Mapping healthcare resources and regional mortality in Europe: a spatial study of current service coverage

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Abstract

The NUTS classification, established by Eurostat, divides the European territories into three levels: NUTS 1 (major regions), NUTS 2 (basic regions), and NUTS 3 (small regions). Our study investigated regional disparities in mortality across 232 NUTS 2 regions in Europe by analysing the function of their spatial health services. Using a spatial error model, we assessed the influence of healthcare expenditures and the number of hospital beds and medical doctors on death rates across eight major disease categories. We employed global and local spatial statistics to capture spatial disparities in resource allocation and death rates. Spatial clustering techniques revealed distinctive but differing patterns regarding mortality and resource allocation, with central and East Europe experiencing higher mortality from circulatory and digestive diseases, with mental and neurological conditions being more prevalent in the more affluent West. Our findings demonstrated decreasing returns at scale across all resources, with varied elasticities depending on disease type. Improved financial resources significantly reduced mortality for most illnesses except for mental or neurological disorders, while outcomes with respect to neoplasms depended on systemic factors beyond spending levels. The number of hospital beds often correlated positively with mortality, indicating system strain and reactive action rather than with preventive healthcare factors. Access to doctors reduced mortality only for mental and neurological conditions, highlighting the importance of specialised, continuous care. Regional affluence was found to consistently reduce mortality for several disease categories, underscoring the role of socioeconomic context in public health. These insights offer crucial guidance for more equitable and disease-specific resource allocation in health policy.

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Introduction

Regional disease prevalence and mortality disparities are well-documented, stemming from complex, multi-dimensional factors. While socioeconomic and demographic conditions significantly influence population health, they often fall outside the direct control of policymakers (Li *et al.*, 2023), while healthcare systems and their resources are largely governable factors. Disparities in healthcare infrastructure, specialist availability and funding are more often seen in urban or wealthier areas, where they exacerbate regional differences and limit equitable access to essential services for vulnerable populations (Ursache *et al.*, 2021; Dong *et al.*, 2023; Wakasugi & Narita, 2023; Al Wosibei *et al.*, 2024). A recent Eurostat study (2023) found that residents in rural and remote areas of the EU have significantly less access to healthcare than their urban counterparts. This is particularly evident in countries like Slovenia, where only 47.5% of village residents and 17.7% of those in uninhabited areas can reach healthcare services within 15 minutes. Similar disparities exist in Finland, Bulgaria, Latvia, and Lithuania, where access for villagers is 21.6 to 29.0 percentage points higher than for those in sparsely populated regions (Eurostat, 2023). Consequently, delayed diagnoses and insufficient treatment in less affluent areas often lead to higher mortality rates (Li *et al.*, 2024). This makes healthcare resources crucial determinants of health. A common approach to assessing impact is through the use of econometric tools that quantifies the strength and direction of each factor's impact on public health. This approach can be extended by adding the geographic dimension, a novelty considering that health outcomes in one location may depend on more than just local inputs. Health-related results of this kind also depend on spatial spill-over (e.g., infectious disease spread, pollution drift, and shared health infrastructures), neighbourhood effects (e.g., local norms about exercise, availability of healthy food, etc.), and spatial heterogeneity (e.g., rural vs. urban differences and regional disparities in healthcare access).

The mortality rate, widely regarded as the most reliable and best-documented "ultimate test" of the performance of healthcare systems, serves as a key health measure (Mbau *et al.*, 2023). Outcomes are typically explained by variables, such as the number of doctors or medical personnel, hospital beds and healthcare expenditures. Sometimes, additional variables, such as income, education or environmental factors, are included. Generally, studies show that increased medical resources tend to reduce disease prevalence and improve health (Auster *et al.*, 1969; Fayissa & Traian, 2013; Caraballo *et al.*, 2025). In our study, we employed an approach that models mortality rates based on proxies for three main types of exogenous factors: the number of doctors as a measure of human capital; the number of hospital beds as a measure of physical (material) capital; and the amount of health expenditures as a measure of financial capital.

The spatial inequality of healthcare resources and specialised facilities, combined with factors like medical tourism and cross-border risk factors (e.g., air pollution, lifestyle), foster "coopetition" (a blend of competition and cooperation) that facilitates the flow of healthcare across borders (Androutsou & Metaxas, 2019; Batakis *et al.*, 2023). Although relationships often are complex, multifactorial and bidirectional, regional health is shaped by neighbour risk factors and healthcare system characteristics (Gaano, 2024; Zacarías-Pons, 2024). In our study, we introduced a spatial health-related function to account for these spatial interactions. Furthermore, various studies highlight disparate spatial patterns, trends and determinants across different diseases. For instance, cardiovascular diseases are often clustered in specific regions, while chronic respiratory diseases and cancer exhibit notably less concentrated geographic distributions (Ahmad *et al.*, 2019; Ren *et al.*, 2022; Calazans & Permanyer, 2023). Therefore, analysing aggregate mortality might be misleading.

Given the absence of statistical information on healthcare funding for the NUTS 2 regions, a proxy methodology had to be employed. Disaggregating healthcare staff expenditures is a reasonable analytical approach, since evidence shows that funding is often determined by existing doctor and facility capacity rather than population health needs. Stuckler *et al.* (2011) found that regions with more doctors receive more investment, which explains most of the allocation differences. Guerrero and Rao (2025) also highlight that health budgets are closely tied to medical service providers, illustrating the utility of the doctor-based expense approximation method. Using workforce metrics may thus offer a practical perspective on expenditure distribution.

Using expenditures distributed by doctors as a proxy for regional health expenditures has some limitations. For example, due to lack of data, our approach overlooks the distribution differences among specialist doctors, which would significantly improve the expense approximation. Additionally, this approach omits regional price variations and the varying regional population structures of individuals aged 65 and above, who tend to incur higher health expenditures. However, it is worth noting that these two factors may often have opposite effects on expenditures: well-developed cities are usually characterised by higher prices but also a younger population, whereas less populated areas are frequently poorer, with lower-priced medical services and an older population. Moreover, although healthcare systems in the EU are not uniform, they all have a substantial public component with a largely unified price structure, while private insurance and providers operate primarily as a supplement rather than as the primary source of care.

Alternative allocation methods for healthcare expenditures were also considered, namely, bed-based and approaches based on the Gross Domestic Product (GDP). However, neither met the estimation requirements: the bed-based method showed insufficient correlation with endogenous variables and the GDP-based method did not provide satisfactory model quality. Nonetheless, the high correlation (0.86) between variables based on doctors one the one hand and GDP on the other supports the use of health expenditures using the number of doctors as proxy. Moreover, the correlation between the number of doctors and expenditures related to this variable is sufficiently low to rule out collinearity (0.43).

To deepen our understanding of how health services function, we independently modelled leading causes of death by disease classification as this allows for the identification of potential commonalities and disparities with regard to how different inputs impact health statistics. The overall aim of our study was to assess the spatial patterns of mortality for eight disease categories and key medical resources. We also quantified the impact of these inputs on cause-specific mortality rates using a spatial tool to investigate the function of health services in a large number of European regions. Our primary hypothesis was that an increase in each resource would have a significant and negative impact on mortality for every medical disorder.

Materials and Methods

Scope of the study

We analysed mortality and healthcare resource patterns in 232 European NUTS 2 regions in 2018, for which the dataset is most comprehensive. For data continuity, the database included regions in the European Union, as well as those in Norway and Switzerland. However, UK Ireland and Iceland were omitted the due to lack of statistical support. The majority of our data was sourced from Eurostat, with some extrapolations performed to address gaps in the time series.[1]

We studied the cardiovascular, digestive, genitourinary, neurological and respiratory systems. In addition, we investigated three groups: disorders of the endocrine, nutritional and metabolic systems; mental and behavioural disorders; and neoplasms (cancer) - eight disease categories in all. Mortality was measured by annual

[1]Some missing information regarding Swiss regions was obtained from Switzerland's Federal Statistical Office (https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy.html) and for Liechtenstein from the Statistics Portal Liechtenstein (https://www.statistikportal.li/de). Other missing data were completed using country-level disaggregation (when NUTS 2 values were unavailable) and, for individual annual gaps, through extrapolation or interpolation under the assumption of a constant regional rate of change.

crude death rates.

The key inputs for our analysis of healthcare function were the number of hospital beds and medical doctors, both numbers normalised per 100,000 inhabitants. As Eurostat lacks direct regional data on healthcare expenditures, we estimated these by disaggregating country-level healthcare expenditures, expressed as Purchasing Power Standard (PPS) in Euros. This was achieved by allocating national expenditure proportionally to each region's share of the country's total number of medical doctors divided by the region's population to derive the per capita value.

Statistics

To investigate the spatial patterns of mortality and healthcare resources, we employed Local Indicators of Spatial Association (LISA), according to which an evaluation of the statistical relationship between values at one region and its neighbours can be performed through the Local Moran's I (statistic (Moran, 1950; Anselin, 1995):

$$I_i = \frac{(z_i - \bar{z})}{\frac{1}{N}\sum_{j=1}^{N}(z_j - \bar{z})^2} \sum_{j=1}^{N} w_{ij}(z_j - \bar{z}) \quad \text{(Eq. 1)}$$

For the quantitative variable z, subscripts i and j represent region indices and $\bar{z}$ denotes the variable's mean over all regions. The factor w_{ij} refers to the elements of the spatial weight matrix W, which, in further analysis, is the 1st-order queen contiguity spatial weight matrix. When a region with a low level of the phenomenon borders regions with similarly low values, Low-Low (LL) clusters form, indicating coldspots. Conversely, in the corresponding opposite situations, High-High (HH) clusters occur, indicating hotspots. Mixed groups exhibit Low-High (LH) and High-Low (HL) clusters. Only those locations for which local statistics differ significantly from zero were analysed. The average local Moran's I_i over all regions result in a global measure of spatial autocorrelation (Moran, 1950; Anselin, 1995).

We based our spatial health production function on the production function introduced and formalised by Charles Cobb and Paul Douglas (1928). We specifically used the function's power form, in its modern econometric format, to assess the return to scale for each input:

$$P_i = \alpha L_i^{\beta} K_i^{1-\beta} \varepsilon_i, \quad \text{(Eq. 2)}$$

where P denotes the production level; L the labour measure; and K the i-th object. Secondly, we applied the Grossman approach (1972) of utilising the economic production function in health studies $H = f(I)$, where a measure of health (H), for instance mortality, prevalence, life expectancy or self-reported health status depends on a vector of inputs (I) including healthcare system resources, but often also external factors such as individual health behaviours, demographics, socioeconomic or environmental factors (Mullahy, 2010).

Since not all determinants of mortality can be captured solely by healthcare inputs (doctors, beds and expenditures) and many external factors, such as air pollution, health behaviours, or informal care networks, might be spatially clustered, we decided to expand the concept of health production function to a spatial error model (SEM) form.[2] Ignoring spatially correlated residuals would bias coefficient estimates and lead to inefficient inference. The general form of the SEM is:

$$y = X\beta + u, \text{ where } u = \lambda W u + \epsilon \quad \text{(Eq. 3)}$$

where y is a dependent variable; X the matrix of explanatory variables; β the vector of coefficients; u the spatially autocorrelated error term; λ the spatial autoregressive coefficient for the error term; and W the spatial weights matrix with ϵ a random *iid* error term (Anselin 1995). In our study, we employed a power-exponential SEM model specified as follows:

$$mortality_i^k = \alpha_0 doc_i^{\beta_1} bed_i^{\beta_2} expd_i^{\beta_3} e^{\alpha_4 aff_i} e^{u_i}, \text{ where } u = \lambda W u + \epsilon \quad \text{(Eq. 4)}$$

where $mortality_i^k$ represents the level of mortality rates in i-th region due to the k-th disease category; *bed*– the number of beds and doc the number of doctors per 100,000 inhabitants; *expd*– healthcare expenditures per capita; aff the affluence dummy representing the quarter of the most affluent regions by GDP per capita; $\beta=[\beta_1,\beta_2,\beta_3]$ the vector of coefficients (interpreted as elasticities or returns at scale); u an spatially autocorrelated error term; λ the spatial autoregressive coefficient for the error term; and W the spatial weights matrix (in our case, 1st-order queen contiguity spatial weight matrix) with the ϵ random *iid* error term. This model captures the unmeasured, spatially structured influences present in regional health studies, where cross-border health determinants (*e.g.*, pollution, migration or informal care provision) exist but are not directly modelled. Our model assumed that regional health production is not isolated, but instead reflects 'coopetition' dynamics in European healthcare, where intra-regional spill-over (positive or negative) matter.

Results

Table 1 summarises key healthcare data from the study. In 2018, the average number of hospital beds was 541 per 100,000 inhabitants, ranging from 102 (Liechtenstein) to 1,278 (Mecklenburg-Vorpommern, Germany). There were on average 390 doctors per 100,000 inhabitants, with a range of 157 (Sud-Muntenia, Romania) to 832 (Ceuta, Spain). The mean healthcare expenditures per capita of € 2,918, varying from € 599 (Sud-Muntenia, Romania) to € 6,388 (Hamburg, Germany) showed the most substantial variability among the resources (45%). Cardiovascular diseases were the primary cause of death, with an average mortality rate of 403 per 100,000 people, ranging from 135 (Île-de-France) to 1,324 (north-western Bulgaria). Cancer followed, averaging 274 deaths per 100,000, from 159 (Ceuta, Spain) to 405 (Limousin, France). Respiratory system diseases showed the greatest variability in death rates (85%) across NUTS 2 regions.

[2] Other spatial models were also considered. The SEM model was consistently statistically better than models with spatially lagged endogenous variables for all diseases and model selection criteria (see Appendix).

Spatial patterns of healthcare resources

The spatial analysis of inputs is presented in Figure 1. The healthcare expenditures per capita exhibited high positive autocorrelation (Global Moran's $I = 0.75$). Corresponding with notable hotspots, the highest levels of financial resources were observed in northern and western Europe, particularly in the regions of Scandinavia, Austria, Switzerland, southern and western Germany, northern Italy and the Benelux. The highest health investments in Europe were also observed in metropolises such as Berlin, Prague,

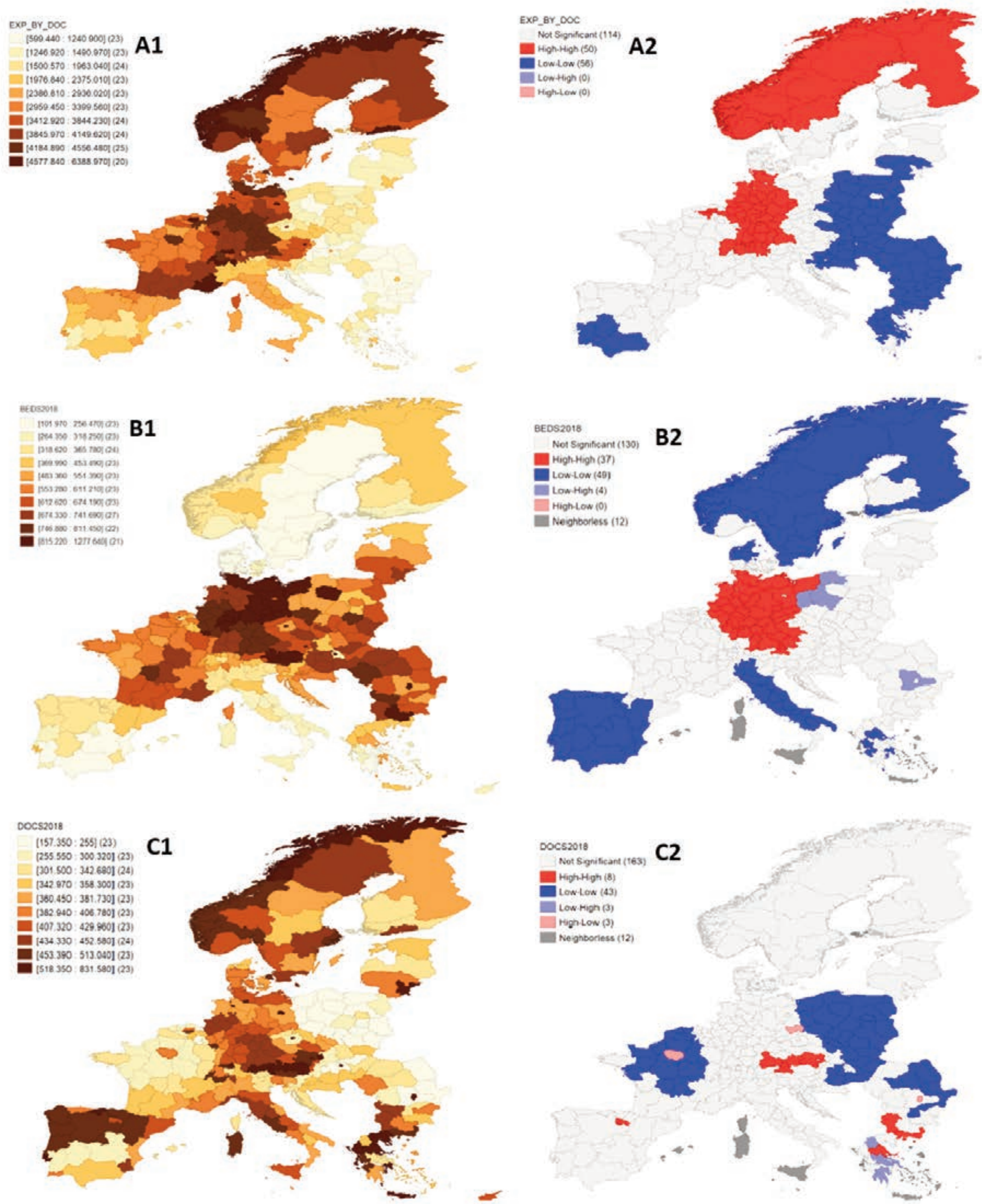

Figure 1. Spatial distribution of inputs, NUTS 2 region, 2018. **A**) Healthcare expenditures per capita (purchasing power standard – PPS Euro); **B**) Hospital beds per 100,000 inhabitants, **C**) Medical doctors per 100,000 inhabitants; 1) Choropleth map, 2) local indicators of spatial association (LISA).

Vienna, and Paris, while the lowest financial input areas were seen in Central and Eastern Europe (CEE), including the Balkans and Lithuania, where a sizable coldspot was created.

Regarding available hospital beds, the highest values were found in western and central-eastern parts of Europe, with the lowest in Scandinavia, the Iberian Peninsula and Italy. The global spatial autocorrelation was strong (I = 0.65), and only a few notable clusters emerged. A single group with a high number of beds was covered Germany, the Benelux, and Austria, while the coldspots were located in the South (Iberian Peninsula, Italy and Greece) and in the North (Scandinavia and Finland).

The third resource – the number of doctors – had a slightly weaker global spatial autocorrelation (I = 0.33), with less defined geographical patterns. The highest numbers of physicians were found in Greece, Bulgaria, Germany, Austria, Czechia, northern Iberian Peninsula and Norway. High values were also observed in some capital cities, such as Bucharest, Berlin, Prague, Copenhagen and Brussels. The lowest number of doctors was recorded in Poland, Slovakia, Hungary, Romania and France, which thus reflected the presence of extensive coldspots. In contrast, only a few limited clusters of this kind were observed in Germany, Czech Republic, Austria, Bulgaria, Greece and the centre of the Iberian Peninsula.

The spatial distribution, as presented in Figure 2, was found to vary considerably depending on the disease selected. For diseases of the circulatory system, the global spatial autocorrelation was high, as evidenced by Global Moran's I = 0.84. As reflected by the cluster analysis, mortality rates are significantly higher in CEE, particularly in the Baltic states and the Balkans, than in Western regions and Scandinavia. Two main coldspots were observed: one shared by France and the Iberian Peninsula, and the other in Scandinavia. Hotspots were seen in Lithuania, Latvia, Estonia and

Table 1. Basic statistics for health production resources and mortality by disease group, 2018.

Variable	Mean	CV (%)	Min	Max
Hospital beds per 100,000 inhabitants	540.9	40	102.0	1277.6
Medical doctors per 100,000 inhabitants	390.2	27	157.4	831.6
Healthcare expenditures per capita	2918.1	45	599.4	6389
Diseases of the circulatory system	403.0	45	134.6	1323.7
Diseases of the digestive system	45.1	31	20.6	102.1
Diseases of the genitourinary system	22.0	45	0.2	60.5
Diseases of the nervous system and sensory organs	44.2	57	9.0	210.2
Diseases of the respiratory system	84.6	32	29.2	178.2
Endocrine, nutritional and metabolic diseases	34.0	43	2.6	83.4
Mental and behavioural disorders	42.5	58	0.1	105.6
Neoplasms	274.1	16	158.8	405.7

CV, coefficient of variation (the ratio of the standard deviation to the mean). Source: Eurostat. Some missing information for Swiss regions was obtained from Switzerland's Federal Statistical Office.

Table 2. Spatial production function error model for selected diseases 2018.

Variable	EXPD estimates (p)	BEDS estimates (p)	DOCS estimates (p)	λ estimates (p	AFF estimates (p)	R^2
Diseases of the circulatory system	-0.310 (0.000)	0.178 (0.000)	0.091 (0.247)	0.861 (0.000)	-0.139 (0.000)	0.81
Diseases of the digestive system	-0.117 (0.067)	0.145 (0.001)	-0.030 (0.694)	0.791 (0.000)	-0.091 (0.007)	0.64
Neoplasms	-0.045 (0.192)	0.137 (0.000)	-0.044 (0.33)	0.603 (0.000)	-0.11 (0.000)	0.47
Diseases of the respiratory system	-0.185 (0.006)	-0.0096) (0.840)	0.156 (0.058)	0.756 (0.000)	-3.429 (0.000)	0.60
Diseases of the nervous system and sensory organs	0.381 (0.000)	-0.79 (0.22)	-0.230 (0.045)	0.045 (0.000)	-0.201 (0.000)	0.70
Mental and behavioural disorders	0.597 (0.003)	0.039 (0.780)	-0.804 (0.000)	0.831 (0.000)	-	0.75
Endocrine, nutritional and metabolic diseases	-0.243 (0.040)	0.233 (0.008)	-0.061 (0.682)	0.678 (0.000)	-	0.37
Diseases of the genitourinary system	-0.440 (0.001)	0.091 (0.370)	0.559 (0.001)	0.700 (0.000)	-	0.48

EXPD, healthcare expenditures; BEDS, number of hospital beds; DOCS, number of doctors; λ, spatial autoregressive coefficient for the error term; AFF, affluence dummy representing the quarter of the most affluent regions by GDP per capita; $R^{2,}$ coefficient of determination.

the Balkans. The overall spatial autocorrelation for digestive system diseases was high (I = 0.65). Mortality rates in the Balkans, Slovakia, Hungary, Lithuania, northern Germany and the Iberian Peninsula tended to be much higher than in Norway, Sweden, Greece, Italy, Switzerland and Austria. This pattern was reflected by three coldspots: in Scandinavia, northern Italy, Switzerland, Austria and Greece, and two major hotspots: one in northern Germany and the other shared by Poland and Bulgaria, with an additional cluster of high mortality emerging in Spain.

Endocrine, nutritional, and metabolic diseases exhibited a distinct spatial pattern, with Global Moran's $I = 0.49$. Mortality due to these disorders was seen as generally high in West Europe, Italy and most of the Iberian Peninsula. Low death rates were noted in the CEE region, Finland and Greece. This distribution was evident in the cluster analysis, with a few LL groupings located in Poland, the Balkans, the Baltic States and Finland, with hotspots observed in Germany, Austria, Italy and Portugal.

The global spatial autocorrelation for the diseases of the genitourinary system was strong (Global Moran's $I = 0.63$). These medical problems proved to be the most hazardous in the Iberian Peninsula and Germany (reflected by two main hotspots). Low mortality, reflected by common coldspots, was observed in France, Scandinavia, Poland, Czech Republic, Slovakia and Hungary.

For mental and behavioural disorders, there was a clear and stable spatial pattern (Global Moran's $I = 0.73$). Low mortality and corresponding coldspots were noted in CEE, while high mortality rates were shown by hotspots in Scandinavia and West Europe – one large cluster was found in Germany, Switzerland and the Benelux, and another in the Iberian Peninsula.

Global spatial autocorrelation was the highest among the analysed diseases (Global Moran's $I = 0.85$) for the diseases of the nervous system and the sensory organs, whose spatial distribution of mortality was quite similar to that of mental and behavioural disorders. High death rates were primarily observed in northern and

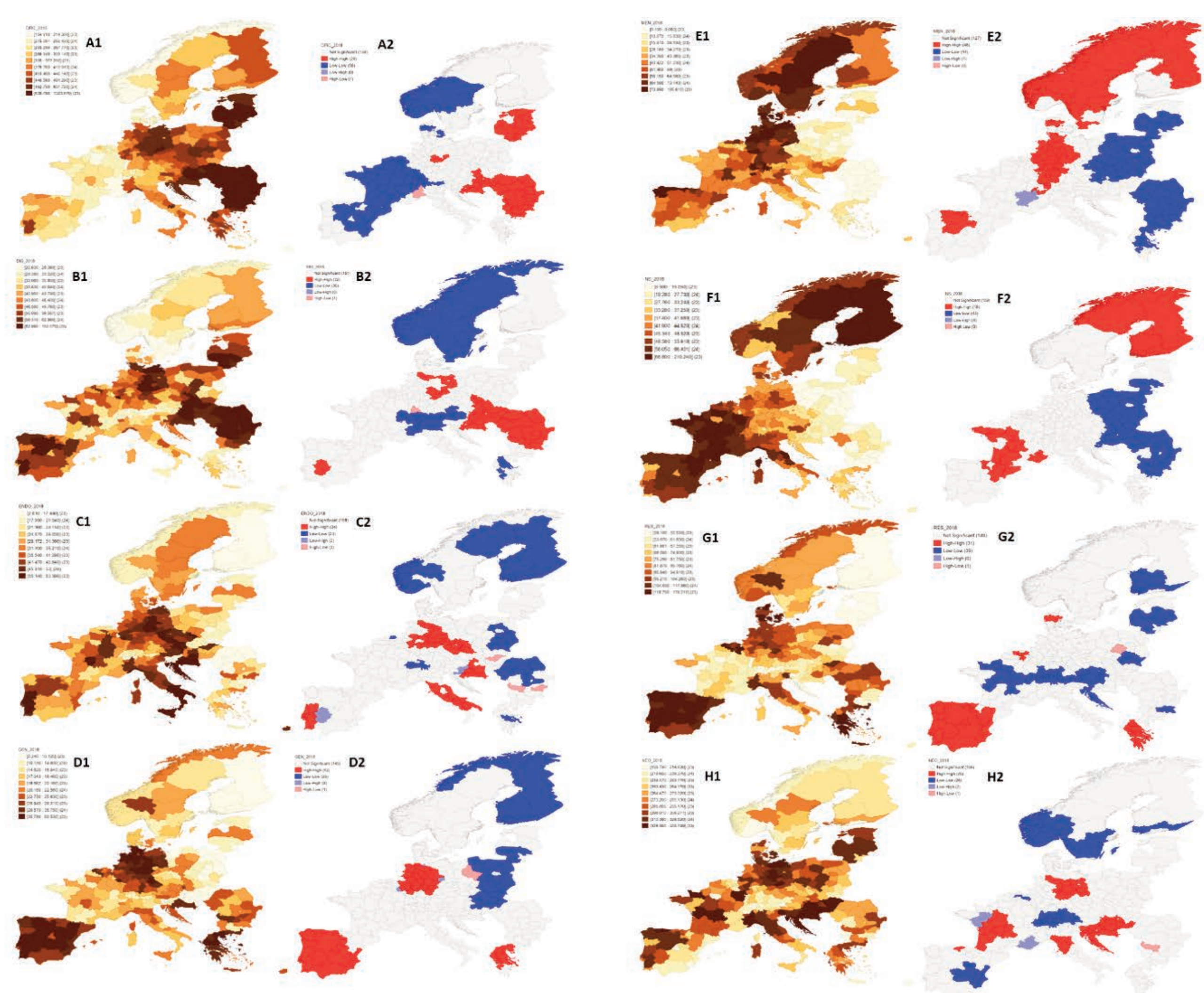

Figure 2. Spatial distribution of mortality rates, NUTS2 region 2018. **A**) Diseases of the circulatory system; **B**) diseases of the digestive system; **C**) endocrine, nutritional and metabolic diseases; **D**) diseases of the genitourinary system; **E**) mental and behavioural disorders; **F**) diseases of the nervous system and sensory organs; **G**) diseases of the respiratory system; **H**) neoplasms; 1) choropleth map; 2) local indicators of spatial association (LISA).

western Europe, while low ones were noted in CEE. This observation was reflected in coldspots appearing from Baltic states, through the Visegrád Group to the Balkans and in hotspots in Scandinavia, France and Spain.

The global spatial autocorrelation for the respiratory system diseases was strong (Global Moran's $I = 0.68$). The mortality rates in the Iberian Peninsula, Greece, Italy, Denmark and Benelux were high, corresponding to the main hotspots. In particular, coastline regions tended to exhibit higher values than in-land ones. Low death rates were recorded in Finland, the Baltic states, certain regions of CEE and France, where a set of coldspots emerged.

In the case of neoplasms, the spatial distribution was not as straightforward as for the previous diseases. The Global Moran's I was the lowest among all the disease groups researched, although still notable ($I = 0.44$). High mortalities were recorded in Croatia, Hungary, northern Italy, Spain, northern and central Germany and Denmark. Spatial clusters were scattered across Europe, with coldspots in central Europe (Germany, Switzerland, Austria), south-eastern Spain as well as southern Norway and Sweden. At the same time, hotspots emerged in Croatia, Hungary, northern Italy, central Germany and France.

Table 2 presents the results regarding the function of the spatial health services based on the error model for selected diseases in 2018. Since doctors, hospital beds, or expenditures do not cause diseases or deaths, the counterintuitive positive correlation should be interpreted as an insufficient response to the demand arising from deteriorating population health.

Estimation results generally indicate that healthcare resources have a significant impact on mortality rates, with the model demonstrating satisfactory explanatory power. Key findings revealed substantial and complex variations: in all categories analysed at least one input was found to be insignificant. Furthermore, the sign, strength and significance of input-mortality relationships were found to vary considerably across specific disease categories. Counterintuitively, the number of beds often correlated positively with mortality for most diseases. Financial expenditure, however, typically correlated negatively with mortality, suggesting that the mortality could be reduced by increase in expenditure, although it showed a positive correlation for neurological and mental disorders. The expected negative correlation between the number of doctors and mortality (more doctors, lower mortality) was observed only for neurological and mental disorders, with other categories, such as genitourinary and respiratory diseases, showing a strong, positive (adverse) correlation. Finally, higher regional affluence was consistently associated with reduced mortality across several major disease groups (circulatory, digestive, neoplastic, respiratory and diseases of the nervous system).

Discussion

Spatial patterns for all diseases were found to be strong, but the regional distributions differed. Higher mortality due to circulatory problems was seen in impoverished regions, while more affluent locations were burdened with neurological diseases and mental and behavioural disorders. The similarity in the spatial patterns of mental and neurological disorders is noteworthy and suggests a need for shared policy interventions, particularly in long-term or community-based care. The European Commission highlights this link, advocating integrated care models to manage the complex needs of patients with mental and neurological conditions (European Commission, 2023). Evidence from other research reports also supports collaborative care models, showing that they improve outcomes for individuals with these disorders across European regions (Magaard *et al.*, 2018).

Based on our estimation results for most disease categories, the number of beds correlated positively with mortality, suggesting a system under strain and a reactive rather than preventive allocation of resources. However, hospital beds were not found to bear any significant impact on death rates for respiratory diseases and neoplasms. Inpatient care, represented by hospital facilities alone, is insufficient for managing severe conditions, which usually require effective prevention, diagnostic and outpatient services for curative treatment. The most prominent underlying cause for this positive correlation might be that regions with a high number of hospital beds could also be areas characterised by elderly or generally unhealthy populations that naturally require more inpatient capacity. Moreover, patients might only access hospital care when their conditions are already severe, which coincides with high mortality. Inpatient care is heavily skewed towards treating acute, often critical, conditions as opposed to long-term treatment of chronic diseases that generally takes place outside hospitals.

Positive correlation of mortality and financial resources indicates that an increase in healthcare expenditures would be insufficient for a significant reduction in mortality from neurological and mental disorders. Moreover, the absolute impact on mortality in these categories remains substantial. Neurological and mental disorders often demand sustained, personalised and multidisciplinary care approaches encompassing medical, psychological and social dimensions, which cannot be adequately addressed through short-term or purely financial interventions. In other words, while funding is a necessary condition, it is not sufficient when outpatient and informal care are essential for mental and neurological patients. In contrast, the relationship between financial expenditures and mortality in most other disease categories is markedly the inverse. This consistent and statistically robust pattern suggests that increased financial inputs are generally effective in improving population health outcomes. Higher expenditures often translate into better access to timely, high-quality care, more advanced medical technologies and well-resourced health facilities. Moreover, financial investment enables better staffing, training and retention of healthcare professionals that directly influence the quality of diagnostics, treatment, and patient monitoring. Greater funding may also allow for more comprehensive preventive programmes, which can reduce the disease burden in the first place.

Although the reduction in mortality is less than proportional to the increase in expenditures, indicating diminishing marginal returns, the impact remains consistently beneficial across disease groups. The relatively low variability in the estimated effect of spending across diseases also reinforces the interpretation that financial investment is a stable and reliable lever for improving health outcomes at the population level. For human resources, the observed positive elasticity for genitourinary and respiratory diseases, where an increase in the number of doctors was correlated with higher mortality rates, suggests a counterintuitive relationship. Rather than indicating that doctors are ineffective or harmful, this finding likely points to underlying systemic inefficiencies, confounding variables and structural mismatches between healthcare supply and population health needs. The positive elasticity could reflect a reactive allocation of resources, rather than a preventive or proactive one. This would especially apply to chronic, high-incidence diseases like respiratory and genitourinary conditions, which often affect older, multi-morbid populations requiring frequent medical attention. Another key factor is the type and specialisation of the doctors. Datasets usually aggregate medical personnel in broad terms without distinguishing between general practitioners and highly specialised clinicians, as in our study. Additionally, the effectiveness of medical personnel is inherently limited in environments that lack the necessary diagnostic and therapeutic infrastructure, such as imaging equipment, intensive care units, or specialised surgical and rehabilitation centres. As a result, higher doctor counts in poorly equipped regions may not translate into reduced mortality, but may instead reflect a misalignment between human and material healthcare resources.

In contrast, the expected negative elasticity, where more doctors are associated with lower mortality, was observed only for neurological and mental disorders (with the latter being the highest absolute estimate of the parameter in the whole study). This suggests that in these domains, physician presence is genuinely important, perhaps even indispensable. In this context, continuous access to medical professionals, particularly psychiatrists, neurologists and community-based practitioners can lead to earlier diagnoses, better disease management and reduced risk of acute episodes that would otherwise lead to hospitalisation or death. The substantial strength of the negative impact of the number of doctors on mortality from neurological and mental disorders may also reflect a greater reliance on interpersonal care and monitoring, which is particularly true for psychiatric and neurodegenerative conditions. Unlike surgical interventions or high-tech treatments that dominate other disease categories, the treatment of mental health conditions often depends more directly on the frequency, duration, and quality of physician-patient interactions. Therefore, increased physician density in this field directly translates to better access, follow-up, and therapeutic continuity, which are known to substantially reduce morbidity and mortality.

Interestingly, the level of affluence in the region was found to be associated with a reduction in mortality from circulatory, digestive, neoplastic, respiratory, and nervous system diseases. This pattern highlights the profound influence of broader socioeconomic conditions on population health, underscoring the importance of structural determinants that extend beyond the healthcare system alone. Wealthier regions tend to exhibit a synergy of interrelated advantages that create more favourable conditions for disease prevention, timely diagnosis, and effective treatment. First and foremost, affluence is strongly correlated with greater access to quality healthcare services, including specialised care, advanced diagnostic technologies, and well-equipped hospitals. In affluent regions, individuals are more likely to undergo regular screenings and receive early interventions, particularly for diseases such as cancers or cardiovascular conditions, where timely detection significantly improves survival rates. Moreover, wealthier populations tend to be better informed about health risks, more health-literate, and more proactive in seeking care. Affluence also enables healthier lifestyles through improved living conditions, better nutrition, and greater opportunities for physical activity.

Among all disease categories, mental illnesses demonstrate the greatest sensitivity to healthcare resources, both expenditures and the number of doctors, despite these two factors exhibiting contradictory effects. Neurological conditions demonstrated aligned responsiveness to healthcare resources with mental disorders. The explanatory power of the function of health services varied across diseases, with endocrine, nutritional, and metabolic disorders proving the most challenging to model accurately. This might be due to critical non-systemic risk factors of endocrine, nutritional, and metabolic diseases not included in the model, such as lifestyle and behavioural characteristics, biological and genetic factors, and societal and environmental factors. Neoplasms were the only disease group that was not significantly influenced by financial health expenditures. This may reflect the unique nature of cancer care, where early detection, access to cutting-edge therapies, and long-term follow-up are critical, but often not directly correlated with overall spending levels. Cancer outcomes depend heavily on highly specialised infrastructure (e.g., oncology centres, radiotherapy units, precision diagnostic centres) as well as timely access to innovation, support that is not always evenly distributed, even in well-funded systems. At the same time, regional prosperity plays a crucial role in reducing cancer-related mortality, but primarily in the top-most affluent regions. This suggests that only at a certain threshold of socioeconomic development do the benefits of wealth, such as better education, healthier lifestyles, higher health literacy and access to advanced healthcare, translate into measurable reductions in cancer mortality (Olejnik & Żółtaszek, 2023). In less affluent or moderately prosperous regions, structural inequalities, delayed diagnoses, or limited access to specialised care may hinder outcomes even if general health spending increases. This indicates a nonlinear effect of prosperity: affluence only leads to substantial mortality reduction for complex diseases such as neoplasms. where multiple enabling conditions (such as good education, resourceful infrastructure and efficient health system) coexist.

Overall, mortality rates across all diseases exhibit decreasing returns to scale in response to healthcare inputs. As basic health issues are addressed, the remaining causes of mortality become more complex, chronic or challenging often requiring highly specialised, expensive and intensive interventions that yield minor improvements in mortality for each additional unit of healthcare input. Additionally, many determinants of health and mortality are outside the direct control of the healthcare system. Factors such as diet, exercise, education, income, environmental quality and social determinants play a significant role. Without addressing these underlying factors, the potential for further mortality reduction from healthcare alone diminishes, even after massive healthcare investment. Moreover, the presence of insignificant or even positive elasticities, particularly for the number of doctors and hospital beds, suggests that they, in some instances, do not necessarily translate into effective prevention or curative outcomes, even when resources support better diagnosis, monitoring or palliative care,

Limitations

The limitations of available data, particularly the lack of disaggregated figures for specialised physicians, hospital services and disease-specific expenditures, constrain the precision of our estimates. Future research would benefit significantly from richer datasets that better capture structures, specialisation and general quality of healthcare services, thereby enabling more nuanced analyses.

Conclusions

The study reveals complex and disease-specific relationships between healthcare resources and mortality in European regions. By applying a spatial health production function across eight major causes of death, we uncovered several crucial findings that challenge simplistic assumptions about the benefits of resource increases and underscore the necessity of context-sensitive policy strategies.

First, inpatient care alone proves insufficient in reducing mortality across the studied diseases. The widespread positive or insignificant elasticities associated with the number of hospital beds suggest that simply increasing physical infrastructure does not translate into improved health outcomes. This counterintuitive relationship likely results from reactive healthcare systems in which beds are allocated to meet already high levels of morbidity, rather than used for prevention of disease progression. A two-way association or reverse causality between mortality and hospital infrastructure cannot be dismissed. Country systems may also lack any form of resource adjustment in response to mortality levels resulting in an insignificant association. Nevertheless, inpatient settings, expressed by the number of hospital beds, primarily address acute conditions that often lack continuity of care, while chronic or complex diseases require supplementary outpatient management, prevention and follow-up services. The implication is clear: more beds do not equate with better care unless complemented by preventive and outpatient services that target the root causes.

Second, the role of medical doctors exhibits substantial heterogeneity across disease types. While a higher density of physician presence correlates with reduced mortality for mental and neurological disorders, conditions that rely heavily on continuous, interpersonal, and multidisciplinary care, it fails to lower death rates for other illnesses. It may even coincide with increasing mortality for genitourinary and respiratory diseases. The positive association paradox likely arises from systemic inefficiencies, such as the misallocation of staff, lack of coordination with other healthcare components or the inherent nature of the aggregated doctor data. Presence of physicians alone is insufficient; their specialisation, deployment context and collaboration with appropriate facilities critically determine their effectiveness. Therefore, a basic headcount may provide a misleading picture of the system capacity, which in turn can affect research findings. Our results emphasise the need for qualitative human capital assessments, going beyond headcounts to measure the alignment between healthcare needs and the available workforce. To sum up, effective use of medical doctors is determined, not by their absolute numbers, but by the extent to which their specialisation, distribution and functional roles are aligned with the health system's needs.

Third, financial resources emerge as the most consistent determinant of improved health outcomes across disease categories, except for neoplasms, neurological and mental disorders. Increased healthcare spending correlates with lower mortality, which supports the idea that financial investment enables broader access to services, more advanced technologies and a more robust healthcare infrastructure. However, the benefits diminish with scale, and this points to the limitations of budgetary expansion in isolation. For diseases like neoplasms, the lack of a significant correlation with expenditure underscores the need for targeted infrastructure and access to cutting-edge treatment, which is often unevenly distributed. In the case of mental and neurological conditions, financial investment alone does not suffice without accompanied by availability of trained professionals and long-term care frameworks.

Notably, mental and neurological conditions are most sensitive to variations in healthcare resources, suggesting that these domains may benefit most directly from targeted healthcare investment, particularly in human capital. The study also sheds light on the profound influence of regional affluence on mortality. Wealthier regions exhibit significantly lower mortality rates in diseases affecting the circulatory, digestive, neoplastic, respiratory and nervous systems. This suggests that structural socioeconomic advantages, such as higher health literacy, better nutrition, improved housing and increased access to early diagnosis and specialised care play a key role in shaping health outcomes. These findings indicate that the effectiveness of healthcare spending is not uniform across all contexts, but amplified in settings where socioeconomic conditions facilitate the uptake and impact of medical interventions. Conversely, in disadvantaged regions, limited health awareness, barriers to access and poor living conditions may constrain the returns on healthcare investment. Policy measures should therefore not only focus on increasing medical resources but also on addressing underlying social determinants, ensuring that health expenditures translate more equitably into improved outcomes. Furthermore, the production function exhibits decreasing returns at scale across all disease categories, which implies that once basic healthcare needs are met, further mortality reductions become increasingly complex, often requiring disproportionately large investments to achieve marginal gains. This underscores the importance of complementary non-medical interventions, including education, economic support and environmental improvements, which all lie outside the healthcare sector but still are essential for sustained health progress.

The findings presented here advocate for disease-specific, resource-sensitive health strategies that recognise the heterogeneous impact of various healthcare inputs. Effective healthcare policy must integrate both quantitative and qualitative considerations, ensure a balanced mix of inpatient and outpatient care and be firmly grounded in the broader socioeconomic landscape. Structural investments in prevention, specialisation, and regional equity are indispensable for reducing mortality and fostering resilient European health systems.

References

Ahmad K, Chen EW, Nazir U, Cotts W, Andrade A, Trivedi AN, Erqou S, Wu WC. 2019. Regional variation in the association of poverty and heart failure mortality in the 3135 counties of the United States. J Am Heart Assoc 8:e012422.

Al Wosibei AAT, Alabdulwahed MFM, Abdularhman IBS, Saeedain+Maram Ali Abdullah AlSadiq JMF, Altalaliwah ASH, Al-Ghamdi MS, Aldossary A, Alshikh ZM, AlQattan, AS. 2024. Critical analysis of healthcare resource distribution, cost-effectiveness, and equity. J Ecohumanism 3:51-70.

Androutsou L, Metaxas T, 2019. Measuring the efficiency of medical tourism industry in EU member states. J Tour Anal 26:115-30.

Anselin L, 1995. Local Indicators of Spatial Association - LISA. Geogr Anal 27:93-115.

Auster R, Leveson I, Sarachek D, 1969. The Production of Health, an Exploratory Study. J Hum Resour 4:411-36.

Batakis D, Sidiropoulos S, Emmanouil-Kalos A, Fouskas T, Zopounidis C, Vozikis A, 2023. Medical Tourism in the Region of Crete, Greece: Perspectives from Healthcare Providers, Hotel Managers, and Medical Tourists. Sustainability 15:16822.

Calazans JA, Permanyer I, 2023. Levels, trends, and determinants of cause-of-death diversity in a global perspective: 1990-2019. BMC Public Health 23:650.

Caraballo LJ, Eslava-Zapata R, Calderón-Ortega M, 2025.

Evaluation of the production function of health in the countries of the organization for economic cooperation and development, Latin America and Colombia. Semin Med Writ Educ 4:460.

Cobb CW, Douglas PH, 1928. A Theory of Production. Am Econ Rev 18:139-165.

Dong E, Sun X, Xu T, Zhang S, Wang T, Zhang L, Gao W, 2023. Measuring the inequalities in healthcare resource in facility and workforce: A longitudinal study in China. Front Public Health 11:1074417.

European Commission, 2023. A comprehensive approach to mental health. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions. COM(2023) 378 final. Retrieved from https://health.ec.europa.eu/non-communicable-diseases/mental-health_en

Eurostat database. Accessed 10 December 2022. Available from: https://ec.europa.eu/eurostat/data/database

Eurostat, 2023. Urban-rural Europe – quality of life in rural areas. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Urban-rural_Europe_-_quality_of_life_in_rural_areas#Accessibility

Fayissa B, Traian A, 2013. Estimation of a Health Production Function: Evidence from East-European Countries. Am Econ 58:134-48.

Gaano JB, Rule C, Celeste JJ, Boñgolan VP, Rivera RL, Caoili SE, 2024. Lessons Learned from the COVID-19 Pandemic: An Analysis of Regional Philippine Data and COVID-19 Outcomes. Int Arch Photogramm Remote Sens Spatial Inf Sci XLVIII-4/W8-2023:259-65.

Grossman M, 1972. On the concept of health capital and the demand for health. J Polit Econ 80:223-55.

Guerrero R, Rao KD, 2025.Why disaggregated data on health expenditures has been elusive, but will not remain so. Lancet Reg Health Am 44:101073.

Li C, Zhang L, Zhang J, Jiao J, Hua G, Wang Y, He X, Cheng C, Yu H, Yang X, Liu L, 2024. Global, regional and national burden due to retinoblastoma in children aged younger than 10 years from 1990 to 2021. BMC Med 22:604.

Li Y, Cao GY, Jing WZ, Liu J, Liu M, 2023. Global trends and regional differences in incidence and mortality of cardiovascular disease, 1990-2019: findings from 2019 Global Burden of Disease Study. Eur J Prev Cardiol 30:276-286.

Magaard JL, Liebherz S, Melchior H, Engels A, König HH, Kriston L, Schulz H, Jahed J, Brütt AL, Reber KC, Härter M, 2018. Collaborative mental health care program versus a general practitioner program and usual care for treatment of patients with mental or neurological disorders in Germany: protocol of a multiperspective evaluation study. BMC Psychiatry 18:347.

Mbau R, Musiega A, Nyawira L, Tsofa B, Mulwa A, Molyneux S, Maina I, Jemutai J, Normand C, Hanson K, Barasa E, 2023. Analysing the Efficiency of Health Systems: A Systematic Review of the Literature. Appl Health Econ Health Policy 21:205-24.

Moran P, 1950. Notes on Continuous Stochastic Phenomena. Biometrika 37:17-23.

Mullahy J, 2010. Understanding the production of population health and the role of paying for population health. Prev Chronic Dis 7:A95.

Olejnik A, Żółtaszek A, 2023. The net effect of wealth on health – Investigating noncommunicable diseases mortality in the context of regional affluence. PLoS One18:e0293887.

Ren HM, Liao MQ, Tan SX, Cheng C, Zhu S, Zheng L, Ma JR, Mu YJ, Li WL, Zhang SW, OuYang RQ, Li SN, Cui YF, Ke XY, Luo ZY, Xiong P, Liu J, Li LP, Liang XF, Zeng FF, Su XF, Han LY, 2022. Global, Regional, and National Burden of Cancer in Children Younger Than 5 Years, 1990-2019: Analysis of the Global Burden of Disease Study 2019. Front Public Health 10:910641.

Stuckler D, Basu S, McKee M, 2011. Health care capacity and allocations among South Africa’s provinces: infrastructure-inequality traps after the end of apartheid. Am J Public Health 101:165-72.

Ursache SA, Gabor VR, Muntele I, Maftei M, 2021. Mortality trends by causes of death and healthcare during a period of global uncertainty (1990-2017). Healthcare (Basel) 9:748.

Wakasugi M, Narita I, 2023. Prefecture-specific prevalence of overweight/obesity is associated with regional variation in the incidence of treated ESKD in Japan. Clin Exp Nephrol 27:132-140.

Zacarías-Pons L, Turró-Garriga O, Saez M, Garre-Olmo J, 2024. Multimorbidity patterns and disability and healthcare use in Europe: do the associations change with the regional socioeconomic status? Eur J Ageing 21:1.

Online supplementary materials

Model selection statistics