ensure they remain both current and accurate. Moreover, the transparency of their methodologies allows users to assess the data's applicability for specific research purposes.

Variables in this study included life expectancy at birth, infant mortality rate, health expenditure per capita PPP, the number of physicians, nurses, and hospital beds, fertility rate, unemployment rate, percentage of the female population, inflation rate, GNI PPP, and GDP PPP. The variables selected for this analysis—health expenditure per capita, the number of physicians, nurses, and hospital beds—were chosen because they are widely recognized as critical indicators of healthcare resource availability and have been extensively used in previous research to analyze population health outcomes [23–28]. Health expenditure per capita reflects the financial resources allocated to healthcare, which has been linked to better health outcomes such as increased life expectancy [29–32]. The number of physicians and nurses is often used as a measure of the capacity of healthcare systems to provide medical services, and prior studies have demonstrated their association with both life expectancy and infant mortality [24, 25, 33]. The number of hospital beds has been included as a broader indicator of healthcare infrastructure, with mixed results in its relationship with population health outcomes. These variables are consistent with previous research exploring the relationship between healthcare resources and health outcomes in cross-national studies [23–28].

Life expectancy at birth was measured in total years, and infant mortality rate was measured per 1,000 live births. This was a cross-national study. Purchasing power parity (PPP) is the widespread metric used to compare countries' currencies through a 'basket of goods' approach [103]. Therefore, health expenditure per capita, GNI, and GDP were calculated in terms of purchasing power parity (PPP) in US dollars. The number of physicians, nurses, and hospital beds was estimated per 1,000 people. The fertility rate was measured as the total number of births per woman. The unemployment rate was calculated as a percentage of the total labor force. The percentage of the female population was estimated as a percentage of the total population. The inflation rate was calculated based on the consumer price index, reflecting the annual percentage change.

Two types of the healthcare systems

Based on the existing literature, the 25 European countries can be divided into two healthcare models: the Beveridge and Bismarck models [42, 47, 104–114]. These models are classified based on how the healthcare system is financed, organized, and delivers care to a population [36]. The classification of the 25 European countries is presented in Table 1. The Beveridge and Bismarck healthcare system types were selected for this study due to their predominance in the European context and their distinct approaches to healthcare financing and delivery [42]. The Beveridge system is primarily funded through taxation, with the government managing healthcare provision, while the Bismarck system relies on social health insurance funds that operate independently from the government [42, 47, 48, 51]. Both systems have been extensively studied in the scientific literature for their impacts on population health and healthcare system performance.

Table 1 Classification of the European healthcare systems

Healthcare model	Countries
Beveridge model	Denmark, Finland, Iceland, Ireland, Italy, Latvia, Norway, Portugal, Spain, Sweden, United Kingdom
Bismarck model	Austria, Bulgaria, Czechia, Estonia, France, Germany, Hungary, Lithuania, Luxembourg, Netherlands, Poland, Slovakia, Slovenia, Switzerland

Other healthcare system models, such as the National Health Insurance model and the Out-of-Pocket model, were considered, but these are less prevalent in the European countries studied and were therefore not included in this analysis. Focusing on the Beveridge and Bismarck models allowed for a more consistent and relevant comparison of healthcare system impacts within Europe.

Descriptive statistics

This study began with a descriptive analysis to explore the data and investigate the specific trends of the studied variables. The allocation pattern of healthcare resources in countries using the Beveridge-type and Bismarck-type healthcare systems was also observed in this analysis. The allocation pattern describes how resources are distributed or allocated across different sectors, projects, geographical areas, or groups within a specific context. Understanding allocation patterns in various fields such as economics, healthcare, environmental management, and business helps optimize resource use and achieve strategic objectives [115, 116]. There were 11 countries in this study using the Beveridge-type healthcare system, accounting for 44%, and 14 countries using the Bismarck-type healthcare system, accounting for 56%. Table 2 shows the descriptive statistics for the two healthcare systems. Figure 1 displays the average life expectancy at birth, average infant mortality rate, average health expenditure per capita PPP in US dollars, and average numbers of physicians, nurses, and hospital beds for the two healthcare systems from 2000 to 2018.

According to Table 2, from 2000 to 2018, Beveridge-type countries had a higher average life expectancy at birth (79.752 years, SD = 2.782) compared to Bismarck-type countries (77.552 years, SD = 3.412). In contrast, the average infant mortality rate was lower in Beveridge-type countries (3.674 per 1,000 live births, SD = 1.560) than in Bismarck-type countries (4.616 per 1,000 live births, SD = 2.146). Figure 1 shows that the trends in life expectancy at birth, infant mortality, health expenditure, and the number of physicians, nurses, and hospital beds follow similar patterns between the two systems. Life expectancy increased, while infant mortality decreased over time in both systems. Health expenditure per capita PPP rose consistently in both Beveridge-type and Bismarck-type healthcare systems. The number of physicians generally increased in Beveridge-type countries, while in Bismarck-type countries, it remained stable until 2011, after which it began to rise until 2018. The number of nurses fluctuated in both systems, growing until 2011 and then varying. Conversely, the number of hospital

Table 2 Descriptive statistics for the two healthcare systems

Variable	Healthcare model	N	Mean	SD	Min	Max
Life expectancy at birth, total (years)	Beveridge model	209	79.752	2.782	70.315	83.432
	Bismarck model	266	77.552	3.412	70.259	83.754
Mortality rate, infant (per 1,000 live births)	Beveridge model	209	3.674	1.560	1.600	11.500
	Bismarck model	266	4.616	2.146	1.900	14.400
Health expenditure per capita, PPP (US dollars)	Beveridge model	209	3300.260	1323.261	434.409	7009.246
	Bismarck model	266	2812.017	1781.990	373.598	8447.556
Physicians (per 1,000 people)	Beveridge model	209	4.077	1.289	2.230	7.961
	Bismarck model	266	3.633	1.0588	2.127	6.633
Nurses (per 1,000 people)	Beveridge model	209	10.785	5.177	3.674	23.113
	Bismarck model	266	8.960	3.507	4.061	22.189
Hospital beds (per 1,000 people)	Beveridge model	209	4.136	1.506	2.140	8.770
	Bismarck model	266	6.387	1.289	3.170	9.120
Fertility rate, total (births per woman)	Beveridge model	209	1.668	0.254	1.210	2.230
	Bismarck model	266	1.494	0.1931	1.150	2.030
Unemployment, total (% of total labor force)	Beveridge model	209	8.094	4.484	1.870	26.090
	Bismarck model	266	7.962	3.971	1.810	19.920
Population, female (% of total population)	Beveridge model	209	51.016	1.1965	49.525	54.2106
	Bismarck model	266	51.496	1.017	49.539	54.0155
Inflation, consumer prices (annual %)	Beveridge model	209	2.265	2.158	-4.478	15.402
	Bismarck model	266	2.506	2.403	-1.418	12.349
GNI, PPP (US dollars)	Beveridge model	209	6.64×10^{11}	8.13×10^{11}	8.06×10^{9}	3.12×10^{12}
	Bismarck model	266	6.23×10^{11}	9.69×10^{11}	1.27×10^{10}	4.73×10^{12}
GDP, PPP (US dollars)	Beveridge model	209	6.70×10^{11}	8.17×10^{11}	8.37×10^{9}	3.16×10^{12}
	Bismarck model	266	6.20×10^{11}	9.50×10^{11}	1.32×10^{10}	4.58×10^{12}

N Number of observations, *SD* Standard deviation

beds decreased across both healthcare systems over the study period.

Table 2 also shows that the means of health expenditure per capita, and the number of physicians and nurses, were higher in Beveridge-type countries than in Bismarck-type countries. Specifically, health expenditure per capita was $3,300.260 for Beveridge-type countries compared to $2,812.017 for Bismarck-type countries. The number of physicians and nurses was also higher in Beveridge-type countries (4.077 physicians and 10.785 nurses per 1,000 people) compared to Bismarck-type countries (3.633 physicians and 8.960 nurses per 1,000 people). However, the number of hospital beds was higher in Bismarck-type countries (6.387 per 1,000 people) than in Beveridge-type countries (4.136 per 1,000 people).

Inferential statistics

Regression analysis

This study employed Grossman's Health Capital Model [44] to explore how healthcare resources and healthcare systems were associated with population health outcomes, specifically life expectancy at birth and infant mortality, in 25 European countries from 2000 to 2018. According to Grossman, health is defined as a durable capital stock that yields an output of healthy time. It is assumed that individuals inherit an initial stock of health, which depreciates with age but can be increased through investments in health [44]. Equation (1) illustrated Grossman's Health Capital Model, which was applied to analyze the relationships between healthcare inputs and population health outputs.

$$H_t = F\left[X_t\right] \quad (1)$$

where H_t represents the health outcome, and X_t encompasses all the inputs that contribute to the health outcome. Previous research has indicated that the health outcome is associated with these inputs: healthcare systems (HS_t), healthcare resources (RE_t), and other variables that potentially influence population health outcomes (C_t) [24, 75, 76, 78, 85, 88, 91, 94, 117–119]. Thus, Eq. (1) can be rewritten as follows:

$$H_t = F\left[HS_t, RE_t, C_t\right] \quad (2)$$

Grossman's Health Capital Model can be effectively utilized in empirical studies through regression analysis, which allows researchers to explore the associations between health investments and health outcomes [120]. Consequently, Eq. (2) can be rewritten as follows:

$$H_{it} = \beta_0 + \beta_1 HS_{it} + \beta_2 RE_{it} + \beta_3 C_{it} + e_{it} \quad (3)$$

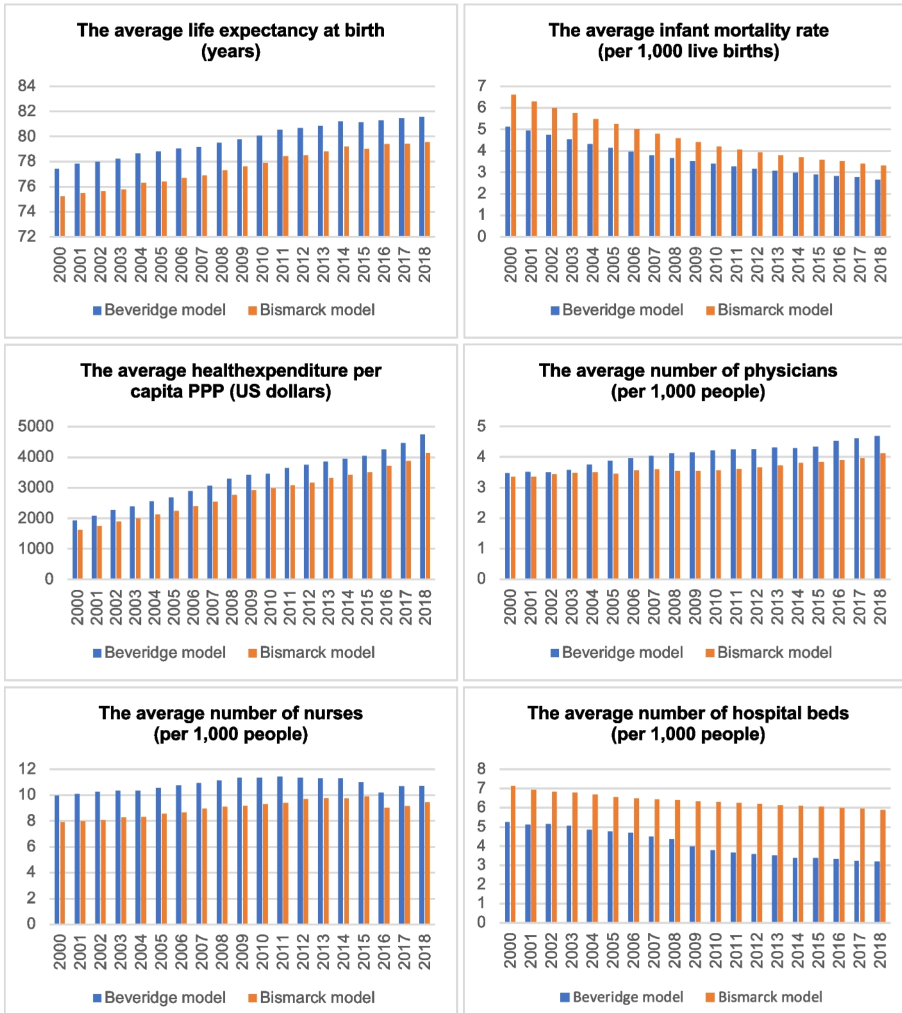

Fig. 1 Average life expectancy at birth, infant mortality, health expenditure per capita PPP, and numbers of physicians, nurses, and hospital beds in the two healthcare systems, 2000–2018

where H_{it} is a health outcome indicator (life expectancy at birth or infant mortality) for country i where $i = 1,2,3\ldots$ at time $t = 1,2,3.$ RE_{it} represents the corresponding healthcare resources, including health expenditure, the number of physicians, nurses, and hospital beds. HS_{it} is the indicator for the type of healthcare system (Beveridge-type or Bismarck-type), and C_{it} includes all the corresponding control variables. β_0 is the intercept. β_1, β_2 and β_3 are the slope coefficients. e_{it} is the random error term.

Since the data contained repeated measurements, a simple linear regression model was unsuitable. Instead, a multilevel model (hierarchical linear model or mixed-effect model) was used to account for the hierarchical structure of the data [121–123]. This approach is particularly suitable for scenarios where higher-level data exert more significant influence on outcomes than lower-level data and is more robust to missing data [123, 124]. The multilevel model helps retain statistical power by modeling data at different levels—year, country, and healthcare system.

This study applied a three-level multilevel regression analysis, with level 1 representing the year, level 2 representing the country, and level 3 representing the healthcare system, as shown in Fig. 2. The model decomposed the total variation in life expectancy at birth and infant mortality into variations between years within each country, between countries within healthcare systems, and between healthcare systems. This study employed a three-level multilevel regression analysis, comprising 19 years nested within 25 countries from two healthcare systems (Beveridge-type and Bismarck-type). The three-level multilevel regression model can be expressed as:

$$H_{ij\tau} = \beta_0 + \beta_1 X_{ij\tau} + u_i + u_{0ij} + u_{1ij} Z_{ij\tau} + e_{ij\tau} \quad (4)$$

Below are the details of each part:

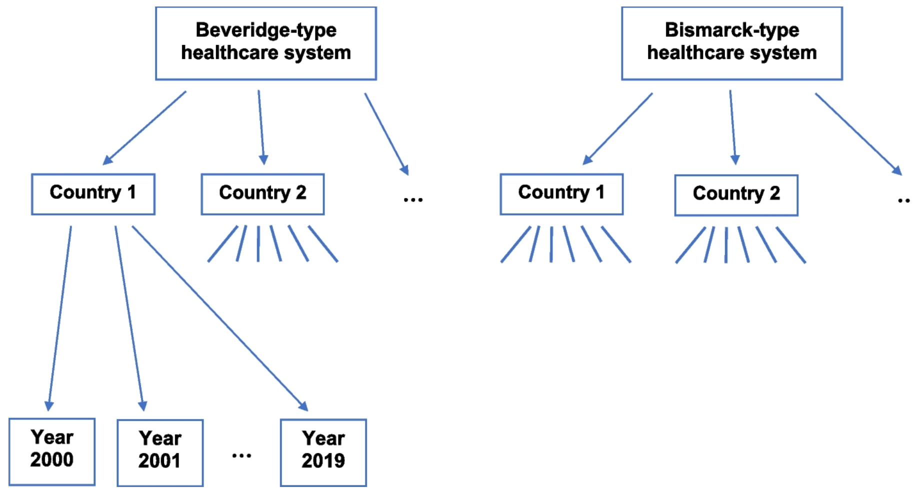

Fig. 2 A Three-level multilevel regression model

$H_{ij\tau}$: The life expectancy at birth or infant mortality for the i-th observation in the j-th country at level 2, nested within the τ-th healthcare system at level 3.

$X_{ij\tau}$: A vector of fixed explanatory and control variables.

$Z_{ij\tau}$: A vector of explanatory and control variables of the random part of the model.

β_0: The intercept for the entire dataset.

β_1: A vector of fixed parameters of the model.

u_i: The random intercept for the i-th healthcare system.

u_{0ij}: The random intercept for the j-th country within the i-th healthcare system.

u_{1ij}:The random slope for the j-th country within the i-th healthcare system.

$e_{ij\tau}$: The deviation from the country mean.

The error terms u_i, u_{0ij}, u_{1ij}, and $e_{ij\tau}$ are assumed to be independently and identically distributed, each with a mean of zero and its respective variance.

In the multilevel model, a linear time trend variable (year) was included at Level 1 to account for the underlying trends in life expectancy at birth and infant mortality over time. The parameter β_1 represents the effect of time (year) on the health outcomes. In the multilevel model used in this study, both fixed and random effects were included for the healthcare system type (Beveridge vs. Bismarck). The fixed effect for healthcare system type captures the overall differences in health outcomes attributable to the healthcare model, providing insight into the general relationship between healthcare systems and population health. The random effects allow for variations within healthcare system types across countries and over time, accounting for country-specific factors and time-variant effects that might not be captured by the fixed effect alone. Importantly, the fixed effect is identified conditional on the random effects. This approach ensures that the fixed effect captures the between-group differences in health outcomes, while the random effect explains the within-group (country-specific) variation in the relationship between healthcare resources and population health outcomes.

This study investigated the association between healthcare resources, healthcare systems, and population health outcomes. The dependent variables—life expectancy at birth and infant mortality—were analyzed against independent variables such as health expenditure, number of physicians, nurses, and hospital beds, along with the type of healthcare system (Beveridge or Bismarck). Control variables, including unemployment, GNI, GDP, and inflation, were associated with life expectancy at birth, while unemployment, GNI, GDP, inflation, and fertility rate were linked to variations in infant mortality [74–78, 81, 83–92, 94, 125–132]. Additionally, the percentage of the female population was included as a control due to its potential association with variations in life expectancy at birth [79].

Before performing the multilevel regression analysis, the data underwent log transformation to meet the assumption of normality [133]. A panel dataset with 25 countries ($n=25$) and 19 years ($T=19$) was analyzed. To address potential issues of multicollinearity—when independent variables are highly correlated—Pearson's correlation coefficient was calculated before the regression analysis [134]. A correlation coefficient (r) above 0.8 suggests significant multicollinearity [135]. Variables with high multicollinearity can distort the model's estimates and were considered for removal to improve the model's robustness [136, 137]. The correlation coefficients between variables are presented in Table S1 of the Supplementary file. Stata version 17 was used to conduct the analysis, and correlations were considered statistically significant at a p-value <0.05.

In the Supplementary file, Table S1 shows that the correlation between GNI PPP and GDP PPP is 0.999, indicating severe multicollinearity. This led to the exclusion of GNI PPP from the analysis to prevent misinterpretation. Correlations below 0.8 did not indicate significant multicollinearity that would distort regression estimates. The remaining variables were retained based on their statistical significance and meaningful effect sizes. Removing variables with moderate correlations could risk underfitting and omitting important explanatory information.

Independent Welch's T-test

The descriptive statistics (Fig. 1) show that, on average, countries using the Beveridge model invested more in health expenditure and had higher numbers of physicians and nurses than countries using the Bismarck model over the past 19 years. Conversely, countries using the Bismarck model allocated more hospital beds. This study explored the allocation pattern of healthcare resources that might affect the performance of these two healthcare systems. Hence, it is also necessary to compare the performance of the healthcare systems. To compare the performance of these healthcare systems, this study used life expectancy at birth and infant mortality as health outcome indicators, which are standard measures for evaluating population health and healthcare system performance [11, 21, 62, 138].

Descriptive statistics revealed that countries using the Beveridge model had higher life expectancy at birth, while those using the Bismarck model had higher infant mortality rates. However, descriptive statistics alone do not account for sampling variability, so inferential statistics are necessary to determine whether these differences are statistically significant or due to chance. The t-test is typically used to compare the means of two groups, but it assumes equal variances within the groups [139].

After examining the data, unequal variances were found between the two healthcare systems, so Welch's t-test was applied. Welch's t-test does not require the assumption of equal variances and was used to test for statistically significant differences in life expectancy at birth and infant mortality between the two systems from 2000 to 2018 [139]. Significance was set at $p \leq 0.05$. The formula for Welch's t-test is:

$$t = \frac{[\mathrm{m}_A - \mathrm{m}_B]}{\sqrt{\frac{S_A^2}{n_A} + \frac{S_B^2}{n_B}}} \tag{5}$$

The degrees of freedom for the Welch's t-test are estimated as follows:

$$df = [\frac{S_A^2}{n_A} + \frac{S_B^2}{n_B}]^2 / [\frac{S_A^4}{n_A^2\,(n_A - 1)} + \frac{S_B^4}{n_B^2\,(n_B - 1)}] \tag{6}$$

The hypotheses are assumed as follows:

- Null hypothesis: The means of the two groups are identical.
- Alternative hypothesis: The means of the two groups are different.

Below are the details of each part:

t: Welch's t-test.

m_A: The mean of life expectancy at birth/infant mortality rate of countries using a Beveridge-type healthcare system.

m_B: The mean of life expectancy at birth/infant mortality rate of countries using a Bismarck-type healthcare system.

S_A: The standard deviation of countries using a Beveridge-type healthcare system.

S_B: The standard deviation of countries using a Bismarck-type healthcare system.

n_A: The sample size of a Beveridge-type healthcare system.

n_B: The sample size of a Bismarck-type healthcare system.

Results

Regression analysis

This study's first research question (Q1) explored how healthcare resources and healthcare systems were associated with population health outcomes. By employing multilevel regression analysis, this question was addressed.

Life expectancy at birth multilevel model

Table 3 displays the regression model results of the multilevel regression analysis for life expectancy at birth. A log transformation was applied to reduce the skewness of the variables. When using the healthcare system as a predictor variable in a multilevel regression, it should first be converted into a dummy variable. Since there are only two healthcare systems, 'The Beveridge model' and 'The Bismarck model,' only one dummy variable was needed. In this study, the 'Beveridge-type healthcare system' was set as the baseline value, and the 'Bismarck-type healthcare system' was added to the regression model as a dummy variable.

The results indicated that the *p*-values for healthcare resources—including health expenditure per capita, the number of physicians, nurses, and hospital beds, the percentage of the female population, inflation, and GDP PPP—were less than 0.05, making these predictor variables statistically significant for life expectancy at birth.

Table 3 The results of the mixed-effects multilevel regression for life expectancy at birth

Dependent variable: **ln_Life expectancy at birth**				
	Coefficient	**Standard Error**	**z-Statistic**	***p*-value**
Fixed-effects parameters				
Intercept (β_0)	3.698	0.336	11.010	0.000*
Slope (β_1)	5.59×10^{-4}	1.72×10^{-4}	3.24	0.001**
Level-1: Time (Year)				
Health expenditure per capita, PPP	8.52×10^{-6}	8.84×10^{-7}	9.64	0.000*
Physicians	0.007	0.001	9.330	0.000*
Nurses	0.001	0.000	5.220	0.000*
Hospital beds	-0.004	0.001	-6.370	0.000*
Level-2: Country level (Country characteristics)				
Unemployment rate	2.50×10^{-4}	0.000	1.210	0.225
Percentage of female population	-0.012	0.001	-11.160	0.000*
Inflation rate	-0.002	3.67×10^{-4}	-5.060	0.000*
ln_GDP, PPP	0.004	0.001	5.950	0.000*
Level-3: Healthcare system (Beveridge or Bismarck models)				
Bismarck-type healthcare system (Dummy)	-0.002	0.002	-1.160	0.245
Random-effects parameters	**Estimate**		**Standard Error**	
Healthcare system (Random intercept, u_i)	4.85×10^{-12}		1.41×10^{-9}	
Country (Random intercept, u_{oij})	1.26×10^{-13}		6.99×10^{-11}	
Country (Random slope, u_{1ij})	1.59×10^{-15}		6.36×10^{-15}	
Error term (e_{ijk})	2.48×10^{-4}		1.61×10^{-5}	

Number of observations is 475; ln = natural logarithm; *Coefficients significant at $p<0.001$ level (two-tailed); **Coefficients significant at $p<0.05$ level (two-tailed)

Conversely, the p-values for the unemployment rate and healthcare system type were greater than 0.05, suggesting these variables do not have a statistically significant association with life expectancy at birth. Table 3 shows that health expenditure per capita PPP, the number of physicians, and nurses, and GDP are positively associated with life expectancy at birth. In contrast, the number of hospital beds, the percentage of the female population, and the inflation rate are negatively associated with life expectancy at birth.

According to Ford [140], the log transformation of the data can be interpreted as follows: For every one-unit increase in health expenditure per capita PPP, the number of physicians, and the number of nurses, life expectancy at birth increased by approximately 0.000852%, 0.702%, and 0.100%, respectively. Similarly, for every 1% increase in GDP PPP, life expectancy at birth increased by 0.004%. Conversely, life expectancy at birth decreased by approximately 0.399%, 1.192%, and 0.199% for every one-unit increase in the number of hospital beds, the percentage of the female population, and the inflation rate, respectively. Table 3 illustrates that the standard deviation for the healthcare system's random intercept is 4.85×10^{-12}. The standard deviation for the random intercept at the country level is 1.26×10^{-13}, and the random slope for the country is 1.59×10^{-15}. Additionally, the standard deviation for the residual is 2.48×10^{-4}.

Infant mortality multilevel model

Table 4 presents the results of the multilevel regression model for infant mortality, with infant mortality designated as the dependent variable. Healthcare resources, including the number of physicians, nurses, hospital beds, and healthcare systems, were analyzed as independent variables. Previous studies have indicated that factors such as unemployment, inflation, and fertility rates are associated with variations in infant mortality rates [81, 83–85, 90–92]; thus, these variables were included as control variables in the model.

In the infant mortality model, the p-values for health expenditure per capita PPP, the number of physicians, nurses, hospital beds, the unemployment rate, and the inflation rate were statistically significant. Conversely, the p-values for the fertility rate, GDP PPP, and the Bismarck-type healthcare system (dummy variable) were not statistically significant. The results showed positive correlations between infant mortality and the number of hospital beds, unemployment, and inflation rates. Conversely, there were negative correlations between infant mortality and health expenditure per capita PPP, the number of physicians, and the number of nurses. Table 4 illustrates that each additional unit in the number of hospital beds, the unemployment rate, and the inflation rate is associated with increases in the infant mortality rate by 4.289%, 1.106%, and 2.429%, respectively. In contrast, each additional unit of health expenditure per capita PPP, and each additional physician and nurse, was associated with decreases in the infant mortality rate by 0.00373%, 2.664%, and 2.664%, respectively. Table 4 also details the variance components of the model: the standard deviation for the healthcare system's random intercept is 5.04×10^{-12}, the standard deviation for the random intercept at the country level is 1.67×10^{-10}, and the random

Table 4 The results of the mixed-effects multilevel regression for infant mortality

Dependent variable: **In_Infant mortality rate**				
	Coefficient	**Standard Error**	**z-Statistic**	***p*-value**
Fixed-effects parameters				
Intercept (β_0)	41.392	5.349	7.740	0.000*
Slope (β_1)	-0.020	0.003	-7.600	0.000*
Level-1: Time (Year)				
Health expenditure per capita, PPP	-3.73×10^{-5}	1.34×10^{-5}	-2.78	0.005**
Physicians	-0.027	0.012	-2.250	0.025**
Nurses	-0.027	0.004	-6.570	0.000*
Hospital beds	0.042	0.009	4.480	0.000*
Level-2: Country level (Country characteristics)				
Fertility rate	4.59×10^{-4}	0.065	0.010	0.994
Unemployment rate	0.011	0.003	3.320	0.001**
Inflation rate	0.024	0.006	4.040	0.000*
In_GDP, PPP	-0.016	0.010	1.540	0.123
Level-3: Healthcare system (Beveridge or Bismarck models)				
Bismarck-type healthcare system (Dummy)	0.030	0.034	0.910	0.365
Random-effects parameters	**Estimate**		**Standard Error**	
Healthcare system (Random intercept, u_i)	5.04×10^{-12}		1.41×10^{-10}	
Country (Random intercept, u_{oij})	1.67×10^{-10}		1.92×10^{-7}	
Country (Random slope, u_{1ij})	1.57×10^{-14}		4.99×10^{-11}	
Residual (e_{ijk})	0.064		0.004	

Number of observations is 475; ln = natural logarithm; *Coefficients significant at $p<0.001$ level (two-tailed); **Coefficients significant at $p<0.05$ level (two-tailed)

slope for the country is 1.57×10^{-14}. The standard deviation for the residual is 0.064.

The results of this study indicated that healthcare resources, including health expenditure per capita PPP, and the number of physicians, nurses, and hospital beds, served as significant predictors of both life expectancy at birth and infant mortality. This term 'predictor' reflects statistical significance in the model used, denoting variables that are associated with variations in the outcomes, not necessarily causing them.

Table 5 Independent sample Welch's T-test results for life expectancy at birth

Group	Number of observations	Mean	Standard deviation	Standard error	*t*-value
Beveridge model	209	79.752	2.782	0.192	7.740
Bismarck model	266	77.552	3.412	0.209	

$p=1.000$ (left-tailed); $p=0.000$ (two-tailed); $p=0.000$ (right-tailed) (Significant at 0.05 level)

Independent Welch's T-test

This study's third research question (Q3) was to investigate whether there is a statistically significant difference in the performance of 25 European countries using Beveridge-type and Bismarck-type healthcare systems over the past 19 years (from 2000 to 2018). Life expectancy at birth and infant mortality were the indicators used to assess the performance of these healthcare systems. The dummy variables for these indicators were not statistically significant in the multilevel regression analysis, implying no significant differences between these two healthcare systems. It should be noted that the purpose of regression analysis is to account for underlying factors that may arise due to the lack of randomization, which in turn addresses issues related to causality or association. This challenge in observational data is addressed by including both independent and control variables in the regression model. However, no regression model can perfectly compensate for the lack of randomization. Therefore, the potential association of unobserved variables with the dependent variables needs to be examined. There are various ways to investigate this association, such as decomposing dependent variables into explained and unexplained components of the regression [141], though this approach is beyond the scope of this paper. Alternatively, a simple t-test can be applied to the level series to assess differences directly. Given the unequal variances between the groups being compared, Welch's t-test was used. The independent Welch's t-test, which is appropriate for comparing means between two groups when the assumption of equal variances does not hold, was employed to compare the average life expectancy at birth and the average infant mortality rates of countries using the Beveridge and Bismarck models.

Table 5 indicates that from 2000 to 2019, the average life expectancy at birth was 79.752 years for countries using the Beveridge model and 77.552 years for those using the Bismarck model. Welch's t-test results showed a statistically significant difference in the life expectancy at birth means of the two healthcare systems; countries using the Beveridge-type system had a significantly higher average life expectancy at birth than those using the Bismarck-type system ($t=7.740$, $p<0.001$ for the two-tailed test). Similarly, as presented in Table 6, the average infant mortality rates were 3.674 for the Beveridge model and 4.616 for the Bismarck model. The Welch's t-test results confirmed a statistically significant difference between the infant mortality rates of the two systems, with countries using the Bismarck-type system showing significantly higher average infant mortality than those using the Beveridge-type system ($t = -5.533$, $p < 0.001$ for the two-tailed test). However, these results need to be interpreted with caution since the multilevel regression analysis did not indicate a similar effect. This discrepancy suggests that other unexplained factors in the regression model may drive the observed differences between these groups.

Table 6 Independent sample Welch's T-test results for infant mortality

Group	Number of observations	Mean	Standard deviation	Standard error	*t*-value
Beveridge model	209	3.674	1.560	0.108	-5.533
Bismarck model	266	4.616	2.146	0.131	

$p = 0.000$ (left-tailed); $p = 0.000$ (two-tailed); $p = 1.000$ (right-tailed) (Significant at 0.05 level)

Discussion

The present research explored the associations between healthcare resources (including health expenditure, the number of physicians, nurses, and hospital beds) and healthcare systems (Beveridge-type and Bismarck-type) with population health outcomes (specifically life expectancy at birth and infant mortality) in 25 European countries from 2000 to 2018. This study also examined the allocation patterns of healthcare resources and their potential correlations with population health outcomes and analyzed the performance of different healthcare systems. Multilevel regression analysis was employed to assess how healthcare resources and healthcare systems are associated with population health. The results indicated that the *p*-values for both models were statistically significant concerning healthcare resources and population health outcomes. However, the associations between healthcare systems and health outcomes were not statistically significant in either model since the coefficient for the dummy variable was insignificant. Previous studies have suggested that healthcare resources, such as health expenditure or the number of physicians, are associated with population health outcomes [23, 27, 28, 117, 142]. This study supports these associations, highlighting correlations between healthcare resources and health outcomes.

For the model concerning life expectancy at birth, the regression analysis results indicated that health expenditure per capita PPP, and the numbers of physicians and nurses were positively correlated with life expectancy at birth, while the number of hospital beds was negatively associated with it. These correlations suggested that higher health expenditure per capita PPP, and greater numbers of physicians and nurses were associated with longer life expectancy at birth. Conversely, an increase in the number of hospital beds was associated with shorter life expectancy at birth.

In this study, healthcare expenditures were positively associated with life expectancy and negatively associated with infant mortality, reflecting the importance of financial resources in improving health outcomes. On the supply side, technological advancements in healthcare are key drivers of rising expenditures, and greater investment in these new technologies could be associated with improved health outcomes. The positive associations observed between healthcare expenditures and life expectancy suggest that, in this context, technological improvements and better medical care access may contribute to population health gains.

However, it is also important to consider the potential inefficiencies in healthcare expenditures. Supply-induced demand and variations in medical practice can lead to inefficiencies and low-value care. While this study did not specifically assess inefficiencies, the positive associations between health expenditures and improved health outcomes suggest that the inefficiency argument may be less problematic in the countries and years covered in this analysis.

On the demand side, factors such as disease prevalence, incidence, and reverse causation—where longer life expectancy increases healthcare demand and, consequently, expenditures—should be considered when interpreting the results. As the findings of this study are based on associations, caution should be exercised in making causal claims regarding the direct impact of increasing healthcare expenditures on life expectancy. Unobserved factors related to the demand for healthcare, such as aging populations and disease prevalence, could also influence the observed associations.

This negative association between the number of hospital beds and life expectancy at birth may be partially explained by the historical and regional context of Eastern European and former Soviet Union countries included in the Bismarck model group. These countries have traditionally maintained hospital-centered healthcare systems, characterized by large hospitals and high bed occupancy rates [143]. This emphasis on inpatient care may reflect inefficiencies in healthcare delivery, such as insufficient focus on primary care and preventive services, which are crucial for improving population health outcomes. Therefore, the higher density of hospital beds in these countries might not indicate better healthcare capacity but rather highlight systemic issues that adversely affect life expectancy.

Control variables such as the percentage of the female population and the inflation rate were also found to be negatively correlated with life expectancy at birth. This suggested that a decrease in these variables was associated with an increase in life expectancy at birth. An unexpected finding of this study was the negative correlation between the percentage of the female population and life expectancy at birth. Previous data showed that female life expectancy at birth is generally higher than that of males [79], which might imply that countries with a higher percentage of the female population would typically exhibit higher total life expectancy at birth. However, the findings from this research indicated the contrary: for every percentage increase in the female population, life expectancy at birth decreased by 1.192%. This unexpected result suggested that other factors may play significant roles associated with variations in total life expectancy at birth, beyond just the gender ratio within a country.

One possible factor contributing to this result could be higher male mortality rates in certain countries. In regions where men experience significantly higher mortality due to factors such as occupational hazards, lifestyle behaviors, or conflicts, the proportion of females in the population increases as a result of losing more men at younger ages. This increased female proportion reflects underlying health issues that are associated with lower overall life expectancy. Another contributing factor could be migration patterns, particularly the emigration of working-age males from Eastern to Western Europe in search of better employment opportunities. This out-migration can lead to a higher proportion of females remaining in the country, often among older age groups, which may affect the demographic structure and contribute to a lower average life expectancy. Therefore, the negative association between the percentage of the female population and life expectancy at birth may reflect underlying demographic and social factors, such as higher male mortality and migration patterns, rather than a direct causal relationship. This highlights the complexity of demographic factors associated with health outcomes.

As expected, GDP PPP was positively correlated with life expectancy at birth. Economic growth is associated with increased life expectancy, potentially due to various interconnected factors. More financial resources are linked to improvements in healthcare infrastructure and greater access to medical services [144]. A higher GDP is also associated with increases in personal incomes, which may enhance nutrition and improve living conditions [145]. As the economy expands, it is possible for governments to invest more in essential public health services like sanitation and clean water. Additionally, economic growth is often correlated with higher educational attainment, which may promote healthier lifestyle choices. Declining poverty rates, another potential consequence of economic development, are associated with improved health outcomes since poverty is closely linked to poorer health [146]. Moreover, increased financial resources might boost health-related research, potentially leading to medical advancements and better treatments. These improvements are thought to contribute to longer life expectancy at birth by enhancing overall health conditions and reducing the prevalence of diseases.

The infant mortality model contrasts with the life expectancy at birth model. Healthcare resources were negatively correlated with infant mortality, with the exception of the number of hospital beds, which was positively correlated with it. Increases in health expenditure per capita PPP, and in the number of physicians and nurses, were associated with lower infant mortality rates, suggesting improved health outcomes. Conversely, a rise in the number of hospital beds was associated with higher infant mortality rates, indicating potentially worse health outcomes. In this model, the control variables—unemployment and inflation rates—were positively correlated with infant mortality. This suggested that increases in unemployment and inflation rates were associated with rises in infant mortality rates, potentially indicating deteriorating health outcomes. Rising unemployment and inflation are typically linked to worsening economic and social conditions, which may contribute to higher infant mortality rates and impair overall health outcomes. Higher unemployment may reduce household income, thereby limiting access to healthcare and adequate nutrition essential for infant survival.

Simultaneously, inflation is associated with escalated costs of necessities such as food and healthcare, further straining family budgets and potentially necessitating cuts in critical health expenditures. Economic downturns may also be linked to decreased public healthcare spending, which can reduce the availability and quality of prenatal and infant care. Moreover, financial stress is often correlated with increased parental stress and mental health issues, which are associated with negatively affecting pregnancy outcomes. Reductions in social services due to economic pressure can limit crucial supports like nutritional programs and financial aid, which are important for infant health. Additionally, strained resources may undermine the overall public health infrastructure, potentially impacting clean water, sanitation, and disease prevention. Collectively, these factors are associated with an increase in infant mortality rates, as economic hardship may indirectly affect health services and family well-being.

This study also aimed to explore the allocation patterns of healthcare resources in countries using Beveridge-type and Bismarck-type healthcare systems, as stated in the second research question. The allocation patterns of healthcare resources for Beveridge-type and Bismarck-type systems are presented in the descriptive statistics. Countries using the same healthcare models tended to allocate healthcare resources similarly, as shown in Fig. 1. Countries adopting the Beveridge model typically invested more in health expenditure per capita and in the number of physicians and nurses than those using the Bismarck model but invested less in hospital beds. Regression analysis results indicated that associations between improved population health outcomes and increased investment in health expenditure per capita, and higher numbers of physicians and nurses were observed. Conversely, a higher number of hospital beds was associated with poorer health outcomes.

Based on the findings from regression analysis and descriptive statistics, the Beveridge-type healthcare system was associated with a seemingly more effective allocation pattern of healthcare resources, characterized by increased health expenditure per capita and higher numbers of physicians and nurses, alongside a reduction in the number of hospital beds. These correlations suggest that the allocation strategies employed by countries using the Beveridge model may contribute to better population health outcomes compared to those using the Bismarck model. However, it is important to note that these findings represent associations rather than causations, and the type of healthcare system alone did not show significant direct effects on these outcomes. External factors and potential confounders not accounted for in this study could also influence these associations.

This study employed life expectancy at birth and infant mortality as health outcome indicators to represent population health outcomes and to compare the performance of Beveridge-type and Bismarck-type healthcare systems. Accordingly, Welch's t-test was used to assess whether the average life expectancy at birth in countries using the Beveridge-type healthcare system was statistically significantly higher than in those using the Bismarck-type system. Similarly, this test was employed to determine if infant mortality in countries with the Beveridge-type system was statistically significantly lower than in those with the Bismarck-type system. The independent Welch's t-test results for life expectancy at birth showed a statistically significant difference between the means of the two healthcare systems ($t = 7.740$, $p < 0.001$, two-tailed). Specifically, the mean life expectancy at birth in the Beveridge-type healthcare system was statistically significantly higher than that in the Bismarck-type healthcare system. Additionally, Welch's t-test indicated statistically significant differences in infant mortality rates between the two systems ($t = -5.533$, $p < 0.001$, two-tailed), with the Beveridge-type system exhibiting lower infant mortality rates than the Bismarck-type system. Thus, the results from Welch's t-test suggested that the Beveridge-type healthcare system was associated with more favorable outcomes in terms of life expectancy and infant mortality over the period from 2000 to 2018. These findings align with previous studies suggesting that the Beveridge-type healthcare system may provide better health outcomes than the Bismarck-type system [43, 147].

This study aligns with prior research that suggests increasing human resources in healthcare, such as physicians, is associated with improved health outcomes [24, 25, 33, 148–150]. This association appears logical because when a healthcare system has a sufficient number of physicians, it is likely that more patients receive treatment, potentially resulting in better health outcomes. Health expenditure is another critical healthcare resource that is significantly correlated with health outcomes. This research supports earlier studies indicating that increased health expenditure is associated with better health results [29–32]. However, the regression analysis suggested that an increase in the number of hospital beds may be negatively associated with healthcare outcomes, which aligns with findings from previous studies [106].

Based on a comprehensive synthesis of the multilevel regression analysis, descriptive statistics, and Welch's t-test results, there is a notable association between the allocation patterns of healthcare resources and the performance of healthcare systems in terms of population health outcomes. Specifically, the Beveridge-type healthcare system, characterized by higher expenditures on health and greater staffing with physicians and nurses, is associated with better health outcomes such as higher life expectancy and lower infant mortality rates, compared to the Bismarck-type system. These findings suggest that the distinct allocation of healthcare resources in Beveridge-type systems contributes significantly to their superior health outcomes. Given these insights, it may be prudent for healthcare systems to reevaluate their resource allocation strategies. Increasing investment in health expenditure and healthcare personnel, while reassessing the need for extensive hospital bed capacity, could potentially enhance health outcomes. This approach aligns with the evidence that suggests a more targeted allocation of resources towards primary care and preventive services rather than a high number of hospital beds, which may reflect and possibly exacerbate higher healthcare needs rather than improve health status. However, while reallocating resources, it is essential to consider that these findings, though statistically significant, are correlational and not necessarily indicative of causation. Factors not examined in this study, such as the quality of care, patient outcomes, and broader socioeconomic conditions, might also play crucial roles in influencing these health outcomes. Thus, any changes to healthcare policy or resource allocation should be approached with caution, supported by further research that explores these additional variables.

Grossman's Health Capital Model suggests that health is a form of durable capital managed by individuals [44]. Health depreciates over time but can be maintained or improved through investments in medical care, healthy lifestyles, and other beneficial activities [44]. The model suggests that higher investments in health capital are associated with enhanced health outcomes. In this study, the positive correlation observed between health expenditure per capita and the number of healthcare professionals (physicians and nurses) with life expectancy at birth, as well as their negative correlation with infant mortality, supports this association. These findings can be interpreted through Grossman's lens as follows: Increasing health expenditure per capita can be seen as boosting investments in health capital. According to Grossman, such investments are expected to enhance the quality and accessibility of medical care, which in turn could help replenish health capital and slow its depreciation. This is reflected in the better health outcomes and prolonged life expectancy at birth observed in populations with higher health expenditures. Moreover, an increase in healthcare professionals is correlated with improved health outcomes. This enhancement can be viewed within Grossman's framework as an increase in the efficiency of health production. More healthcare professionals mean enhanced access to medical services, potentially leading to more effective medical interventions and preventive measures that collectively contribute to boosting the population's health capital.

However, an notable aspect of these findings is the negative correlation observed between the number of hospital beds and life expectancy at birth, coupled with a positive correlation with infant mortality. This could suggest that a higher hospital bed count per capita might reflect a higher disease prevalence or more significant healthcare needs, indicating a population with potentially lower overall health capital. Such an observation implies that having more hospital beds is not merely an indicator of resource availability but could also signify deeper systemic health challenges that are not addressed simply by increasing capacity. This aspect aligns with Grossman's perspective that the quality of health capital investments, not merely their quantity, profoundly impacts health outcomes.

These interpretations support Grossman's view that health capital is enhanced through strategic investments in healthcare but also highlight the complexity of healthcare system dynamics. The association with hospital beds underscores that not all investments yield positive outcomes. Thus, there is a need for strategic planning that balances preventive and curative healthcare to enhance overall healthcare system efficiency and public health. In summary, these findings reinforce the importance of investing in healthcare resources to enhance health capital, as proposed by Grossman. They illustrate how enhancing healthcare quality and accessibility is associated with positive effects on population health. However, they also caution against assuming that all forms of healthcare investments, such as increasing hospital beds, will automatically lead to better health outcomes, underscoring the need for a more sophisticated approach to healthcare investment.

Limitations

This research provides insights into the associations between healthcare resources and healthcare systems with health outcomes, the allocation patterns of these resources, and healthcare system performance. However, there are some limitations to this study.

First, it explored the link between healthcare resources, healthcare systems, and health outcomes over a 19-year period, from 2000 to 2018. Future studies should also examine more recent years.

Second, this study only investigated how healthcare resources and systems are associated with population health outcomes and how the allocation patterns of healthcare resources could be related to healthcare system performance in European countries. It is challenging to conclude that countries on other continents would show similar results, even if they employ the Beveridge and Bismarck models, due to differing regional characteristics.

Third, an important limitation is the potential confounding effect of regional and historical factors on health outcomes. Many countries classified under the Bismarck model in this study are Eastern European or former Soviet Union states, such as Bulgaria, Czechia, Estonia, Hungary, Lithuania, Poland, Slovakia, and Slovenia. These countries have undergone significant socioeconomic transitions since the dissolution of the Soviet Union, often characterized by lower economic development, higher poverty rates, and residual impacts from previous healthcare systems. These factors may contribute to the observed differences in life expectancy and infant mortality between countries using the Beveridge and Bismarck models. Therefore, the disparities observed may not solely reflect the impact of healthcare system type but also the legacy of historical, economic, and social conditions unique to these regions. Without adjusting for these confounding factors or including regional indicators, it is difficult to isolate the influence of the healthcare system on health outcomes. Future research should consider incorporating additional control variables such as education levels, income inequality indices like the Gini coefficient, and regional classifications to better account for these effects.

Additionally, while significant associations between healthcare system types and health outcomes were observed, these results should be interpreted with caution due to potential confounding factors. Countries were not randomly assigned to healthcare systems, and differences in healthcare resources and outcomes may also reflect underlying geographic, economic, and social factors. While this study controlled for some of these factors (e.g., GDP, inflation, female population), future research could employ more sophisticated methods, such as propensity score matching, to compare countries with similar characteristics and more effectively isolate the influence of healthcare system type on health outcomes.

Furthermore, another limitation of this study is the potential for endogeneity bias between healthcare expenditures and life expectancy. It is possible that higher life expectancy leads to increased healthcare expenditures due to greater healthcare demands associated with an aging population. This reverse causation might affect the associations observed in the study. Although this research controlled for variables such as GDP, inflation, and the percentage of the female population, other important factors like the age profile of the population and disease prevalence were not included in the model. Future research should consider incorporating these variables and exploring methods such as instrumental variable regression or addressing reverse causality to better isolate the direction of the relationship between healthcare expenditures and life expectancy at birth.

Additionally, while this study focused on identifying associations between healthcare resources and health outcomes, it did not model the rates of growth or include lagged variables for healthcare resources. Incorporating such models, including first differences or lagged resource variables, could provide more insights into the dynamic relationships between healthcare expenditures and health outcomes, potentially reducing the bias caused by contemporaneous health shocks and reverse causality. Future research could consider employing these methods to better isolate the temporal effects of healthcare investments on population health.

Conclusions

This study utilized descriptive and inferential statistics to explore the relationships between healthcare resources, Beveridge-type and Bismarck-type healthcare systems, and population health outcomes across European countries. It also examined how these two distinct healthcare systems allocated these resources and the subsequent impact on system performance. The findings revealed that increased financial (health expenditure) and human resources (physicians and nurses) were consistently associated with improved health outcomes in both system types. In contrast, a greater number of hospital beds was correlated with poorer health outcomes within these systems, suggesting inefficiencies in facility utilization specific to the Beveridge-type and Bismarck-type models.

The analysis also demonstrated that countries with similar healthcare models exhibited comparable patterns in resource allocation. These patterns appeared to significantly influence health outcomes and the overall performance of healthcare systems, indicating that more strategic resource distribution could have enhanced system effectiveness and efficiency. These insights were crucial for policymakers engaged in healthcare planning and reform. They highlighted the potential benefits of reallocating resources towards more human and financial investments while reconsidering the emphasis on expanding facilities. Such strategic shifts could not only have improved health outcomes but also led to more economically efficient healthcare systems.

However, it is crucial to note that the associations identified in this study do not imply causation. These findings should be interpreted as indicative rather than definitive, underscoring the need for further research to explore these relationships in greater depth. Future studies should aim to delineate the causal pathways and consider additional variables such as the quality of care, accessibility, and patient satisfaction, which may also significantly affect health outcomes and system performance. Additionally, exploring these associations in different regional contexts could provide a broader understanding of how universal these patterns might be and whether they hold true across various healthcare system models.

Future studies

This study focused on analyzing the relationships between healthcare resources and systems with population health outcomes within Beveridge-type and Bismarck-type systems across European countries. Future research should broaden this scope to include diverse healthcare systems from different continents, exploring how various healthcare resource allocations impact health outcomes on a global scale. In addition to expanding geographic scope, future studies should consider employing more sophisticated methodologies to address potential endogeneity bias and reverse causality, such as instrumental variable regression or propensity score matching, to better isolate the causal pathways between healthcare expenditures and health outcomes.

Furthermore, incorporating models that account for rates of growth and lagged variables in healthcare resources could provide more detailed insights into the temporal effects of healthcare investments on population health. These methods could help to mitigate the bias caused by contemporaneous health shocks and better capture the dynamic nature of healthcare resource utilization and its impact on health outcomes.

Additionally, future research could investigate the optimal allocation of healthcare resources needed to maximize health outcomes, considering both efficiency and equity. Such studies could offer more specific insights into the efficient distribution of healthcare resources worldwide, potentially informing more effective healthcare strategies and policies. Given the inherent limitations of macroeconomic healthcare data, there is also a critical need for the development of methodologies that can more accurately interpret the unexplained variance in regression analyses, allowing for a more comprehensive understanding of the factors driving population health outcomes.

Abbreviations

CDC	Centers for disease control and prevention
GDP	Gross domestic product
GNI	Gross national income
NHI	National health insurance model
OECD	Organization for economic cooperation and development
PPP	Purchasing power parity
WHO	World health organization

Supplementary Information

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Supplementary Material 1.

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Data availability
The data are available publicly.
https://data.worldbank.org/
https://ec.europa.eu/eurostat/databrowser/bulk?lang=en
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Declarations

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