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GRINS FOUNDATION

TEMME-Health Final report

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Executive summary

This report presents the results of the TEMME-Health (Territorial Mapping Model for an Equitable HEALTHcare) project, developed by the University of Urbino within the GRINS initiative. Its core objective is to create a robust, data-driven framework to evaluate the Italian National Health System (NHS) by integrating macroeconomic, territorial, institutional, and environmental perspectives. The project focuses on developing composite, georeferenced indicators to support evidence-based decision-making and equitable health policy.

The report explores the financial evolution of Italy's healthcare system, highlighting structural reforms introduced by the 2001 constitutional changes and their implications for regional autonomy. Despite progress, the current resource allocation model remains misaligned with constitutional goals, especially in addressing regional disparities and ensuring full financing of Essential Levels of Care (LEA). The proposed solution involves a new model to estimate standard healthcare needs based on efficiency, socio-economic conditions, and expected service levels.

Macroeconomic analysis using VAR techniques confirms a bidirectional relationship between economic growth and healthcare expenditure, emphasizing healthcare's role as both a cost and an investment in human capital. Decentralisation and interregional mobility are also examined: while autonomy fosters service adaptation to local needs, it also risks increasing inequality. Healthcare mobility networks are mapped using complex network theory to identify structural inefficiencies and regional imbalances.

The empirical core is structured into four thematic streams:

1. *Regional financial needs* – a model estimates standard health needs integrating supply, demand, and efficiency data (1998–2022);
2. *Composite output indicators* – a multidimensional framework evaluates local health authority performance (2022);

3. *Healthcare mobility* – interregional patient flows are analysed to assess territorial equity and service attractiveness;
4. *Environmental context* – indicators such as air quality and soil degradation are included to account for health determinants.

Finally, the TEMME-Health project offers a comprehensive and replicable approach for improving transparency, efficiency, and fairness in healthcare governance across Italy.

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LIST OF ABBREVIATIONS

CIPESS	Comitato interministeriale per la programmazione economica e lo sviluppo sostenibile
FSN	National Health Care Fund (Fondo Sanitario Nazionale)
GRINS	Growing Resilient, Inclusive and Sustainable
HHI	Herfindahl-Hirschman concentration index
LEA	Livelli Essenziali di Assistenza (Essential Levels of Care)
LEP	Livelli Essenziali delle Prestazioni (Essential Levels of Services)
LTC	Long-Term Care
NHS	National Health System
NSG	Nuovo Sistema di Garanzia (New Guarantee System)
PCA	Principal component analysis

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1 REPORT OVERVIEW

This project has been financed by the GRINS Foundation (Growing Resilient, Inclusive and Sustainable (GRINS)) within the Extended Partnership Call for Proposals entitled "*Economic and Financial Sustainability of systems and territories*" with the aim of the development of an integrated set of heterogeneous georeferenced databases for the study of the different dimensions relevant to examine the current status and evolution of economic and social conditions of the Italian territories and of the economic system as a whole.

This report, in particular, documents the preliminary results and theoretical frameworks of the TEMME-Health project (TErritorial Mapping Model for an Equitable HEALTHcare) - University of Urbino Carlo Bo - which oversees the subsection related to the mapping of Italy's critical measures of the National Health System (NHS).

This final report is structured as follows: Initially, Chapter 2 provides a comprehensive overview of the financial structure of the Italian National Health Service (NHS). This includes an analysis of the primary funding sources, allocation mechanisms and the roles played by various governmental and regional entities; second, the NHS functions as a national system that contributes significantly to economic growth at the macro level is explored in Chap. 3. This chapter delves into the role of the NHS as a major economic driver, stimulating employment, generating demand for medical supplies and services, and supporting industries related to healthcare infrastructure and innovation. Finally, Chap. 4 examines this regional impact in detail, highlighting how the decentralised structure of the NHS enables regions to tailor healthcare services to meet local needs, promoting economic development at the territorial level.

These topics are essential in the report for several reasons:

1. **Understanding Financing Mechanisms** (Chap. 2): Analysing the financing of the National Health Service (NHS) in Italy is crucial

to understanding how healthcare is sustained and the economic choices that impact public health services. Financing strategies have significant effects on service accessibility, quality, and sustainability. Exploring these aspects helps stakeholders make informed decisions to ensure that healthcare remains accessible and resilient, especially in changing economic environments.

2. **Macro-Level Economic Impact** (Chap. 3): The NHS not only contributes to public health, but also acts as a major driver of economic growth at the macro level. By examining its role in economic terms, the report can highlight how healthcare spending influences GDP, employment, and productivity across the country. More in particular, this section employs a time-series VAR model to explore the dynamic interrelations between key economic, demographic, and healthcare variables in Italy from a long-term perspective. By accounting for major institutional reforms as structural breaks, the analysis reveals how shocks propagate through the healthcare system and affect its sustainability over time.

3. **Regional and Local devolution** (Chap. 4): Italy's NHS is organised with regional autonomy, allowing regions to tailor healthcare delivery to local needs. Exploring these regional differences offers insight into how decentralised governance affects service quality and equity in healthcare. Understanding these disparities is crucial for policy recommendations that aim to reduce inequalities and ensure that all regions can provide adequate healthcare regardless of local economic conditions.

Building on these premises, this report adopts a comprehensive approach by exploring **three main application streams**. These streams are designed to facilitate the estimation not only of individual measures, but also of a diverse array of data, reflecting the multifaceted nature of healthcare dynamics. The ultimate goal is to develop robust and actionable metrics that can be readily used by policy makers to inform strategic decision making and improve governance within the health sector. By focusing on usability and relevance, these metrics aim to bridge the gap between complex statistical analyses and practical applications, ensuring that insights are accessible and impactful.
In the coming months, this diverse collection of databases and measure-

ments will be integrated into a unified geographical database.

STREAM 1 - Regional financial health standard needs, Chap. 5

In this stream, an innovative financial resource perequation model to estimate standard health care needs is proposed; variables of local demand, supply, cost, technical efficiency of production factors will be taken into account to determine optimal resource allocation.

Domain: Cost

Estimated measures: Estimation of regional health standard needs + local demand variables, contextual factors, inputs and outputs produced

Level of detail: Regional

Time series: 1998-2022

Dataset uploaded to AMELIA:
TEMME_Stream1_standard needs.xlsx

STREAM 2 - Multi-directional composite indicator, Chap. 6

In this stream, a new methodology is applied to the construction of endogenous composite indicators in health domain to produce a reliable overall measure for the evaluation of individual hospitals.

Domain: Output, Outcome

Estimated measures: Output composite indicator

Level of detail: Local Health Authority

Time series: 2022

Dataset uploaded to AMELIA:
TEMME_Stream2_multidirCI.xlsx

STREAM 3 - Healthcare mobility, Chap. 7

In this stream, the interregional compensation scheme of the Italian NHS is conceptualised using complex network theory, where Italian regions represent the nodes (or vertices) and the monetary and numerical trade flows between regions and the corresponding connections (or edges). In this way, we can use specific indicators to analyse the structural characteristics of our network. In traditional analysis

of complex networks, one of the most important problems is related to the identification of the importance of nodes that, in our case, are represented by regions.

Domain: Demand

Estimated measures: we concentrate on three prevalent centrality measures frequently used in the economic literature: (weighted-) degree centrality, eigenvector centrality and Herfindahl-Hirschman concentration index (HHI).

Level of detail: Regional/Provincial

Time series: our database includes the amount of (bilateral) exchanges between regions in terms of both the value generated by extra-regional health services and the number of patients. The first database covers the period from 2002 to 2021, while the second database ranges from 2002 to 2022. Updated to the latest available year, both databases thus allow us to also examine the impact of the 2020 health crisis on the health mobility flows between regions.

Dataset uploaded to AMELIA:
TEMME_Stream3a_patients_data.xlsx
TEMME_Stream3b_patients_panel.xlsx
TEMME_Stream3c_monetary_vol_data.xlsx
TEMME_Stream3d_monetary_vol_panel.xlsx

STREAM 4 - Environmental conditions, Chap. 8

In this stream of analysis, the main environmental context indicators are calculated to account for the effects they may have on public health. This approach allows us to integrate environmental determinant into the assessment of health outcomes, recognizing their critical role in shaping population well-being and healthcare needs.

Domain: Contextual variables

Estimated measures: Soil degradation, air quality, water status, urban waste and composite environmental index

Level of detail: Municipal level

Time series: 2023

Dataset uploaded to AMELIA:
TEMME_Stream4_environment_indexes.xlsx

Finally, this report was crafted through a collaborative effort, with each contributor bringing invaluable insights and unique expertise to the table. The diverse range of skills represented among the team members enriched the analysis, allowing for a comprehensive and multidimensional approach to the subject matter.

Urbino team:

- Francesco Vidoli, PI and Associate Professor of Economic Statistics
- Agnese Sacchi, Associate Professor of Public Finance
- Giuseppe Travaglini, Full Professor of Economic Policy
- Chiara Subrizi, Research Fellow

The Urbino team was joined and supported by a group of additional collaborators, whose combined efforts and expertise contributed significantly to the depth and quality of the project.

Collaborators:

- Mauro Mare', Full Professor of Public Finance, Luiss Business School
- Francesco Porcelli, Associate Professor of Economics, La Sapienza University
- Elisa Fusco, Assistant professor of Economic Statistics, University of Florence
- Giovanni Carnazza, Assistant Professor of Public Finance, Pisa University
- Alberto Cardillo, ISPRA researcher, GIS expert

2 THE EVOLUTION OF HEALTH CARE SPENDING IN ITALY

In Italy, the structure of relationships among various governmental tiers (Central State, Regions, Provinces, Metropolitan Cities, Municipalities) has evolved through a historical layering of legislation. These laws have been added over time, from when the Republic was proclaimed to today, often lacking a systematic approach. The current constitutional framework, which was revised in 2001 through Articles 114, 116, 117, 118 and 119, strengthened the foundations of a configuration centred on administrative and fiscal devolution, attributing to the central state the task of reducing territorial disparities through the guarantee of a uniform provision of essential services on a national scale. The concepts of autonomy, devolution of powers, and consistency in the provision of essential services are currently integrated in a system of fiscal equalisation that covers an important portion of the current expenditure budget, amounting to more than 180 billion €, earmarked for the financing of services that are fundamental for the welfare of citizens, ranging from health and environmental protection, social support, ancillary services for education, to security, road management, and local transport.

The 2001 constitutional reform led to a major overhaul of Article 119 of the Italian Constitution, introducing a principle of financial autonomy for subcentral government entities, such as municipalities, provinces, metropolitan cities, and regions. This legislative amendment grants these entities the power to generate revenue through their own taxes, tariffs, levies on assets, and to benefit from coparticipations in state tax revenues, guaranteeing them the ability to self-finance the public functions for which they are responsible. The objective is to allow each authority to fully cover the standard expenses for the public functions assigned to

it, making use of equalising transfers from the central state to bridge any inequalities between tax capacity and expenditure needs.

In contrast to the previous financial setup, the reform excludes the possibility of earmarked state transfers as an ordinary source of financing, limiting state transfers to those of an equalising nature, aimed at reducing economic disparities between the various areas of the country. This choice, relatively unique in the international context, was driven by the desire to promote a more efficient use of resources by eliminating purely financing transfers not related to specific needs or projects aimed to remove economic and social imbalances.

Despite the introduction of these financial autonomy mechanisms, some uncertainties remain. The first concerns the precise definition, at the various levels of government, of the public functions that are to be guaranteed through the full funding obtained by equalisation. The second open question is how to ensure that the unconstrained character of equalisation transfers does not undermine the ability of local authorities to effectively and efficiently deliver the public services attributed to them. To address these issues, the reform integrates further provisions within reformed Article 117 C., attributing to the state the exclusive competence to determine the Livelli Essenziali delle Prestazioni (Essential Levels of Services) (LEP) concerning civil and social rights that must be uniformly guaranteed throughout the national territory, as well as the definition of the fundamental functions assigned to municipalities, provinces, and metropolitan cities. These measures aim to complete the framework of the reformed Chapter V of the Constitution, providing a legislative architecture that supports the financial autonomy of subcentral entities while ensuring the uniform and high-quality provision of basic public services throughout Italy.

Although there have been appreciable advances since 2001, the regulatory principles of fiscal equalisation, extended from health to social services and from regions to municipalities, are not yet fully harmonised with constitutional dictates. The implementation of Law 42 of 2009, which rests on the pillars of decentralisation and solidarity to give substance to the constitutional vision of 2001, has not yet been completed. This partial implementation, although it has undoubtedly modernised the intergovernmental dynamics, as evidenced by the introduction of standard needs for the health sector and for the fundamental functions

of municipalities, has given rise to new problems and urged pressure for greater decentralisation on the part of the economically more advanced regions, within the framework of what has been called '*differentiated regionalism*' provided for by Article 116 C. and now being implemented.

For the Regions, which in the Italian system have as their main responsibility the provision of health services, Law 42/2009, in implementing the 2001 constitutional framework, consistently establishes that the expenses associated with the LEP of the Regions include, first and foremost, those for health and social assistance. The health sector, therefore, with its more than 130 billion in current public spending (equal to more than 80% of the Regions' current spending) is by far the leading sector in the entire financial decentralisation process sought by the 2001 constitutional reform, in addition to being the Regions' main spending responsibility. The same Law 42/2009 established that for the expenditure sectors subject to LEP, healthcare at the head, the full financing of the standard needs determined 'in compliance with the standard costs associated with the essential levels of the services to be provided under conditions of efficiency and appropriateness throughout the national territory' is guaranteed.

Therefore, in order to be in line with the current constitutional framework, the process of determining the standard healthcare requirements of each region should follow three crucial steps: 1) the LEP setting, 2) the determination of the standard unit cost of the services, and 3) the calculation of the financial requirement as the product between the LEP and the standard unit cost. After the enactment of Law 42/2009, the implementation of the regional standard needs of the health sector was concretely implemented with Legislative Decree 68 of 2011; thus making it possible, as of 2013, to activate the new mechanism for the distribution of the indistinct component of the National Health Care Fund (Fondo Sanitario Nazionale) (FSN) that, in fact, today guides equalisation in healthcare. Despite the fact that today we have a precise identification of the healthcare LEP through the definition of Livelli Essenziali di Assistenza (Essential Levels of Care) (LEA), the mechanism to calculate the standard needs that came from Legislative Decree 68/2011 does not allow the direct identification of the standard needs needed to meet the LEPs, since the latter mainly have an ex post performance monitoring function.

BOX 1 - Insight LEAs

The individual's right to health, protected by Articles 2 and 32 of the Constitution, must be guaranteed through the provision of services traceable to the LEA in the health sector, as identified in the Decree of the Prime Minister of 12 January 2017 implementing Articles 117 and 120 of the Constitution.

This box proposes a summary of the services currently envisaged in the DPCM annexes, with reference to the Core LEAs defined in the Ministerial Decree of the Ministry of Health of 12 March 2019, providing a concise but complete list. In particular, it discusses the indicators used, in place of the 'LEA Grid' (in force until 2019), to assess the provision of LEAs by the Regions. These indicators are divided into three macro-areas: collective prevention and public health, district care, and hospital care. Within the sphere of district assistance, specific attention has been given to sociohealth care, giving it an autonomous connotation in view of a possible integration with the LEP for social services, an area of exclusive competence of the Regions and local authorities.

Collective prevention and public health activities: these include the surveillance, prevention, and control of infectious and parasitic diseases, health protection in open and closed environments, safety in the workplace, animal health and veterinary urban hygiene, food safety, the prevention of chronic diseases through the promotion of healthy lifestyles, and the performance of medico-legal activities for public purposes. These services are aimed at the entire population and are provided directly by national health services or through contracted physicians and paediatricians.

District care: ensures a range of services accessible to the entire resident population, including outpatient and home management of pathologies, 24-hour continuity of care, health care in tourist resorts, emergency interventions, supply of medicines and medical devices, outpatient specialist care, and rehabilitation support. It also includes spa care for specific pathologies.

Sociosanitary assistance in the district: It guarantees, for the non-self-sufficient population and those in fragile conditions, access to health

> and social services at home, semi-residential and residential, the taking in charge of the person and the multidimensional assessment of needs. The Regions and Autonomous Provinces organise these activities, ensuring uniformity on their territory.
>
> Hospital care: provides a wide range of healthcare services, including emergency interventions, ordinary hospitalisation, programmable surgical or invasive procedures, specialist care, posthospitalisation support, specialist toxicology consultations, transfusion and transplant services.

Legislative Decree 68/2011 establishes that standard healthcare needs must be determined in line with national and EU public finance constraints, aiming at the uniform fulfilment of the Essential Levels of Care (Livelli Essenziali di Assistenza - LEA) throughout the country. It provides for the definition of a per capita standard cost, based on the age-adjusted population, calculated as a weighted average of the per capita expenditure of the benchmark Regions (Emilia-Romagna, Marche, Veneto, Lombardy and Umbria) for their ability to guarantee the Essential Levels of Care in economic balance. Since 2013, the standard national health requirement is determined to guarantee the LEAs, dividing it into three levels of care (prevention, district, hospital). The average standard cost is calculated from the costs of the three first benchmark Regions (Emilia-Romagna, Umbria and Marche), chosen for their economic equilibrium in providing the LEAs, among the five best. The distribution of the undivided share of the National Health Fund is then made by applying this average cost to the population of each region, weighted by age, as established annually by the State-Regions agreement. Simplifying, the mechanism provides that the healthcare requirement is based on a calculation per capita, weighted 65% on the resident population and 35% on the age adjusted population, making the standard cost an almost irrelevant constant in the distribution process. Consequently, despite the emphasis on LEAs and standard costs, the actual methodology approximates a uniform per capita approach with slight age-related variations, **in which standard costs are effectively irrelevant**.

Let us now analyse in more detail the current mechanism of resource allocation in the health sector. On the sidelines of the State-Regions agreement of 9 November 2023 (Rep/acts 262/CSR), CIPESS Resolution No. 33 of 30 November 2023 defines at € 128.869 billion the current level of

financing of the National Health Service to which the State ordinarily contributes. The total allocation is then subdivided between an undistinguished share of 123.8 billion € intended for the financing of the LEAs and a share of resources related to the satisfaction of specific services amounting to 4.2 billion. The new level of the national healthcare requirement, which represents the overall financing of public and accredited healthcare in Italy, was increased by the Budget Law 2023 (Law 197 of 2022 Art. 1 paragraph 535) by 2.150 billion € for the year 2023, providing for the following increases for the coming years: 2.3 billion for the year 2024 and 2.6 billion starting from the year 2025. Table 1 below details the structure of the total requirement for 2023.

Table 1: National Health System needs, 2023 (Del. 4/2023 CIPESS)

Macro destination	**Amount (millions of €)**
Unrestricted funding 2023, of which 3,074 restricted	123.810
Restricted in favour of the Regions and Autonomous Provinces	2.452
Restricted in favour of other entities	1.098
Premium fund - provision	644
Share allocated to the Innovative Medicines Fund 2023	864
Total	128.869

Table 2 details the increases allocated in the Budget Law for 2023 (Law 197 of 2022 paragraph 535).

Official forecasts on the development of healthcare expenditure (a component that includes additional expenditure items of the healthcare sector, including private expenditure, with respect to healthcare requirements related to regional transfers), which can be found in the main economic planning documents (NADEF 2023) show values close to 133 billion for 2024, and close to 137 billion for 2025, both of which amount to 6. 2% of GDP.

Starting in 2023, the CIPESS resolution of 8 February 2023 introduced new criteria for allocating the unrestricted share, in order to take greater account of socioeconomic and demographic aspects. In particular, a 0. 75% share of total resources will be allocated based on the mortality

Table 2: Increases in the National Health Requirement allocated in the Budget Law for 2023 (Art. 1 para. 535)

SSN funding level	2022	2023	2024	as from 2025
LB 2022 (co. 258)	124.061	126.061	128.061	128.061
LB 2023 (para. 535)	-	+2.150	+2.300	+2.600
TOTAL	124.061	128.211	130.361	130.661
Higher energy source costs (DL. 50/2022 Energia and DL. 144/2022 Aiuti-ter)	-	1.600	-	-
Increased FSN resources (DL 34/2023 Energy and Health)	-	1.400	-	-

rates of the population under 75 years of age, and a further 0.75% share will be allocated on the basis of the socioeconomic conditions of the territories (indicators relating to particular territorial situations that impact healthcare needs). This is a small step towards adjusting the criteria for determining healthcare needs more in line with the needs of the population, but its scope is certainly still very modest.

Thus, the unallocated segment of the unrestricted financing, totaling € 120,736 million, is distributed in accordance with the aforementioned framework, assigning:

- 118,925.100 million (corresponding to 98.50%) on the basis of the criteria of resident population and frequency of health consumption by age, thus applying the procedure set forth in paragraphs 5 to 11 of Article 27 of Legislative Decree No. 68 of 6 May 2011;
- 905.52 million (corresponding to 0.75%) based on the mortality rate of the population (under 75 years);
- 905.52 million (corresponding to 0.75%) based on the overall figure resulting from the indicators used to define particular territorial situations that impact health needs.

In the distribution of 98. 5% of indistinct financing, net of the shares already allocated for specific purposes, the average cost per capita for the different levels of care was first calculated, based on the benchmark regions. This calculation considered the population updated to January

2022, in accordance with the relevant regulations. The average cost per capita obtained was then multiplied by the weighted population of each region and autonomous province, to allocate the funding proportionally.

Table 3 below shows the percentages of expenditures to be allocated to the three levels of care, indicating for each the weighting criteria of the reference population. An analysis of population weighting criteria leads to the conclusion that 65% is allocated on the basis of a uniform capital share, while the remaining 35% is allocated on the basis of the age-weighted population.

Table 3: Expenditure percentages and population weighting criteria by level of care

Service level	**Percentage of expenditure**			**Population weighting criteria**
Prevention			5%	Unweighted
District	51%	Primary care	7%	Unweighted
		Pharma	11.71% (*)	Cap imposed on total needs of constrained sums
		Specialised	13.30%	Weighted
		Territorial	18,99%	Unweighted
Hospital			44%	50% Weighted population, 50% Unweighted population
(*) of indistinct needs				

Once the financial requirements of each region have been defined, based on the above, each region finances its standard needs from the following sources:

- *The National Health Service companies' own revenues (co-payments)* amount to an average of 1.5% of requirements;
- *The general taxation of the Regions*: regional tax on productive activities - IRAP (in the revenue component destined for financing healthcare), and regional surtax on personal income tax - IRPEF.

Both taxes are quantified to the extent of the revenues determined by the application of the national base rates, equal on average to 26% of requirements;

- *The co-participation of the Special Statute Regions and the Autonomous Provinces of Trento and Bolzano*: these entities co-participate in the healthcare financing up to the extent of the needs not met by the sources described in the previous points, except for the Region of Sicily, for which the co-participation rate has been set since 2009 at 49.11% of its healthcare needs (Law 296/2006, Article 1, Paragraph 830);

- *The State Budget*: finances healthcare needs not covered by the other sources of financing essentially through the co-participation in value-added tax - VAT (destined for ordinary statute Regions), excise duties on fuels and the National Health Fund (a share is destined for the Sicilian Region, while the rest in total also finances other healthcare expenditure tied to certain objectives), amounting on average to 64% of the needs.

Table 4 shows the details of the financing components of the national health requirement for each individual region as reported in the latest CIPESS resolution (33/2023).

Table 4: Financing structure of the undivided share of the national health requirement, detail by region (CIPESS Resolution 4/2023)

REGIONS AND AUTONOMOUS PROVINCES	Conventional own revenues and income of health companies	Participation of Special Statute Regions and PA	IRAP	IRPEF surtax	Integration under Legislative Decree 56/2000	National Health Fund	Total resources for indistinct financing of LEAs (Before mobility)
PIEDMONT	167.095.971		1.623.995.594	838.348.000	6.473.310.411		9.102.749.976
VALLE D'AOSTA	4.341.336	166.713.241	62.403.000	25.136.000		2.624.050	261.217.627
LOMBARDY	344.688.926		5.289.136.664	2.155.095.000	12.874.200.708		20.663.121.298
PA BOLZANO	17.089.038	569.785.632	358.076.000	124.425.000		15.054.834	1.084.430.504
PA TRENTO	17.328.157	689.333.190	291.122.000	108.355.000		13.089.991	1.119.228.338
VENETO	187.978.900		2.073.431.353	945.251.000	6.974.999.418		10.181.660.671
FRIULI VENEZIA GIULIA	47.484.584	1.658.176.274	578.486.000	242.517.000		37.115.057	2.563.778.914
LIGURIA	62.729.872		495.499.680	299.296.000	2.436.845.267		3.294.370.819
EMILIA ROMAGNA	171.955.829		2.114.911.422	922.940.000	6.155.897.003		9.365.704.254
TUSCANY	138.369.096		1.400.843.948	691.108.000	5.615.594.567		7.845.915.611
UMBRIA	34.031.402		246.347.258	145.970.000	1.433.310.929		1.859.659.589
MARCHE	57.467.177		488.602.655	257.388.000	2.350.466.067		3.153.923.899
LAZIO	162.193.247		3.187.931.878	1.041.389.000	7.497.611.225		11.889.125.350
ABRUZZO	41.537.068		299.954.025	188.644.000	2.176.692.905		2.706.827.998
MOLISE	12.952.736		12.950.922	38.601.000	561.454.045		625.958.703
CAMPANIA	163.215.831		1.024.939.721	622.887.000	9.653.335.620		11.464.378.172
PUGLIA	113.350.898		733.779.524	477.170.000	6.892.466.956		8.216.767.378
BASILICATA	16.926.354		27.619.499	69.326.000	1.032.431.276		1.146.303.129
CALABRIA	47.418.994		8.728.239	199.095.000	3.605.383.821		3.860.626.054
SICILY	128.084.893	4.857.632.202	1.206.569.700	530.456.000		3.287.146.167	10.009.888.962
SARDINIA	45.917.138	2.545.892.216	533.642.000	219.755.000		49.305.375	3.394.511.729
Total	1.982.157.447	10.487.532.754	22.058.971.082	10.143.152.000	75.734.000.217	3.404.335.474	123.810.148.974

An analysis of the current funding mechanism reveals at least three critical issues.

First of all, the LEAs do not directly participate in the determination of standard health requirements (national and regional), and therefore no role is recognised for the quantitative levels of the services to be provided to satisfy the demand of the territories. As a result, the system does not seem to guarantee the full financing of the LEAs, as would instead be required by the Constitution, art. 117, c. 2, lett. m. In fact, the LEAs operate only as an ex post monitoring tool, whose effectiveness is today very reduced. In fact, a new monitoring system called Nuovo Sistema di Garanzia (New Guarantee System) (NSG) is being implemented from January 1, 2020, with the aim of overcoming the current system based on the LEA Grid.

Secondly, standard costs still have a limited operational function and the definition of standard needs does not promote efficiency in the provision of health services, as there is no link to the level of efficiency of 'virtuous' regions in determining regional needs.

Lastly, a limited tax autonomy of the regions emerges: in particular, for IRAP, a reduction process has been underway for some time, and its probable abolition has been announced; while the regional IRPEF covers only 8% of the indistinct financing. In addition, this tax is essentially paid by two types of taxpayers - employees and pensioners - while income from self-employment and assets is exempt.

The equalisation mechanism of healthcare resources cannot, therefore, be considered fully in line with the constitutional principles and those of Law 42 of 2009. A revision of the criteria for defining and standard needs and for the distribution of the indistinct health fund should explicitly use the LEAs - possibly mediated by the construction of composite indicators of the overall level of services offered - in defining the standard needs of each region.

The latter should then be identified with a model of the type:

$$\begin{cases} \text{Standard cost} = f(\text{Socioeconomic background, demographics}) \\ \text{Standard needs} = \text{Standard cost} \cdot \text{LEA} \end{cases} \tag{1}$$

where the standard cost (Eq. 1) is statistically estimated by considering not only demographic elements, such as the age of the population, but also factors related to the provision of services, such as input costs (labour and capital), that allow a measurement of efficiency. Following this, the standard needs would respond directly to the level of services to be provided on the basis of the LEAs assessed at standard cost and grouped by homogeneous groups to overcome the complexity that would result from finding a standard cost for each LEA.

In Chap a simulation exercise will be carried out of the application of this model to standardising healthcare expenditure. 5. The outcome of this exercise, despite involving several simplifications in the data structure used for the analysis, highlighted the shortcomings of the current system to evaluate standard healthcare needs.

In particular, if the assessment of the standard needs were to explicitly take into account the achievement of an adequate level of services throughout the entire peninsula, the distribution of the National Health Fund would have to be revised in favour of the southern regions so as to close the output gap - that is, the deficit of services assessed with respect to the potential demand for services of each territory - mainly concentrated in this part of the country. However, through an efficient evaluation of standard costs, the levels of technical and price inefficiency would be made explicit, which would lead to a revision of the distribution of the National Health Fund in favour of the central-northern Regions. In fact, the percentage of inefficient expenditure tends to be concentrated, like the output gap, in the southern regions.

In 2023, Italy recorded public health expenditures of € 134.7 billion compared to € 131 billion in 2022 (NADEF 2023). This figure emerges in a post-pandemic context, characterised by significant fluctuations in health expenditure relative to the Gross Domestic Product (GDP). In particular, with reference to what is reported in the NADEF 2023, healthcare expenditure is expected to decrease as a percentage of GDP from 6.7% in 2022 to 6.1% in 2026, reflecting the current economic and social dynamics. Considering the recent upturn in inflation, 2022 saw a decrease in real terms of healthcare expenditure of approximately € 4 billion.

If we take a closer look at the composition of health expenditure in 2022 (the last year for which ISTAT reports its decomposition), significant data emerge: 130 billion come from public sources, while a further 41 billion

represent direct private expenditure (out of pocket), including 4.6 billion spent on private insurance. In total, therefore, out-of-pocket expenditure reaches € 171 billion considering both the public and private components. Among the various expenditure components, welfare (€91 billion) and pharmaceuticals (€35 billion) maintain a predominant role, followed by expenditure for Long-Term Care (LTC), which stands at around €17 billion as a healthcare component (see Table 5).

Table 5: Structure of health expenditure 2022. Source ISTAT, System of Health Accounts

	Public Administration	Voluntary financing schemes	Direct household expenditure	All funding schemes
Healthcare for treatment and rehabilitation	74.165	1.493	15.305	90.963
Long-term (health) care (LTC)	12.834	110	3.953	16.897
Auxiliary services	11.852	358	2.691	14.901
Pharmaceuticals and other therapeutic products	19.763	339	14.818	34.920
Disease Prevention Services	10.386	752	68	11.206
Governance and administration of the health system and financing	1.364	1.616	0	2.980
Total	130.364	4.668	36.835	171.867

From 2012 to 2022, total healthcare expenditure showed an average nominal growth of 20%, highlighting complex and variable economic dynamics. Within this increase, out-of-pocket spending saw a 17% increase in direct household spending and a 60% increase in private insurance

spending. Of particular interest is the expansion of prevention spending, which has seen an impressive increase 98%, highlighting a change in public health approach, with a greater focus on prevention (see Table 6).

Table 6: Nominal evolution of the components of health expenditure between 2012 and 2022. Source ISTAT, System of Health Accounts

	Public Administration	Voluntary financing schemes	Direct household expenditure	All funding schemes
Healthcare for treatment and rehabilitation	12%	47%	22%	14%
LTC	14%	233%	14%	15%
Auxiliary services	32%	24%	-14%	20%
Pharmaceuticals and other therapeutic products	30%	51%	20%	26%
Disease Prevention Services	96%	56%	10%	92%
Governance and administration of the health system and financing	-1%	87%		33%
Total	20%	60%	17%	20%

When comparing Italy's overall health expenditures with that of the main OECD member countries, Italy shows one of the lowest proportions of GDP, standing at 9.3%, of which 2.3% represents direct household expenditure (out-of-pocket). However, when one considers specifically the weight of out-of-pocket health expenditure, Italy has one of the highest ratios among the OECD countries, with a substantial 25% of the total. This figure reflects the peculiarities of the Italian healthcare system and

highlights the challenges the country faces in ensuring equitable access to healthcare, in a context of increasing economic and demographic pressures (see Figure 1 and Figure 2).

Figure 1: Health expenditure in the main OECD countries as % of GDP, years 2015 and 2021. Source OECD

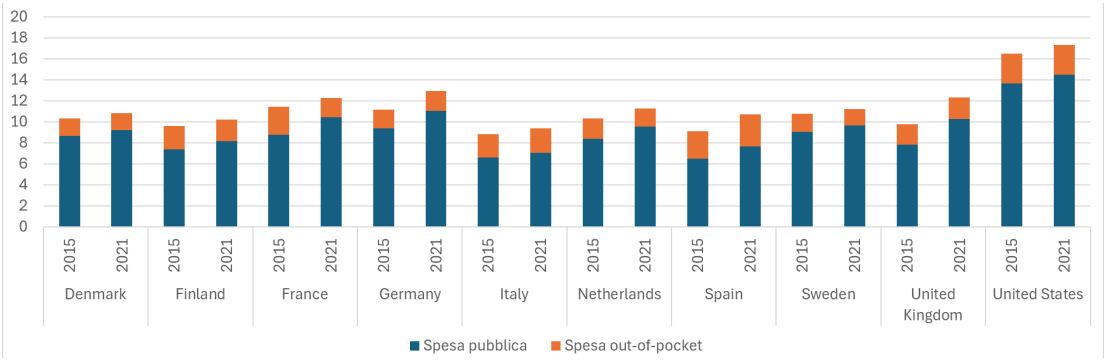
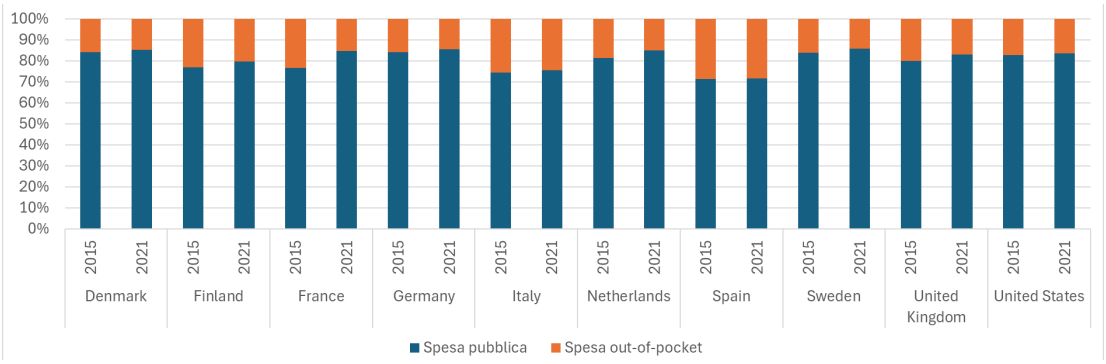


Figure 2: Composition of health expenditure in the main OECD countries, years 2015 and 2021. OECD source



Looking at the regional structure of Italian healthcare expenditures, Figure 3 highlights regional differences in current per capita expenditure in the years 2018-2022, offering interesting insight into geographical disparities in healthcare provision. In addition, the nominal trend 2022-2108 reflects the projected growth in health expenditure for each region over the long term. The data are expressed in euros and are based on nominal values, as indicated by the source, ISTAT Health for All. It should be noted that seven Regions are currently defined as Regions under a Reduction Plan (PdR), namely Abruzzo, Calabria, Campania, Lazio, Molise, Apulia and Sicily, with two of these (Molise and Calabria) being under commissioner status.

Starting from Northern Italy, we note regions such as Valle d'Aosta, Trentino-Alto Adige and Veneto that show a steady and significant increase in expenditure per inhabitant, suggesting an increasing investment in public health. Valle d'Aosta shows the highest percentage growth (26%) between 2022 and 2108, followed by Trentino-Alto Adige (22%) and Veneto (21%), suggesting a commitment to further improve the already high level of health services. This could reflect not only a greater availability of resources, but also a response to the needs of a population that in some areas may be older and therefore more in need of healthcare.

Compared to Mezzogiorno, the situation is more complex. Regions such as Calabria and Campania show lower increases (13% and 20%, respectively) than some northern regions. However, there are exceptions, such as Molise, which shows an astonishing increase 23%, which could be interpreted as an attempt to close historical gaps in the provision of healthcare services.

The per capita current health expenditure figure may be influenced by several factors: population density and average age may play a significant role, as well as the efficiency and effectiveness of the local health system and the commitment to disease prevention. The higher health expenditure in some Northern Regions could be correlated to a health system that has a greater capacity to provide services by also collecting part of the demand not satisfied in the Southern Regions, the latter phenomenon being recorded in the flows of health mobility. The GIMBE Observatory Report 2024 on interregional health mobility in 2021 shows a total value of 4.247 billion euros, marking an increase compared to previous years. Regions with a significant positive balance, indicating a high attractiveness for healthcare services, are mainly in Northern Italy, while those with a negative balance, reflecting a greater leakage of healthcare, are in Central and Southern Italy. In addition, more than half of the value of active mobility is attributed to private facilities, highlighting a trend toward outsourcing of healthcare services. On the other hand, the South may suffer from a chronic lack of investment, both public and private, which is reflected in a health service with limited resources, reduced accessibility, and sometimes a lower quality of service.

Figure 3: Current health expenditure (euros per inhabitant), nominal values. Source: elaborations on the ISTAT Health for All database

	anno 2018	anno 2019	anno 2020	anno 2021	anno 2022	Trend nominale 2022-2108 %
Piemonte	1.882	1.951	2.063	2.162	2.232	19%
Valle d'Aosta	2.012	2.066	2.371	2.445	2.526	26%
Lombardia	1.947	1.971	2.057	2.137	2.201	13%
Trentino-Alto Adige	2.121	2.109	2.371	2.521	2.595	22%
Veneto	1.779	1.810	1.957	2.082	2.148	21%
Friuli-Venezia Giulia	2.097	2.066	2.135	2.267	2.340	12%
Liguria	2.059	2.094	2.205	2.337	2.416	17%
Emilia-Romagna	1.946	1.950	2.179	2.185	2.250	16%
Toscana	1.893	1.954	2.129	2.169	2.244	19%
Umbria	1.948	1.961	2.094	2.200	2.278	17%
Marche	1.846	1.888	2.001	2.091	2.163	17%
Lazio	1.852	1.925	2.063	2.148	2.213	19%
Abruzzo	1.859	1.909	2.016	2.055	2.123	14%
Molise	2.079	2.309	2.320	2.466	2.556	23%
Campania	1.744	1.790	1.905	2.034	2.098	20%
Puglia	1.857	1.916	1.996	2.118	2.188	18%
Basilicata	1.867	1.895	2.001	2.102	2.179	17%
Calabria	1.788	1.848	1.912	1.959	2.026	13%
Sicilia	1.832	1.885	2.014	2.139	2.207	20%
Sardegna	1.981	2.046	2.125	2.319	2.397	21%
Italia	1.881	1.925	2.049	2.144	2.212	18%

3 MACROECONOMIC DETERMINANTS OF HEALTH

The interplay between economic growth and health spending is a pivotal topic in economics and public policy. Economic growth often leads to higher health spending as societies allocate more resources to improve healthcare systems, increase life expectancy, and improve quality of life. Simultaneously, better health outcomes contribute to economic productivity, forming a reciprocal relationship. This chapter examines this connection by exploring the factors driving health spending, its influence on economic growth, and the related policy implications.

3.1 ECONOMIC GROWTH AS A DRIVER OF HEALTH SPENDING

Economic growth profoundly influences health spending by increasing national income and expanding the allocation of public and private resources. As economies advance, individuals, households, and governments place greater emphasis on improving healthcare access and outcomes. This dynamic is shaped by structural transformations in economic systems and the interplay of short-, medium-, and long-term economic trends.

In the short and medium term, rising income levels play a pivotal role. Higher incomes enable individuals and households to allocate more resources to healthcare, both through direct out-of-pocket spending and indirectly through insurance premiums. Empirical studies confirm that

healthcare is a normal good, with demand increasing as income increases (Moscone & Tosetti, 2010; De Rock *et al.*, 2022).

In the long term, additional factors come into play. Demographic changes, particularly those related to ageing populations, significantly influence health spending. Economic growth is often accompanied by longer life expectancies and stronger healthcare systems (Vidoli & Auteri, 2022), which, in turn, increase the demand for medical services among the elderly.

Technological progress also emerges as a key factor. Economic development drives innovation, including advancements in medical technologies and pharmaceuticals. Although these innovations improve health outcomes, their widespread adoption often increases healthcare costs. As the World Health Organisation (WHO, 2022) observes, healthcare expenditure as a proportion of GDP tends to grow with economic development, reflecting the prioritisation of health as a cornerstone of social welfare.

3.2 HEALTH SPENDING AS A CATALYST FOR ECONOMIC GROWTH

Investments in health, which encompass both tangible and intangible equipment and knowledge, play a crucial role in stimulating economic growth by improving the productivity and well-being of the workforce. Physical capital and technological advancements are closely intertwined, contributing to productivity and GDP growth (Solow, 1962; Kaldor, 1957; Bellocchi *et al.*, 2021). Health is a key aspect of human capital that significantly influences economic growth by improving labour productivity and labour conditions. Good health improves life expectancy, motivates savings and investments, and supports technological development and capital accumulation.

Numerous studies confirm a positive correlation between health spending and economic growth, although the relationship varies between countries and depends on factors such as human capital levels and governance. For example, in developing countries with medium or high human capital, health spending positively affects growth, while in others,

the impact may differ. Jack (1999) shows that labour productivity is important for human capital investments, especially the physical and mental abilities of the workforce. Strauss & Thomas (1998) prove the existence of a positive relationship between health and labour productivity. Toor & Butt (2005) explore the issue for the Pakistani economy and find that the main determinants of health expenditures are economic growth, urbanisation, the rate of schooling, the rate of crude birth, and foreign aid.

It should be noted that empirical findings from global research highlight *bidirectional causality* between health expenditures and economic growth in many contexts, including countries of Africa, Asia, and the OECD (Chaabouni & Abednnadher, 2014). Specifically, efficient health investments can improve outcomes such as life expectancy and reduce mortality rates, demonstrating health's central role in driving long-term economic development.

Medical and pharmaceutical innovations, supported by investments in capital goods, equipment, and medical infrastructure, play a significant role in driving economic development. These advances improve labour productivity by fostering healthier individuals, thus reducing sick days and extending active working years. Research indicates that a one-year increase in life expectancy can boost GDP per capita by as much as 4% (Bloom & Canning, 2008). In addition, they contribute to the development of human capital, as health expenditures complement education investments, together improving the quality and capacity of the workforce (Chansarn, 2010). Finally, improved access to healthcare addresses income inequality, promoting social cohesion and economic stability. Healthier societies not only reduce disparities, but also attract foreign investment, further accelerating economic growth (Bhattacharjee *et al.*, 2017; Bettin & Sacchi, 2020).

However, the relationship between health spending and economic growth is not uniform between countries. In high-income countries, such as Italy, health spending often grows faster than GDP, driven by technological innovation and ageing populations. Excessive spending without efficiency improvements can strain public finances and reduce funding for other productive investments. In low and middle-income countries, limited resources and infrastructure restrict the benefits of health spending. Cost-effective interventions, such as vaccination and maternal care

programmes, yield the highest economic returns (Jakovljevic & Getzen, 2016).

Finally, it is important to emphasise that the efficiency of health systems is critical to determining the impact of health spending on growth. Efficiency refers to the achievement of optimal health outcomes using minimal financial and human resources (Cylus *et al.*, 2016). In Europe, countries with strong governance and accountability mechanisms often achieve better health outcomes per dollar spent (Önen & Sayın, 2018). In these studies, efficiency is measured using indicators such as life expectancy, infant mortality, resource utilisation, and administrative costs.

3.3 A VAR ANALYSIS

Recognizing the mutual influence between economic growth and healthcare spending, as documented in the literature (Hitiris & Posnett, 1992; Bloom *et al.*, 2004; Suhrcke *et al.*, 2006; Hall & Jones, 2007; Lopreite & Mauro, 2017), we adopt a Vector Autoregression (VAR) model to empirically assess the dynamic interactions among key economic, demographic, and healthcare variables in Italy. The VAR framework is particularly suitable for capturing the complex, time-dependent feedback loops between macroeconomic indicators and health system performance without imposing strong a priori causal assumptions (Enders, 2015).

Our analysis focuses on six core variables: GDP per capita, public debt-to-GDP ratio, number of medical doctors, medical patent activity, the old-age index, and life expectancy at birth. These indicators reflect the multifaceted nature of healthcare provision, encompassing both demand- and supply-side dynamics (Hartwig, 2008), while also incorporating aspects of health innovation and population structure (Breyer *et al.*, 2010).

Italy offers a unique empirical setting due to its long and rich data availability – spanning nearly seven decades – and its distinctive institutional evolution. Two major healthcare reforms structure the period of analysis: the creation of the National Health Service (NHS) in 1978 and the regional decentralization process between 1992 and 2001 (France & Taroni, 2005; Costa-Font & Turati, 2018). These institutional shifts are treated

as structural breaks in our analysis, enabling a comparison of regime-specific dynamics over time.

While prior studies have primarily relied on cross-sectional or panel approaches to explore the determinants of health spending (Barros, 1998), our time-series VAR approach provides insight into how shocks to economic or demographic variables propagate through the healthcare system across different institutional environments.

By modelling these interdependencies over time, the VAR analysis contributes to a more nuanced understanding of the economic sustainability of healthcare systems and informs the design of policies capable of addressing demographic ageing within the limits of fiscal capacity (Breyer *et al.*, 2010).

3.3.1 Model specification and shock identification

We employ a Vector Autoregression (VAR) framework with Cholesky decomposition for structural identification. VAR models are particularly well suited for analysing complex interdependencies among multiple time series variables, as they allow each variable to be treated as endogenous and influenced by its own lags and the lags of all other variables in the system (Sims, 1980). This flexible structure avoids imposing strong theoretical assumptions on causality while capturing the dynamic feedback among variables.

The empirical analysis is based on *annual data* from 1954 to 2024, incorporating six key variables into the VAR system: the Old Age Index (AI), medical-sector-specific patents (PAT), GDP per capita (GDP_POP), the general government Debt-to-GDP ratio (DEBT), Life Expectancy at Birth (LEB), and the Number of Public Doctors (MED). These variables were selected to reflect demographic pressures, healthcare innovation, macroeconomic performance, fiscal constraints, and healthcare provision, offering a comprehensive perspective on the evolution of Italy's health system.

Following conventional practices in structural VAR modelling, the variables are ordered according to theoretical assumptions about contemporaneous causality and the temporal flow of information (Christiano *et al.*, 1999). The Old Age Index is placed first, as demographic variables

tend to evolve slowly and are considered exogenous in the short term. Medical patents, capturing technological innovation, follow, given the gradual diffusion of innovation within the healthcare system. GDP per capita and public debt are included next, reflecting the responsiveness of macroeconomic conditions to demographic trends and innovation. Life expectancy and the number of doctors are ordered last, as they are assumed to respond contemporaneously to economic and demographic conditions rather than drive them in the short run.

The VAR model is formally expressed as:

$$Y_t = A_0 + A(L)Y_{t-1} + \epsilon_t \tag{2}$$

where Y_t is the vector of endogenous variables:

$$Y_t = [AI_t, PAT_t, GDP\_POP_t, DEBT_t, LEB_t, MED_t]' \tag{3}$$

A_0 is a vector of intercepts, $A(L)$ is a matrix polynomial in the lag operator L capturing lagged effects, and ϵ_t is a vector of reduced-form innovations.

To identify structural shocks from the reduced-form residuals, a Cholesky decomposition of the variance-covariance matrix Σ of ϵ_t is applied. This recursive identification scheme imposes a lower-triangular structure, which is consistent with the assumed causal ordering of variables (Christiano *et al.*, 1999). The resulting impulse response functions (IRFs) and forecast error variance decompositions (FEVDs) provide insights into how shocks to specific variables propagate through the system over time.

The model is estimated over the full sample as well as over relevant subsamples to account for institutional structural breaks. In particular, the period is divided around two major healthcare reforms in Italy: the establishment of the National Health Service (NHS) in 1978 and the regionalization of healthcare between 1992 and 2001 (France & Taroni, 2005). Estimating the VAR over these distinct regimes allows us to assess whether the dynamic relationships between economic conditions, demographics, and health outcomes changed in response to institutional transformation (Perron, 1989).

3.3.2 Data transformation and stationarity

Before estimating the VAR model, we tested all variables for stationarity to determine the appropriate form of transformation. Non-stationary data can lead to spurious regressions and invalid inference in time-series models (Enders, 2015). We applied a battery of standard unit root tests to each of the six variables in level form: the Augmented Dickey-Fuller (ADF) test, the Phillips-Perron (PP) test, the DF-GLS test, and the KPSS test (both level and trend specifications). This multi-test approach ensures more reliable inference, as individual unit root tests can sometimes yield conflicting results depending on sample size and data properties.

All variables — the old-age index (AI), medical patents (PAT_tot), GDP per capita (GDP_POP), debt-to-GDP ratio (DEBT_GDP), life expectancy at birth (LEB), and number of public doctors (MED_pubb) — were found to be non-stationary in levels, with results consistently indicating the presence of unit roots across tests. We therefore applied a log-first-difference transformation (i.e., $\Delta \log(x_t)$) to all series. In their differenced form, the variables passed all stationarity tests, with the null of a unit root rejected by the ADF, PP, and DF-GLS tests, and the null of stationarity not rejected by the KPSS test.

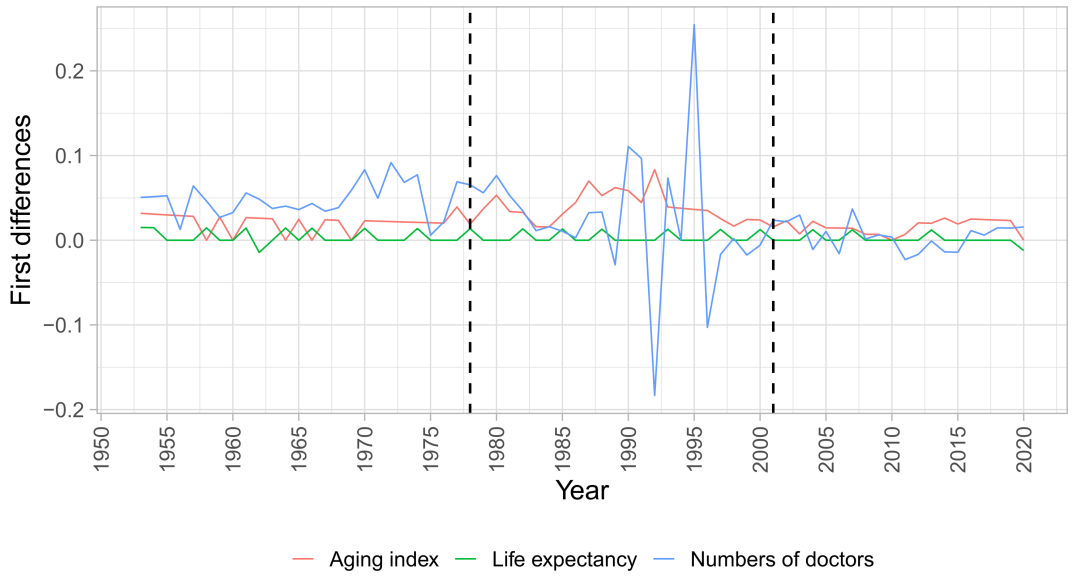
Figures 4 and 5 present the first-differenced series over the 1954–2020 period, capturing short-run dynamics across three key institutional phases in Italy's healthcare system: pre-NHS (1954 – 1978), centralized NHS (1979 – 1991), and regionalized healthcare system (1992 – 2020).

In the *pre-NHS era*, first differences of demographic variables (AI and LEB) show modest but steady positive trends, while economic variables (GDP per capita, DEBT_GDP) and innovation proxies (PAT_tot) exhibit more volatility, likely reflecting post-war economic restructuring. Doctor growth remains low but stable.

The *centralized NHS* phase sees more consistent positive growth in medical patents and life expectancy, suggesting that universal healthcare access may have enhanced both innovation incentives and outcomes. Simultaneously, the ageing index accelerates. Debt growth becomes more pronounced during this period, consistent with rising public health expenditures.

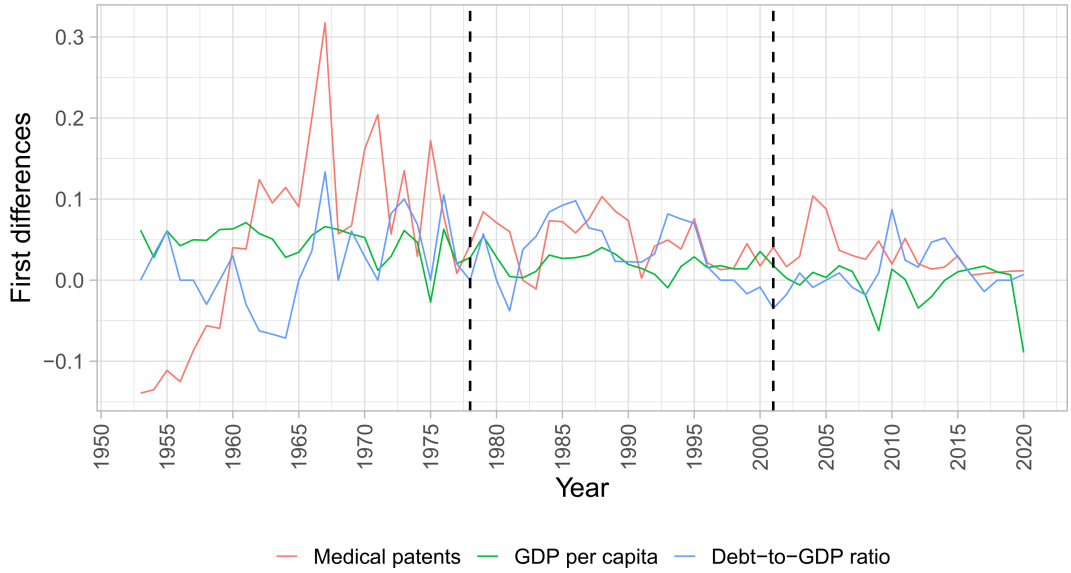
In the *regionalization era*, variability increases notably — particularly for MED_pubb and DEBT_GDP — likely reflecting institutional fragmentation and fiscal decentralization. Medical patent growth appears more subdued and irregular, while demographic trends (ageing and life expectancy) continue steadily. GDP per capita becomes more volatile, especially during the post-2008 crisis and subsequent austerity phase.

Figure 4: Time series: Ageing, Life expectancy, Number of doctors



Transforming variables to stationary form allows us to proceed with the VAR analysis using differenced series. The observed shifts across regimes underscore the relevance of estimating the model over sub-periods to capture institutional change and structural breaks.

Figure 5: Time series: Patents, GDP per capita, Debt-to-GDP ratio.



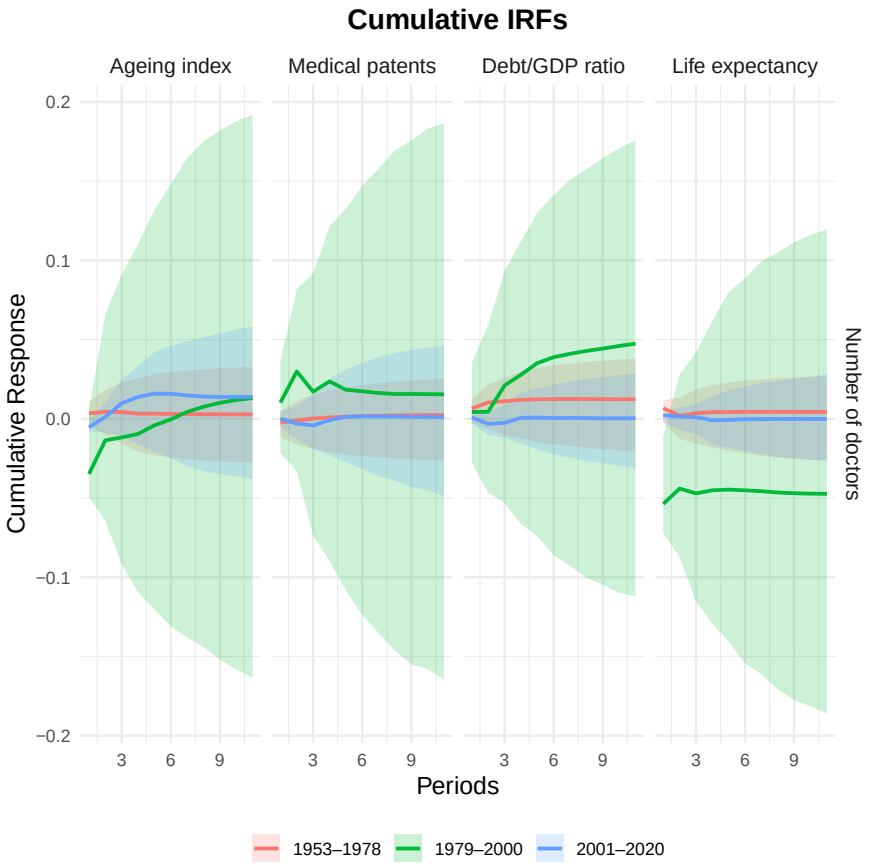
3.3.3 Impulse Response Functions (IRFs)

Figure 6 illustrates the cumulative impulse response functions (IRFs) of the number of public doctors to structural shocks in four key variables — aging index, medical patent activity, debt-to-GDP ratio, and life expectancy — across three healthcare regimes: pre-NHS (1953–1978, red line), centralized NHS (1979–2000, green line), and regionalized healthcare (2001–2020, blue line).

Shock to Aging Index (Panel 1): In the centralized NHS era (green), a positive shock to the aging index results in a small but negative cumulative response in the number of doctors, reaching approximately –0.03 log points (roughly –3%) after 10 years. This may reflect the pressure of demographic aging not being adequately met with increases in healthcare staffing. In contrast, the pre-NHS and regionalized regimes (red and blue) show virtually no response, remaining close to zero throughout the 10-period horizon.

Shock to Medical Patents (Panel 2): Technological innovation exhibits heterogeneous effects. During the centralized NHS period, a positive patent shock leads to a short-term increase in doctor numbers, peaking around +0.02 log points (+2%) by year 3, before stabilizing. This suggests some responsiveness in staffing to innovation under centralized

Figure 6: Cumulated Impulse Response Functions (IRFs).



coordination. Both the pre-NHS and regionalized periods show negligible effects, with cumulative responses fluctuating around zero. The narrow confidence bands during the NHS period imply a relatively well-identified and consistent effect.

Shock to Debt-to-GDP Ratio (Panel 3): Fiscal shocks yield the most substantial and persistent effects. In the centralized NHS era, a positive debt shock leads to a strong and sustained increase in the number of doctors, with the cumulative response reaching +0.08 log points (+8%) by period 10. This counter-intuitive result may reflect public hiring expansions in the face of growing debt burdens, possibly driven by political motivations or automatic expenditure mechanisms. In contrast, both pre-NHS and regionalized regimes show responses near zero, suggesting that debt expansions in those contexts did not translate into workforce increases.

Shock to Life Expectancy (Panel 4): Improvements in life expectancy generate a modest but negative effect on doctor numbers during the centralized NHS era, with a cumulative decline of about –0.03 log points over 10 years. This may indicate that improved health outcomes under centralization reduced the perceived need for expanded staffing. In the other two regimes, the responses are statistically indistinguishable from zero, again highlighting the unique responsiveness of the centralized system.

Overall, the NHS period (1979–2000) stands out as the most dynamically responsive regime, with clear and statistically significant IRFs in three of four dimensions. The number of doctors was particularly sensitive to fiscal and innovation shocks during this era. In contrast, the pre-NHS and regionalized periods show flat or noisy responses, suggesting either institutional inertia (pre-1978) or fragmented and ineffective policy transmission (post-2001).

These patterns underline the role of institutional design in shaping the responsiveness of healthcare provision to demographic, economic, and technological pressures. Centralization appears to have enabled a more coherent and active policy response, whereas decentralization introduced volatility and weakened systemic feedbacks.

3.4 POLICY MEASURES

The intricate relationship between economic growth, health expenditure, and efficiency offers opportunities and challenges to policy makers. Although economic growth expands healthcare spending, ensuring efficient allocation and utilisation of resources is paramount. Numerous factors and constraints determine the success and effectiveness of policy measures aimed at strengthening the bidirectional relationship between economic growth and health spending.

Policymakers should focus on improving efficiency by prioritising preventive care measures such as vaccination programmes and health screenings, which can reduce dependence on expensive treatments. Cost-saving strategies, including the use of generic drugs and optimised procurement processes, further contribute to this goal. Investments in healthcare technologies such as telemedicine and electronic health records streamline service delivery and minimise inefficiencies.

Effective governance and equity are central to achieving sustainable healthcare systems. Transparent funding allocation and routine evaluations of health outcomes, supported by robust governance frameworks, improve both efficiency and fairness. Decentralised approaches empower local health authorities to address specific regional needs, while Universal Health Coverage (UHC) ensures equitable access to healthcare. Innovative financing mechanisms, such as progressive taxation and social health insurance, are vital to maintain UHC (Sanogo *et al.*, 2019).

Integrating health with broader economic policies is crucial for developing human capital. Initiatives promoting workplace wellness and school health programmes amplify the positive effects of health on workforce productivity (Graff Zivin & Neidell, 2013).

Adaptability and innovation are indispensable to address changing health challenges, as demonstrated during the COVID-19 pandemic. Policymakers should invest in research and development while adopting flexible regulatory frameworks to facilitate the rapid implementation of cost-effective innovations, such as artificial intelligence in healthcare.

Lastly, public-private partnerships can play an important role in complementing public healthcare spending, especially in infrastructure and

technology. However, strong regulatory measures are essential to ensure that quality and accessibility are not compromised (Torchia *et al.*, 2015).

3.5 CHALLENGES AND REMARKS

The primary goal of this chapter was to explore the intricate relationship between health expenditure and economic growth. Causation can go in either direction, making it particularly useful and necessary to empirically evaluate the cause-and-effect relationship (Granger causality) and the relative size of observed phenomena (Granger (1969).

On empirical ground, GDP and per capita income are traditionally used as dependent variables, while independent variables include out-of-pocket expenditure, per capita health expenditure, public health expenditure, the ratio of drug expenditures to GDP and the share of current health expenditures in GDP.

The empirical studies reviewed in this chapter reveal a significant positive relationship between GDP and variables such as the share of current health expenditures in GDP, out-of-pocket healthcare spending, public health expenditure, and health expenditure per capita. In essence, increases in health expenditures, both at individual and national levels, are shown to contribute to economic growth. This indicates that investments in health services have a positive impact on economic growth and the welfare system.

However, the findings also highlight that increased individual health expenditures tend to reduce per capita income levels, whereas rising public health expenditures boost per capita income. This suggests that public health spending plays a crucial role in supporting economic growth. In general, every allocation to health services can be regarded as an investment, with such expenditures indirectly fostering economic growth.

Therefore, both individual and public health expenditures significantly affect economic growth, particularly by enhancing the overall health of the population. Higher spending on health services correlates with lower infant mortality rates, increased life expectancy, and a healthier and more productive society. Public investments in health programmes also act

as macroeconomic stabilisers. Although increased health expenditures do not always guarantee better health outcomes, they are particularly beneficial for improving the well-being of vulnerable groups, especially when driven by government spending. Consequently, healthier individuals contribute more effectively to economic growth through enhanced productivity.

Thus, the current literature underscores that investments in health services are integral to supporting economic growth, highlighting their dual role as both a social and economic driver.

In summary, strengthening the relationship among economic growth, health expenditure and efficiency requires a multifaceted approach. By enhancing efficiency, promoting equity, and linking health policies to broader economic goals, policymakers can ensure that health spending drives both economic and social development. With sustained vigilance and adaptive strategies, countries can create resilient health systems that underpin prosperity and societal well-being.

4 THE NHS BETWEEN CENTRAL AND REGIONAL GOVERNMENTS

Devolution in NHS refers to transferring decision-making powers, responsibilities, and resources related to the health sector from the central government to local or regional authorities. Devolution aims to create more responsive and locally tailored health services. This chapter examines the impacts, challenges, and opportunities of devolving healthcare responsibilities, taking advantage of the theoretical and empirical literature and the ongoing debate on this topic.

4.1 KEY ASPECTS OF DEVOLUTION IN THE HEALTH SECTOR

Most European countries have implemented reforms that involve the territorial reorganisation of public services over the past few decades. The delivery of healthcare exhibits the most relevant reallocation of power to subnational governments in European unitary states, including Italy (Costa-Font & Turati, 2018). Devolution reshapes the governance structure of health systems by shifting management and organisation tasks from national governments to subnational authorities.

Intuitively, the rationale is the desire for the government to be accountable to citizens with heterogeneous preferences and needs across local jurisdictions, as stated by the seminal contribution by Oates (1972). In this context, the devotion of public resources can give local authorities greater autonomy over budget allocation and healthcare provision, resulting in more efficient and responsive services.

However, the *"experience good"* nature of healthcare could limit individuals' ability to objectively assess the performance of the health system, which is the prerequisite for keeping local politicians accountable for their policy choices (Costa-Font & Greer, 2016). Moreover, the costs of healthcare devolution will likely be affected by interregional spillovers and diseconomies of scale, altering the optimality of public investment decisions and driving a free-riding attitude by local politicians (Piacenza & Turati, 2014; Porcelli, 2014).[1]

On equity grounds, the devolution of healthcare responsibility and provision might foster inequalities in public sector activities if the equality of all citizens throughout the national territory is established at the constitutional level. In fact, devolution can result in divergent health outcomes, leading to disparities between regions, where some areas can achieve better health targets due to higher resource management or more favourable socio-economic conditions (Ferrario & Zanardi, 2011).

As described by Cavalieri & Ferrante (2016), in Italy, the marginal benefit of healthcare decentralisation[2] is not constant. Still, it depends on the level of regional wealth, favouring the poorest regions. From a policy perspective, improving health outcomes (that is, infant mortality rates) due to decentralisation is contingent on the characteristics of where it takes place.

4.2 BENEFITS OF HEALTHCARE DEVOLUTION

As for other public functions devoted to providing public goods and services to citizens, there is the possibility of tailored health solutions among the benefits of healthcare devolution. Indeed, it enables regions to develop health strategies better aligned with their population's specific needs, preferences, and socio demographic structure.

1 For example, health prevention initiatives promoted by one region are likely to benefit neighbours. In addition, advantages from the collective purchase of many healthcare resources and the joint administration of healthcare structures (e.g., hospitals) might favour a centralised solution.

2 It is measured by the degree of decision-making autonomy in the allocation of tax revenues and the extent to which regions rely on fiscal transfers from the central government

Increases in local accountability would result, since local governments are more directly responsible to the population they serve. Ultimately, this can drive improvements in healthcare delivery. Healthcare, such as housing and social security, is typically treated as a "local public good" in light of its proximity to community life (e.g., home care, territorial medicine, hospitals, primary healthcare), and is usually associated with a redistributive-oriented type of expenditure (Sacchi & Salotti, 2016).

In terms of expenditure composition, healthcare devolution is expected to increase public investments in public input, which reduce production costs for private firms at the cost of more long-term and less-direct-in-character public expenditures such as investments in hospitals (Kappeler & Välilä, 2008; Grisorio & Prota, 2015). Put differently, healthcare devolution should increase economically productive public investment.

Accordingly, this kind of decentralisation could foster innovation and "laboratories" (Rose-Ackerman, 1980) as higher regional autonomy may lead to innovative approaches and pilot programmes that could be scaled up if successful. As an example, regions in federal countries (e.g., Germany) have often been able to pursue public health policies that have not been achieved at the national level, as documented by Katikireddi *et al.* (2017).

From an interesting perspective, the benefits of healthcare devolution could be evaluated in three directions, dealing with equity, efficiency, and resilience of health systems as proposed by Abimbola *et al.* (2019). The first direction relies on Tiebout's approach (Tiebout, 1956), stating that (health) decentralisation could mitigate the existing inequalities in the distribution of people, resources, and outcomes in a territory and increase overall efficiency thanks to the "voting by feet"[3]

The "close to ground" represents the second dimension, reflecting the closeness between governments and citizens/voters to address information asymmetry in healthcare relations (Arrow, 1963). Finally, mutual accountability and support relationships between many institutional centres, community health committees, and health boards could work as "watching the watchers" where all actors in governance must be held accountable as pointed out by Hurwicz (2008).

3 Based on the assumption that people are mobile enough to move.

4.3 CHALLENGES AND LIMITATIONS NOWADAYS

The challenges and limitations of the NHS are related to many aspects, such as disparities in resource availability, the potential intergovernmental coordination failure, and the regulatory and normative complexities. First, not all regions might have adequate financial and human resources, potentially widening the gap in quality and outcomes of healthcare across territories.

Second, devolution reforms might complicate national efforts to guarantee uniform access to services and universal coverage. More importantly, they might undermine coordinated and effective responses to common and national health emergencies.

Finally, regional health systems might navigate the complex legislative framework, preventing efficient decision-making processes. We try to explore those issues by recalling the pandemic and its heritage until the ongoing debate on the differentiated autonomy proposal.

4.3.1 The current NHS: Lessons from the COVID-19 pandemic

The severe health crisis due to the COVID-19 pandemic has shown the limits of a multilevel governmental structure and regional systems. Sharing health risks has represented a valid exit strategy for rethinking more centralisation of the health sector. The principle of healthcare as a global public good was reinforced during the pandemic, based on the fact that the properties of the well-known characteristics of non-excludability and non-rivalry (Samuelson, 1958) extend to the whole country, if not to the planet (Buchholz & Sandler, 2021).

The role of negative externalities directly caused by the disease and those indirectly due to the health policies implemented in the various territories was evident such that a unified response at the national and even the European level became the only adequate response to address the health crisis, as well as the economic and social ones (Grazzini *et al.*, 2023). Moreover, the tragedy of the events has affected not only the health status of citizens. However, it has somehow tested the health status of the NHS, highlighting its fragilities and weaknesses.

In this framework, territorial disparities between regions have become even more marked. Indeed, regions have tried to face the pandemic with different resources, systems, and organisational settings. After the pandemic, the result was different degrees of resilience and a different recovery capacity. The administrative capacity of some decentralised authorities has played a crucial role in assessing the pressure on the health system and implementing rapid and effective response strategies in conjunction with the central government (Dzau & Balatbat, 2020).

Additionally, a general request for greater health protection has emerged, resulting in the placing of public intervention back in the centre of the health system. In other words, the pandemic crisis in Italy has put pressure on the fundamentals of the health system, starting from its governance, highlighting the limits of weak intergovernmental coordination, particularly where responsibilities in health matters overlap and involve many geographically heterogeneous territories. As shown by Rodríguez-Pose & Burlina (2021), during the first wave, the effectiveness of the central government was far more critical than that of the regional government in taming the virus, resulting in lower levels of excess mortality.

In general, the experience of the pandemic stresses how coordination at the highest level is desirable to address negative externalities in Italy. As recently shown by Lago-Peñas *et al.* (2022) for more than 100 countries around the world, a country's reaction and health performance depended critically on its institutional setting that may facilitate, rather than hinder, coordination policies to implement preventive and timely measures to face and contain the pandemic across territories.

Far from continuing to recede, the role of the state in the health sector has begun to strengthen measurably. It reverses the course by re-centralising substantive political and fiscal decision-making processes in many European healthcare systems, including Italy (Saltman, 2008). This could contrast with the recent demand for increasing regional autonomy and power for specific public functions such as health protection.

4.3.2 Healthcare and regional autonomy reforms: issues to worry about?

The NHS aims to guarantee universal coverage and uniform access to services to citizens on the national territory. Accordingly, regional auton-

omy in the health sector has always been a source of intense debate and is often identified as the primary source of regional disparities.

Article 117 (paragraph 3) of the Constitution states that "health protection" is one of the topics of concurrent legislation, with overlapping legislative powers of both the State and the Regions. The widely shared interpretation is that the State is responsible for the normative and regulatory framework. At the same time, Regions are responsible for the detailed legislation concerning the adequate provision of health services (Bordignon *et al.*, 2024).

Law 86/2024, recently approved by the Italian Parliament, has defined the implementation of article 116 of the Constitution - the so-called "differentiated autonomy" - as a culmination of a long journey of some Regions' requests.[4] In this context, a crucial issue concerns the definition of the "minimum service standards" for the healthcare matter to be guaranteed to each citizen throughout the national territory, free of charge or upon payment of a participation fee (i.e., the ticket), with public resources collected through general tax revenues.[5]

Recently, the Council decided to radically revise the architecture of the law on differentiated autonomy, highlighting, among others, the critical issue of the LEP definition and each related service regarding civil and social rights, including healthcare. One of the rationales, as observed by many scholars, experts, and institutions (Volpe, 2019; Bank of Italy, 2023; Arcano *et al.*, 2024; De Vincenti, 2024), deals with the persistent inequalities in services provided across the twenty-one regional healthcare systems, which will likely increase when implementing the differentiated autonomy reform. As highlighted by Arcano *et al.* (2023), despite the relative homogeneity in the availability of resources, inequalities in health outcomes continue to be observed and could increase with such a reform.

4 After the constitutional reform in 2001, the possibility for Regions to request the attribution of additional forms and particular conditions of autonomy has been introduced. In recent years, nine regions have requested greater autonomy, and in 2017, a referendum was held in two of them (Lombardy and Veneto) to confirm citizens' requests.

5 It refers to the essential level of services, i.e., the "Essential Levels of Performance", the so-called LEP, which derives from the "Essential Levels of Care", the so-called LEA. The services included in the LEA definition refer to three areas: collective health care in living and working environments (prevention activities for individuals and the community), district care (health and social-health activities and services in the area) and hospital care (activities and services offered in hospitals).

From a policy perspective, the practical risk of significant differentiated autonomy is to renounce policies favouring convergence toward common service standards for healthcare and intensifying territorial divides and disparities. Moreover, it is reasonable to expect a worsening of patient mobility flows towards the Central-Northern Regions of the country, with negative consequences also for the citizens of those regions due to congestion problems (Bordignon *et al.*, 2024). Therefore, compelling reasons exist to argue that differentiated autonomy could produce the paradoxical outcome of displeasing everyone.

On the theoretical ground, as argued by Fiorillo *et al.* (2021), the differentiated autonomy proposal could represent a sort of *asymmetric decentralisation* setting, which is common in modern democracies and societies. It is the result of voluntary exchange between regional and central governments, rather than a war of conquests or secession threats, to successfully manage a multilevel governance structure. For the Italian health sector, the case might reflect citizens' heterogeneous preferences at the regional level or a better position by regional governments concerning their cost structure so that they can provide health services at lower costs than the central government.

Of course, this institutional setup must be complemented by equalisation schemes and tools that can make the adverse consequences of differentiated autonomy less severe.

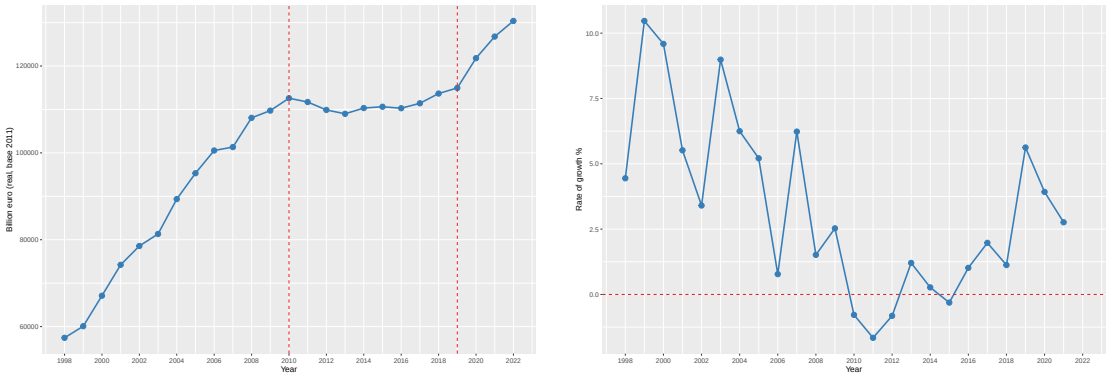
5 STREAM 1: REGIONAL FINANCIAL HEALTH STANDARD NEEDS

5.1 INTRODUCTION AND RESEARCH QUESTIONS

The current structure of the Italian National Health System (see Chap. 2), assigns to regional governments the responsibility of redressing territorial imbalances achieving a set of guaranteed service levels (first known as "*uniforms*" and later as "*essential*" services level, LEA). As a result of the Italian dual economy, intergovernmental grants are the main source of funding in poor southern regions, and local fiscal revenues are the main source of funding in richer northern and central regions.
In this setting, Italian regions share a common budgeting mechanism and a common institutional framework, but maintain administrative autonomy (even with respect to private expenditure cofinancing) facing different local demand and supply factors (for a more complete description of the Italian healthcare system, see Levaggi & Zanola, 2003).
Given this financing scheme, it was therefore crucial to develop a proper funding scheme between the central and regional governments to overcome the "*soft budgeting constraint*" issue well specified by Kornai *et al.* (2003) and Bordignon & Turati (2009) for the Italian case.
Given that the "*public health policy is the result of the interaction of several layers of government*" (Bordignon & Turati, 2009), since the 1990s the Regions presumably inflated their expenditure and expected the Central government to pay off their annual deficits in the belief that it would cover the remaining costs.
The evolution of public health expenditure since the end of the 1990s confirms this trend, showing three main temporal segments (Figure 7). Until 2010 a strong upward trend is evident; expenditure increased to

6.6% of GDP, a significant increase compared to 5.0% in 1998. In 2010, this trend seems to stop and national expenditure remains substantially constant in monetary value, while from 2019-2020, also as a result of the Covid pandemic, healthcare expenditure appears to have started a growing path[1].

Figure 7: National health expenditure. Source: Istat (Health for All), period 1998-2022



(a) (b)

The "*strategic game*" based on local government expectations played essentially at political level by regional and central governments, at least until 2006-2010, was that Regions claimed that the Central government deliberately underfinances them while the Central government claimed that Regions overspend. This led to implementation of a new set of funding rules.
Expenditure restraint since 2006-2010 is the result of implementation of two joint agreements ("*Patti per la Salute*" in Italian) between the Central government and Regions for the years 2007-2009 and 2010-2012[2]. The new set of rules focusses on the transition from a system based on "*soft budget constraint*" to one based on the "*strong empowerment principle*" through the introduction of spending cut plans ("*Piani di rientro*" in Italian) for the Regions with excessive deficit spending.

Against this background and given this robust mechanism for the containment of new debt and stronger regional accountability, analysing regional health expenditure as a micro-funded strategic game is relatively

1 Note that Italy, with current health expenditure at 9.0% of GDP (OECD data, 2022), ranks slightly above the OECD average of 9.2% of GDP, and behind countries such as France (12.1%), Germany (12.7%) and the US (16.6%).
2 Confirmed for the period 2014-2016 and 2019-2021.

uninformative. Identifying structural regional imbalances at the macro level that cannot be attributed to local factors and may be due to efficiency and different regional supply may be more informative.
In particular, when expenditure is expressed as a percentage of GDP, Italy is divided into two large clusters, typical of Italian economic dualism: SD and SDS Regions[3] increased their mean expenditure from 7% of GDP in 1998 to almost 10% of GDP in 2015, overcoming 10% in 2021, while the other regions[4] (NRS, NR, CR) spend, on average, 6% to 7% of GDP.

The comparison between per capita expenditure and expenditure as a percentage of GDP confirms the key need for proper equalisation criteria for public health resources in order to ensure a relatively homogeneous level throughout Italy (in terms of expenditure and service level). The joint agreements of 2014-2016 raised the issue of introducing standard expenditure needs calculation in the health sector, as originally conceived in 2011 (Act. 68/2011), albeit in a basic form.
The Italian National Audit Office (Corte dei Conti, 2015, p. 197) noted that the current quantification criterion of regional health needs was still mainly based on regional population; therefore, it proposed to find a set of indicators to assess efficiency and appropriateness for each region with reference to an aggregate level for each macro level of assistance[5].

As conducted in a previous research paper Francese & Romanelli (2014), our aim was to identify the main drivers of expenditure differentials at a regional level; the main improvement concerns the explicit calculation of technical inefficiency (through output and input composite indicators) and the estimation of *output gap*[6] for a better understanding of the global performance of each Region.
Moreover, this analysis creates a bridge between the literature on intergovernmental fiscal equalisation and that on local government performance indicators and incentives in the public sector (see *e.g.* Mizell, 2008; Burgess & Ratto, 2003; Lockwood & Porcelli, 2013).

3 Southern regions (SD): Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria; Special Administrative Regions of the South (SDS): Sicilia, Sardegna.
4 Special administrative Northern regions (NRS): Valle d'Aosta, Trentino Alto Adige, Friuli Venezia Giulia; Northern regions (NR): Piemonte, Lombardia, Veneto, Liguria, Emilia Romagna; Central regions (CR): Toscana, Umbria, Marche, Lazio.
5 Hospital care (44% of health expenditure), district care (51%) and community care (5%).
6 Difference between the standard and the historical service level.

In fact, evaluation and continuous improvement in terms of output, quality, access to care and cost of national health systems have become a key issue in the policies of more developed countries (see *e.g.* Fisher *et al.*, 2009). Much work has recently been done to improve estimation models, both from an administrative point of view (national authorities, such as the United Kingdom National Health Service and the Canadian Institute for Health Information, have been established) and from a methodological point of view (Jencks *et al.*, 2000; Kwon, 2003; Nuti *et al.*, 2011).
Evaluation of national health systems can be conducted according to a plurality of subjects and objectives: the breadth of performance and financial or service indicators can be considerable, ranging from analysis of the whole system to specific experiences of individual patients.
In the international literature, the evaluation of performance and efficiency or supply level analysis has been carried out at the supranational, national, regional, and local level (see *e.g.* Ibrahim, 2001).
In such complex systems, what needs to be measured is a key question. In general, health care systems can be evaluated with respect to factors such as quality/quantity of care, access to care, and cost/expenditure; although of interest, these dimensions are not the only analytical dimensions. For example, Paakkonen & Seppala (2014), evaluated accessibility, efficiency, and equality of treatment.
But the real challenge of evaluation methods, at least from a statistical and econometric point of view, is the *multidimensionality* of national health systems. From a practical point of view, to evaluate such subjects, robust and reliable techniques are necessary that measure complex phenomena in a synthetic way. For example, to compare improvements in performance, quality, or service level, it is crucial to have: *(i)* a set of comparable indicators built on a reliable information system and *(ii)* robust methods that allow one to integrate the information into a single measure to set or indicate benchmarks or reference parameters.
In particular, Smith (2002) highlights three critical methodological aspects concerning composite indicators in the analysis of the health sector: *(i)* calculation of the set of weights, *(ii)* sterilisation of the effects of external variables on performance and *(iii)* the assumptions underlying the calculation models. With regard to these aspects, he notes the absence of a broad consensus on a shared methodology to identify the optimal set of weights to be used for the composite index.
Finally, Bankauskaite & Dargent (2007) observe that aggregate measures of demand and supply for health services lack "*precision and combine uncertain weighting systems, imprecision arising from the potential non-comparability*

of component measures, and misleading reliability in the form of whole-population averages that mask distribution issues".

Against this background, new methods are proposed to estimate regional supply and technical efficiency in a robust way: the optimal set of weights is chosen endogenously to the data and is consequently independent of the choices made by individual researchers.

5.2 METHODOLOGICAL PROPOSAL AND DATA

The proposed methodological approach can be divided into four logically distinct phases:

1. in the first step the *aggregate level* of performance (output) and input employed in the healthcare system are estimated for each region and each year (paragraph 5.2.1);

2. in the second phase, the level of *technical efficiency* is calculated on the basis of the input and output composite indicator (paragraph 5.2.2);

3. the third phase is devoted to estimation of demand in reduced form (named *output function*); in particular, this phase aims to calculate the standard service level that, compared with the historical service level, makes it possible to locate the *output gap* for each region by measuring how each regional system meets its demand. Regions producing more services (in terms of quality and quantity) than the standard will have a positive *output gap*, while Regions with a negative *output gap* will have performance that is lower than the potential demand from their territories 5.2.3);

4. the last step of our approach concerns estimation of the *cost function* in a reduced form (named *expenditure function*) that makes it possible to identify the standard requirements of each region; technical inefficiency and the *output gap* are included as covariates, and the fixed effects approach makes it possible to estimate the price inefficiency of production inputs for each region. In this way, standard needs can easily be calculated for each region, isolating the share of

historical expenditure due to inefficiency at the required level to fill the performance deficit (paragraph 5.2.3).

Data used for the analysis come form the last release of *Health For All* [7] dataset containing a wide panel of indicators on the healthcare system, health status and population socio-demographic characteristics at Regional level. For the analysis purpose, the period 1998-2022 has been selected.

5.2.1 Output and input composite indicators

The aggregate level of input and output was calculated using a specific composite indicator (CI) technique named "*Benefit of the Doubt*" (BoD) by Melyn & Moesen (1991). Several authors (*e.g.* Sorensen, 2014 and Lauer *et al.*, 2004) consider this to be one of the most promising techniques developed in the last two decades, especially due to its theoretical properties; it is particularly useful in avoiding subjective choices in the multidimensional health sector.
Unlike other weighting methods based on mean measures, BoD makes it possible to find the optimal set of weights for the elementary indicators of each unit *endogenously*[8]. In this way, the resulting indicator is the highest possible for each unit: a property particularly "*useful in policy arena, since policy-makers could not complain about unfair weighting: any other weighting scheme would have generated lower composite scores*". Nardo *et al.*, 2008.

The application of production efficiency techniques to the field of CIs is relatively straightforward, as suggested by Witte & Rogge (2009), because "*the Benefit of the Doubt approach is formally tantamount to the original input-oriented CCR-DEA model of Charnes et al. (1978), with all questionnaire items considered as outputs and a dummy input equal to one for all observations*".
In fact, the basic framework for productivity designates a production technology in which the activity of each decision-making unit is charac-

7 The last released at the time of the analysis is the one of October 2024. For more details, see: https://www.istat.it/sistema-informativo-6/health-for-all-italia/

8 In other words "not in an arbitrary way", since in many fields of application it is not possible *ex-ante* to assign a given weight to each indicator or, more generally, the same weight to each unit.

terised by a set of inputs $x \in \mathbb{R}_+^p$ used to produce a set of outputs $y \in \mathbb{R}_+^q$. The production set is the set of technically feasible combinations of (x, y):

$$\Psi = \{(x, y) \in \mathbb{R}_+^{p+q} | x \text{ can produce } y\} \tag{4}$$

where Ψ is the so-called support of $H(x, y)$.
Given this premise, the Farrell-Debreu efficiency scores (input oriented) for a given production scenario $(x, y) \in \Psi$ when x is constant and equal to 1 for every unit (as in CIs) may be written as:

$$\theta(x, y) = \inf\{\theta | (\theta, y) \in \Psi\} \tag{5}$$

and consequently the FDH estimator is provided by the particular disposal hull of the sample points:

$$\widehat{\Psi}_{FDH} = \{(\mathbf{1}, y) \in \mathbb{R}_+^{1+q} | y < Y_i, i = 1, ..., n\}. \tag{6}$$

Hypothesising the convexity of Ψ, the convex hull of $\widehat{\Psi}_{FDH}$ can be named $\widehat{\Psi}_{BoD}$ in accordance with Cherchye & Kuosmanen (2002):

$$\begin{aligned} \widehat{\Psi}_{BoD} = \{(\mathbf{1}, y) \in \mathbb{R}^{1+q} | y < \sum_{i=1}^{n} \gamma_i y_i \text{ for } (\gamma_1, ..\gamma_n) \\ \text{such that } \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \geqslant 0, i = 1, ..., n\}. \end{aligned} \tag{7}$$

For technical details of the BoD methodology and for robustness enhancements, see for example *e.g.* Vidoli *et al.* (2015).

The most important BoD properties are: *(i)* the set of weights is determined *endogenously* through the observed performance of each unit and the benchmark is not based on constraints or theoretical choices, but is the linear combination of observed performances; *(ii)* the *CI* is *weak monotone* and *scale invariant* and *(iii)*, as already mentioned, the set of weights is *the highest possible* for a single unit.

5.2.2 Technical efficiency

In the second step of our approach, the composite input and output indicators estimated by the BoD technique described above are used to measure the level of technical efficiency achieved by each region in the health service sector.
Efficiency is usually measured with reference to the relationship between resources employed and the products obtained. From an applicative point of view, this means:

- in output space, for a given technology and inputs, outputs actually produced match maximum potentially producible outputs;
- in input space, for a given technology and output level, the amount of input used matches the minimum potentially usable quantity.

In the last few decades, frontier productive efficiency methods have been widely developed[9] and are usually estimated by two different (parametric and non-parametric) techniques.

More specifically, methods can be named "parametric" when a particular form of production (cost) function is assumed, while they are called "nonparametric" when the form is not assumed and the frontier is only identified by some specific properties.
Besides classical estimation methods, in the last few years several interesting methods, which can be seen as a "bridge" between the two groups, have been developed: semi-nonparametric and semiparametric methods. Table 7 suggests a non exhaustive taxonomy.

Another distinction between models may lie in the specification of error term: in deterministic models, it is assumed that all observations (x, y) belong to the production set Ψ, while in stochastic models there may be noise in the data and it may happen that $(x_i, y_i) \notin \Psi$ for some i.
All classical methods are affected by some basic imperfections; nonparametric *DEA*, for example, seems particularly flexible and generalisable, but it is not possible to recognise whether the differences in efficiency - namely the distance between the observed and maximum possible output - are due to technical inefficiency or noise / outlier effects Greene, 2008. The parametric frontier *SFA* instead allows explicit distinction in

9 For a complete survey, see Fried & Lovell (2008).

Table 7: Estimation techniques by production technology

Production technology	Frontier techniques
Nonparametric	*DEA*, Farrell (1957); Charnes *et al.* (1978) *FDH*, Deprins *et al.* (1984); Grosskopf (1996) *Order*-m, Daraio & Simar (2007)
Semi-nonparametric	*StoNED*, Kuosmanen & Kortelainen (2012) *StoNEZD*, Johnson & Kuosmanen (2011)
Semiparametric	Park & Simar (1994), Park *et al.* (2007)
Parametric	*SFA*, Aigner *et al.* (1977); Meeusen & van den Broeck (1977) *DFA*, Aigner & Chu (1968)

the error term between inefficiency, ascribable to inefficiency factors, and measurement errors, due to accidental noise and therefore not directly attributable to the local policy maker; however, the most important drawback associated with the *SFA* approach is lack of flexibility due to a priori specification of the production function and the error term.

As will be discussed in more details in Section 5.3.3, the technical efficiency score was calculated was done both with parametric tools (*SFA*) and with non-parametric ones (*DEA* and Order-m). While displaying similar dynamics, we finally opted for the first methodology being able to better gauge the efficiency evolution over time, given the necessity to relax the constant production function hypothesis with long time series.

5.2.3 Demand and expenditure function

The proposed model is focused on estimation of the public demand and supply functions as reported in equations (8) and (9) respectively:

$$q = d(R, D, c) \tag{8}$$

$$c = s(P, S, q) \tag{9}$$

where q are the services offered; c the unit cost of services; R average regional income (GDP); D demand covariates (for example, population structure); P input prices and S contextual supply variables (such as household expenditure).
The dependent variable is considered per capita[10].

Demand function

In order to simplify the estimation process, the reduced form of the demand function is obtained by substituting equation (9) in (8) and it is therefore equivalent to the model in equation (10) named *output function*:

$$q = h(R, D, P, S) \tag{10}$$

Switching from the output to the empirical theoretical model first requires definition of dependent variable q that must correctly enclose the level of health services of each Region. To this end, a composite indicator CI_{it} for the output was calculated for each region i and year t to capture the multi-output characteristic of the typical production function of the health sector[11].
Taking advantage of the panel structure of our dataset, the empirical model can then be written as a linear panel fixed effects model as shown in equation (11):

$$CI_{it} = \alpha_i + \eta_t + \beta_1 R_{it} + \beta_2 D_{it} + \beta_3 S_{it} + \epsilon_{it} \tag{11}$$

where i is the reference region; t the reference year; CI_{it} the output composite indicator; β the coefficients; α_i the regional fixed effects; η_t the annual fixed effects and ϵ_{it} the idiosyncratic error. Note that in the absence of detailed information on input (labour and capital) prices, their impact on spending is only approximated by regional fixed effects.
Finally, the model in equation (11) is better specified by including a set of structural variables:

10 Other normalisation criteria (*e.g.* the equivalent population for the consumption of hospital services, Francese & Romanelli, 2014) were not considered due to implicit inclusion of a demand variable in the cost structure.

11 Note that in the absence of the explicit local preferences set, the BoD procedure makes it possible to find the best weighting structure, which is equal to the other units without implicitly requiring a uniform distribution of local preferences.

1. mobility flows in terms of net balance between entry and exit patients between Regions (M_{it}) in order to measure whether regional output meets domestic demand or also the demand for patients from other regions. This indicator can also be interpreted, albeit indirectly, as a proxy for regional health service quality;

2. the average effect of the joint agreements (*Patti per la Salute*) (z_{it}) on service levels of Regions[12] that signed them in the period 2006-2022 (last year of our sample).

Hence the final model of the output function can be specified as:

$$CI_{it} = \alpha_i + \eta_t + \beta_0 M_{it} + \sum_{t=1998}^{2022} \beta_t z_{it} + \beta_1 R_{it} + \beta_2 D_{it} + \beta_3 S_{it} + \epsilon_{it} \quad (12)$$

and effectively estimated with the *Within-the-Group* (WG) estimator; the estimated values $\hat{CI}_{it}$ can thus be defined as the standard output of each Region, taking as benchmark the Region that, for the same contextual variables, produces the highest performance per capita (*i.e.* the greatest fixed effect):

$$\hat{CI}_{it} = E[CI_{it}|\alpha_{max}, \eta_t, R_{it}, D_{it}, S_{it}] \quad (13)$$

Note that the effects of mobility and joint agreements are excluded from equation (13).
The difference between historical output CI and standard output, namely the output gap (w_{it}), can be calculated by year t and Region i as:

$$w_{it} = CI_{it} - \hat{CI}_{it} \quad (14)$$

Finally, it is important to estimate the share of *output gap* due to the different mobility of patients between regions (w_{it_mob}); thus, for regions with positive mobility, it is possible to more precisely identify a region's "own" *output gap* (w_{it_own}) as the output produced for its residents. Equations (15) and (16) show the analytical formulae.

$$w_{it\_mob} = E[CI_{i,t}|M_{i,t}] \quad (15)$$

12 Lazio, Abruzzo, Molise, Campania, Calabria and Sicily.

$$w_{it\_own} = CI_{i,t} - \hat{CI}_{i,t} - w_{it\_mob} \tag{16}$$

The expenditure function

To simplify the estimation process, the cost function of health services in reduced form can be obtained substituting equation (8) into (9); the cost function in equation (17) usually known in the literature as *expenditure function*.

$$c = f(P, S, R, D) \tag{17}$$

The longitudinal structure of our dataset makes it possible to use a linear panel fixed effects empirical model as shown in equation (18):

$$H_{it} = \phi_i + \tau_t + \gamma_1 S_{it} + \gamma_2 R_{it} + \gamma_3 D_{it} + u_{it} \tag{18}$$

where i is the reference region; t the reference year; H_{it} the current health expenditure; γ the coefficients; ϕ_i the regional fixed effects; τ_t the annual fixed effects and u_{it} the idiosyncratic error. Again, in this case, because of the lack of detailed information on input prices, the relative impact on spending is approximated through the regional fixed effects.
The public expenditure function model specified in equation (18) is very similar to the classical one; the originality of our approach lies in inclusion of two estimated variables among the covariates: nonparametric technical inefficiency θ_{it} and by way of the estimated demand function, the *output gap* w_{it}. Thus the final formulation of the expenditure function can be written as:

$$H_{it} = \phi_i + \tau_t + \delta_1 \theta_{it} + \delta_2 w_{it} + \sum_{t=1998}^{2022} \gamma_t z_{it} + \gamma_1 S_{it} + \gamma_2 R_{it} + \gamma_3 D_{it} + \psi_{it} \tag{19}$$

where the dummy z_{it} is again included in order to measure the contribution of the joint agreements on spending levels.

The first target of the proposed estimation strategy is to obtain consistent and unbiased estimates for: δ_1, the share of expenditure due to technical inefficiency; δ_2, the amount of expenditure needed to fill the deficit in terms of performance in the different Regions; γ_t, the effectiveness of the joint agreements in reducing spending being equal to the socioeconomic context and output level.

The second objective pertains to the estimation of price inefficiency for each regional system through regional fixed effects ϕ_i; taking the Region with the smallest fixed effect as a benchmark, it is possible to measure the distance between the fixed effects and the minimum value for each Region.
The total value of inefficiency I_{it}, therefore has two parts (equation 20):

$$I_{it} = \hat{\delta_1}\theta_{it} + [\hat{\phi}_i - \hat{\phi}_{min})] \tag{20}$$

where the first component (θ_{it}) measures technical inefficiency for the purpose of estimating possible savings linked to better use of input $[\hat{\phi}_i - min(\hat{\phi}_i)]$ measures price inefficiency or the possibility of using the same quantity of inputs with a lower unit cost. It is important to note that technical inefficiency is (by construction) a time variable, whereas price inefficiency is not; price inefficiency should therefore be interpreted as the average level for the entire period of analysis.

The last step of the analysis involves the calculation of standard expenditure needs according to two specifications:

1. In the first specification, standard needs ($\hat{H}^a_{it}$) take into account inefficiency I_{it}, but not differences in service levels throughout the territory, recognising standard expenditure compatible with historical services to each region.

$$\hat{H}^a_{it} = E[H_{i,t}|\phi_{min}, \delta_2 w_{it}, \tau_t, R_{i,t}, D_{i,t}, S_{i,t}] \tag{21}$$

2. in the second specification, in addition to inefficiency, standard needs ($\hat{H}^b_{it}$) take into consideration the share of expenditure required to fill the *output gap* ($\hat{\delta_2} w_{it}$); this second measure allows

every Region to offer (at the efficient cost level) the maximum service level needed to fully satisfy the demand from its territory.

$$\hat{H}^{b}_{it} = E[H_{i,t}|\phi_{min}, \tau_t, R_{i,t}, D_{i,t}, S_{i,t}] \tag{22}$$

5.3 RESULTS

5.3.1 Output composite measure

As illustrated in Section 5.2.1, the first step of the analysis consists in estimating the aggregate regional health level in terms of output[13] produced in the years 1998-2022 by the Italian Regions.
Specifically, the output CI is an aggregate measure of the "quantity" of services provided. It must not be regarded as an indicator of appropriateness of the services or linked to the outcome of treatments because:

1. one of the main advantages of the BoD method is the possibility of obtaining the most objective set of weights; introducing additional considerations about value or appropriateness of each simple output would expose to unacceptable risk of distortion of the results;

2. the correct definition of care appropriateness cannot be entered by economic researchers, but should primarily be set by the policy maker based on medical and/or epidemiological criteria; otherwise there is risk of confusing historical with desired service level;

3. in a cost framework, the output indicator should reflect the "quantity" of output produced independently of other criteria (appropriateness, sustainability or social relevance).

To build the composite indicator, is firstly necessary to accurately select the output variables to be considered. Subsequently, to exclude spurious correlations between the simple indicators, Principal component analysis (PCA) was conducted to obtain independent and uncorrelated factors.

13 It is quite normal that results be strongly linked to the basic data available and its quality and uniformity throughout the national territory.

Table 8 reports the principal orthogonal and independent factors[14] for the simple output indicators. The first three PCA eigenvalues account for approximately 60% of the total variance, allowing for a clear interpretation of the individual factors based on the variables most strongly associated with them. Factor 1 appears to be positively linked to variables characterizing hospital size, and to a lesser extent, to home healthcare assistance and medical guard services; factor 2 to extra-hospital territorial assistance (*i.e.* general practitioners and paediatricians) and, in a negative way, to day-hospital acute discharge that could likely decrease when territorial assistance is widespread and effective; factor 3 is positively linked to pharmaceutical territorial assistance (*i.e.* prescriptions and drugs consumption) and negatively linked to emergency room accesses that can similarly be less used when a better territorial assistance is in place.
Looking at composite indicator time-series (Figure 8), it can be noticed that output globally increased over the last 25 years. However, when analysing the dynamics of the individual factors, it becomes clear that the overall trend results from the combination of two opposing patterns: while the hospital size component remains relatively flat over time, showing a significant decline during the Covid-19 period that was not fully recovered by 2022, territorial healthcare services, and even more markedly, prescription and drug consumption, experienced a sharp increase.

5.3.2 Input composite measures

Using a similar analytical process, the input variables involved in the production process were analysed in order to summarize the information; Table 9 shows the PCA input factors including labour (healthcare system personnel; doctors, nurses, rehabilitators) and capital (healthcare equipment and beds).
Some considerations about capital goods chosen for the analysis are necessary: capital goods are not easily compared in terms of quality or substitution rate (between new and old goods), especially for specialized health sectors. It is therefore desirable to include a subset of capital goods in the analysis that are comparable and shared by all regional

14 The printed values are multiplied by 100 and rounded to the nearest integer. Values greater than 60 are marked with an asterisk. Values less than 30 are not printed; Rotation method: Varimax with Kaiser normalization

Figure 8: Robust Benefit of the Doubt output composite indicator by Region, time series: 1998-2022.

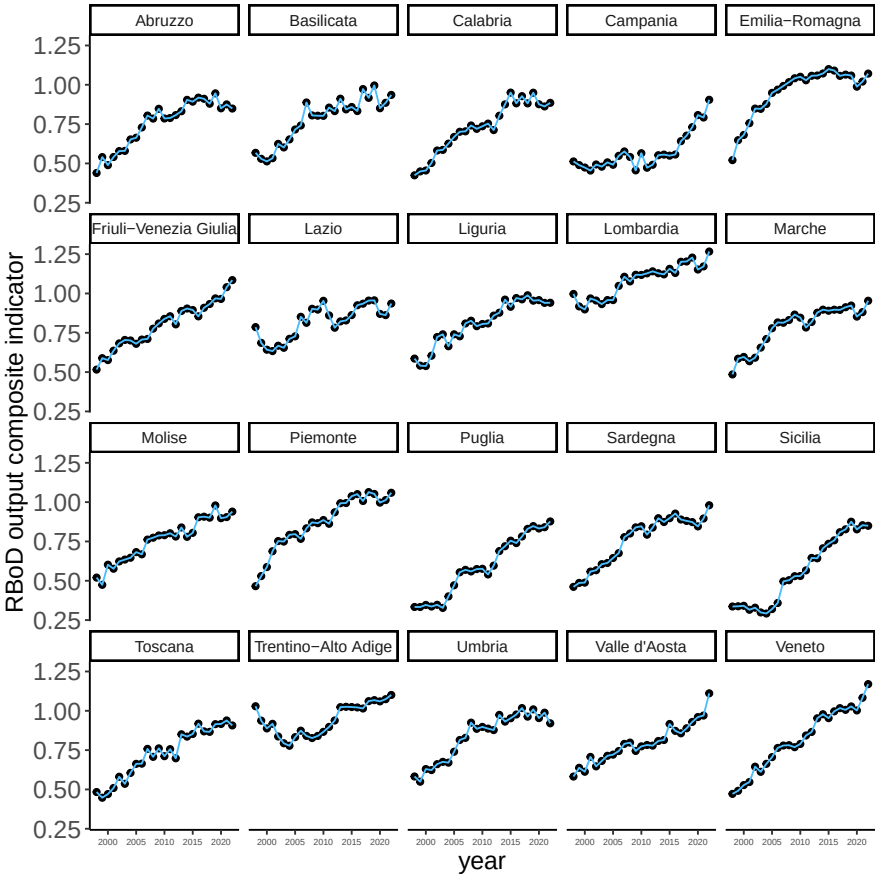


Table 8: Principal component analysis - output factors

	Factor1	Factor2	Factor3
Home healthcare assistance - n. cases	62		30
Medical guard - n. hours	30		
N. Hospitalization - acute	90		-33
N. Hospitalization - long care and rehab.	94		
Days of hospitalization - acute	92		
Days of hospitalization - long care and rehab.	94		
Average n. of patients - general practitioners		94	
Average n. of patients - paediatricians		72	
Discharge rate - outpatient surgery acute		-33	
Prescriptions - per capita			51
Emergency room - access rate			-36
Drugs consumption rate			76

units. From an "industrial" point of view, these goods can help identify hospitals with "better" equipment. Although this issue is beyond the scope of the present paper, it may be a useful tool for improving estimate reliability.
We therefore chose only basic hospital capital goods available in all Regions and selected a mix of hospital and extra-hospital goods. Similarly, we divided the healthcare system personnel into public and accredited private sectors.

The inputs PCA results in two factors
These results are reflected in the RBoD input composite indicator (Figure 9) where the Regions characterised by a stronger healthcare infrastructural system stand out, mirroring to a greater extent the first factor (public sector) dynamics.

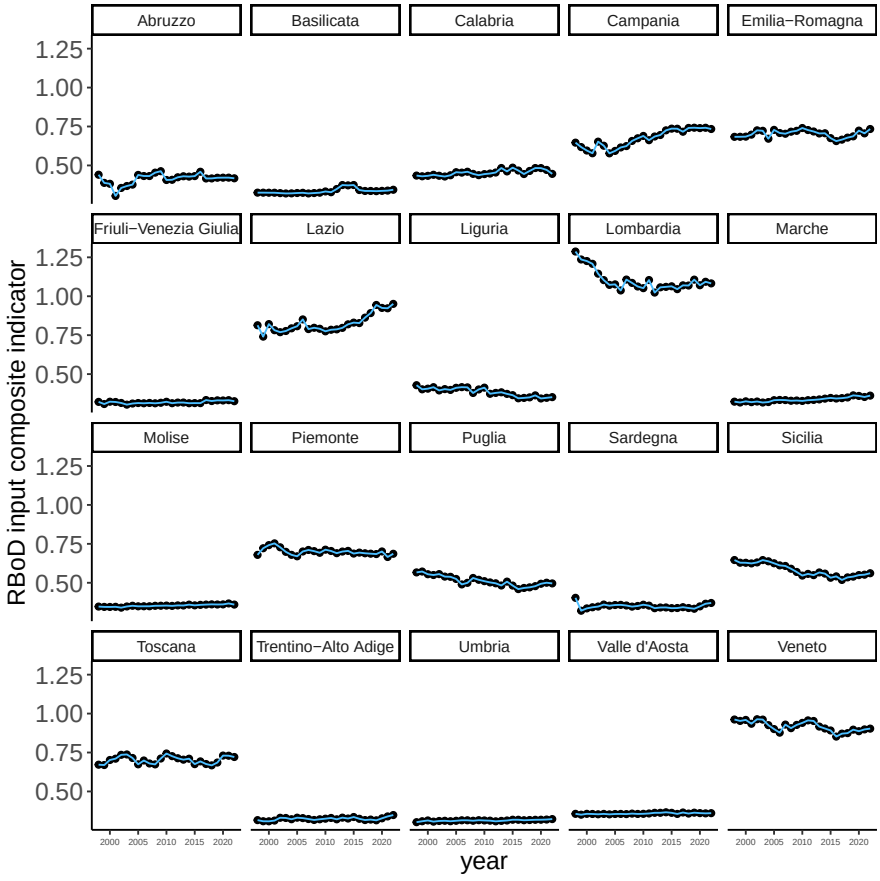
5.3.3 Technical production efficiency

Once service level (output) and resources (inputs) used in the production process have been analysed, the relative technical efficiency index (relative to the benchmarks) can easily be calculated for each region and each

Table 9: Principal component analysis - input factors

	Factor1	Factor2
Computed tomography - n. in hosp.	66	69
Operating tables - n. in hosp.	87	46
Radiological groups - n. in hosp.	77	53
Medical guard doctors - n.	39	34
Public hospitals beds - acute	85	43
Public hospitals beds - long care and rehab.	80	39
Public hospitals beds - outpatient surgery	67	34
Doctors and odontologists - total n. in the NHS	81	49
Nurses - total in the NHS	91	39
Other personnel - total in the NHS	91	37
Doctors - public	79	60
Nurses - public	85	52
technicians - public	84	51
Rehabilitators - public	74	51
Other personnel - public	80	53
Computed tomography - n. extra-hospital		50
Radiological groups - n. extra-hospital	46	54
Doctors - private	52	82
Nurses - private	54	84
Technicians - private	53	82
Rehabilitators - private	36	83
Other personnel - private	56	81
Private hospital beds - acute	52	71
Private hospital beds - long care and rehab.	43	73
Private hospital beds - outpatient surgery		52

Figure 9: Robust Benefit of the Doubt input composite indicator by Region, time series: 1998-2022.



year. More in particular, the technical efficiency score was calculated including the output composite indicator and the single input indicators for the PCA analysis (see table 9) even if a second estimation using the two input factors is also performed for robustness check.
The calculation was done both with parametric tools (*SFA*) and with non-parametric ones (*DEA* and Order-m). While displaying similar dynamics, we finally opted for the first methodology, being able to better gauge the efficiency evolution over time, given the necessity to relax the constant production function hypothesis with long time series.

Figure 10 shows the *SFA* technical efficiency trends by region and year (1998–2022). A modest increase in efficiency is observed across nearly all regions, except for Basilicata, Sardinia, Trentino-Alto Adige, and Campania, which maintained a relatively stable average over the 25-year period. In 2022, Emilia-Romagna, Veneto, Lombardy, Piedmont, and Tuscany exhibited the highest healthcare system efficiency levels. While most of the smallest regions exhibit highly fluctuating dynamics, Umbria, Puglia, Emilia-Romagna, and Piedmont show the highest average year-over-year increases.

5.3.4 Demand function estimation and the *output gap*

The model presented in Section 5.3.4 has been employed to estimate the demand function for healthcare services. The dependent variable used in the estimation is the composite output indicator described in Section 5.3.1. In line with the empirical specification outlined in Equation (12), the output function includes the following categories of explanatory variables:

- Structural variables, such as interregional hospital mobility balances;
- Contextual demand-related variables, including regional GDP per capita, used as a proxy for income, the demographic structure broken down by age groups, and other demand-side determinants;
- Institutional factors, such as the presence of regional recovery plans (categorized by year of implementation) and a dummy variable capturing the impact of the COVID-19 years.

Figure 10: SFA technical efficiency indicator by Region, time series: 1998-2022.

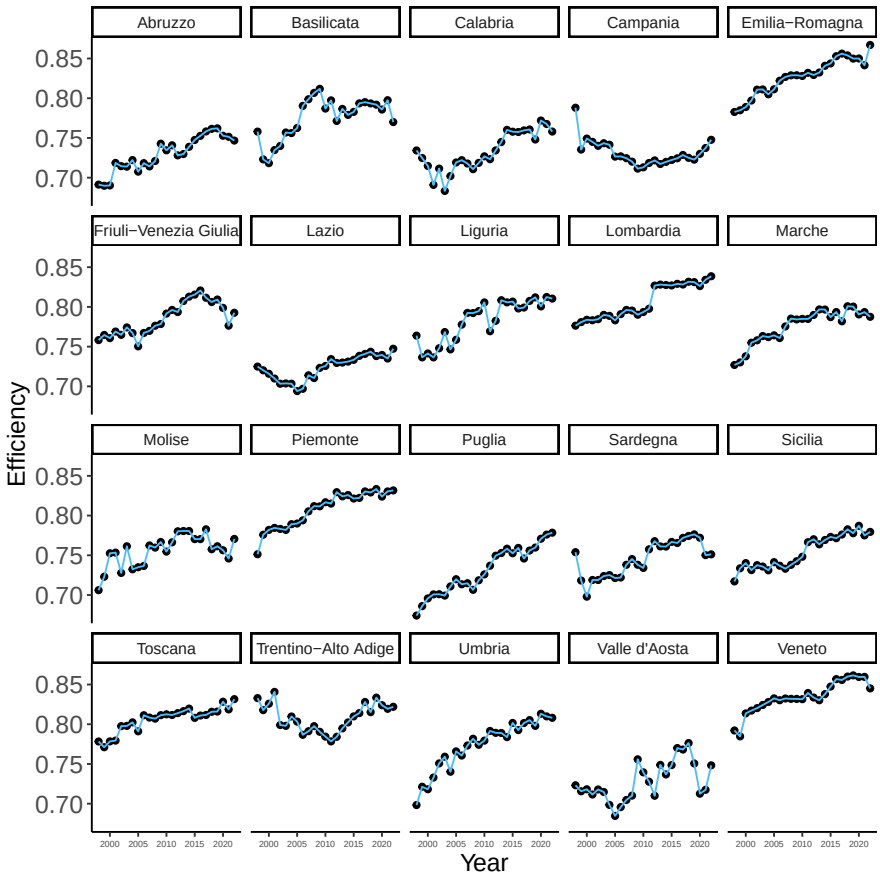
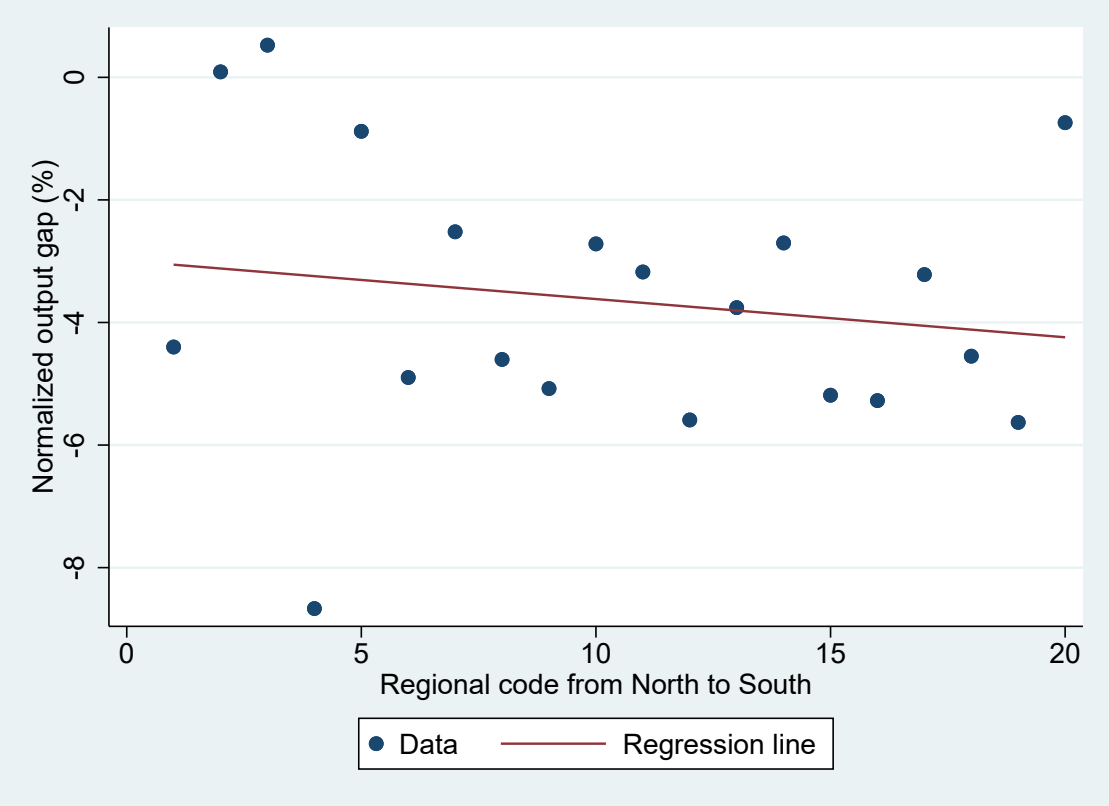


Figure 11: Output Gap and North to South regions - Year 2022



Thanks to the longitudinal structure of our dataset, which spans 25 years (from 1998 to 2022) and covers all 20 Italian regions, we estimate a fixed effects panel data model using the within transformation estimator. This approach allows us to control for both time-invariant regional heterogeneity and temporal shocks by including regional fixed effects and year fixed effects among the regressors, in accordance with the empirical framework set out in Equation (19).

Tables 10 and 11 report the point estimates of the coefficients from the demand function. Column 1 presents the estimates derived from the full specification of the output function, which serves as the baseline model for all subsequent analyses. Columns 2 through 7 display the results of partial models, each excluding specific groups of explanatory variables. This stepwise approach is intended to assess the individual contribution of each category of independent variables to the overall explanatory power of the model.

Figure 12: Inefficiency and North to South regions - Year 2022

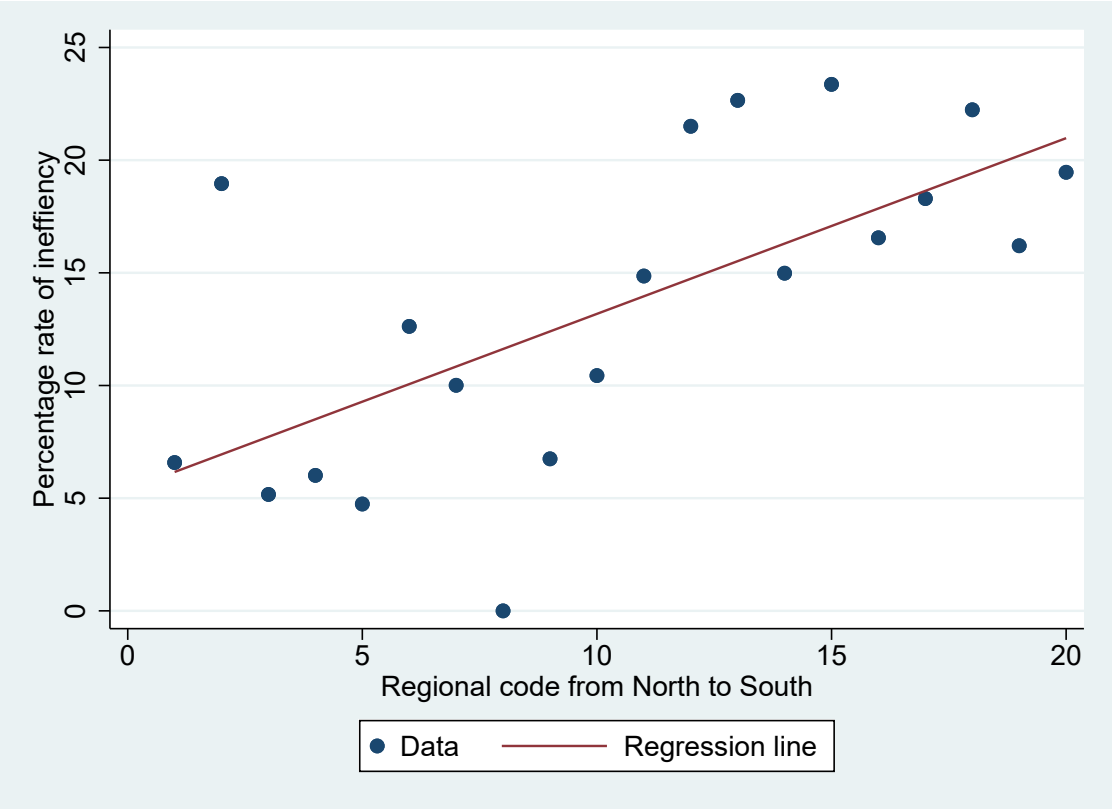


Table 10: Demand function by estimation model, dependent variable = composite output indicator, years 1998 - 2022 - 1 part

Variable	Output function (col. 1 to 7)						
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	OLS (5)	OLS (6)	OLS (7)
Inter-regional hospital mobility balances (active-passive) - rate of total population	0.0366	-0.00203	-0.00187	-0.00157	0.0298	-0.00165	0.0164
	[0.027]**	[0.910]	[0.921]	[0.922]	[0.089]*	[0.934]	[0.179]
Total number of years in spending cut plan for a region	0.0189		0.0112				
	[0.140]		[0.688]				
GDP per capita	0.00157			0.000402			
	[0.271]			[0.855]			
Resident pop. 0-4 M+F - \% total pop	0.0382				0.102		
	[0.647]				[0.318]		
Resident pop. 5-14 M+F - \% total pop	-0.0777				-0.0900		
	[0.030]**				[0.017]**		
Resident pop. 15-24 M+F - \% total pop	-0.00632				-0.0181		
	[0.735]				[0.262]		
Resident pop. 25-34 M+F - \% total pop	0.0171				-0.000787		
	[0.250]				[0.968]		
Resident pop. 35-44 M+F - \% total pop	-0.0426				-0.0540		
	[0.013]**				[0.014]**		
Resident pop. 45-54 M+F - \% total pop	-0.0607				-0.0672		
	[0.046]**				[0.046]**		

Table 11: Demand function by estimation model, dependent variable = composite output indicator, years 1998 - 2022 - 2 part

Variable	Output function (col. 1 to 7)						
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	OLS (5)	OLS (6)	OLS (7)
Resident pop. 55-64 M+F - \% total pop	-0.0835				-0.0791		
	[0.003]***				[0.004]***		
Discharge rates from traumas and poisoning	-0.0000223					-0.000192	
	[0.964]					[0.821]	
Out-of-pocket household expenditure rate	0.00346						0.0000221
	[0.192]						[0.995]
Activity rate for over 15	0.00310						0.00546
	[0.538]						[0.370]
C.I. on discharge rates for illness related to pollution and social themes	-0.191						-0.209
	[0.007]***						[0.019]**
Life expectancy in good health at 65 years old	0.00610						0.00195
	[0.179]						[0.718]
COVID	0.751	0.425	0.421	0.423	0.723	0.408	0.392
	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***
N	359	359	359	359	359	359	359
R-sq	0.916	0.880	0.880	0.880	0.903	0.880	0.898
adj. R-sq	0.906	0.871	0.871	0.871	0.894	0.871	0.889

Number of observations = 383; s.e. clustered at region level, p-value reported in brackets.
* significance less than 10%, ** significance less than 5%, *** significance less than 1%.
Regional fixed effects and annual fixed effects from 1998 to 2022 are included in all models.

5.3.5 Expenditure function estimation

Following a parallel strategy to that adopted for the demand function, the model presented in Section 5.3.4 was applied to estimate the expenditure function for healthcare services. The dependent variable used in this analysis is the per capita current public healthcare expenditure, as reported by ISTAT in the *Health for All* database.

Consistent with the augmented expenditure function model specified in Equation (19), the set of explanatory variables includes the following:

- (i) Structural variables, such as the technical inefficiency index computed in Section 5.3.3 and the output gap estimated through the output function described in previous Section;
- Contextual demand-side variables, used here as instrumental variables for output within the cost function framework, including regional GDP per capita (serving as a proxy for income), the demographic structure classified by age groups, and health risk indicators associated with population health conditions;
- Contextual supply-side variables, such as household healthcare expenditure, an indicator of technological advancement in medical services, and other factors linked to general living conditions;
- Institutional variables, specifically the presence of regional recovery plans categorized by year of implementation and the Covid dummy.

It is important to highlight that, with the exception of the structural variables, the set of regressors used in the expenditure function mirrors those used in the output function. The only substantive difference lies in the nature of the structural determinants. This close alignment between the two models reflects the underlying theoretical framework, which conceptualizes the cost and output functions as two interrelated components of the same healthcare production process.

Once again, the longitudinal structure of our dataset allowed us to estimate a linear panel data model with fixed effects using the within-the-group estimator. This approach enables the control of unobserved regional heterogeneity and time-specific effects by incorporating both regional and year fixed effects among the regressors.

Tables 12 and 13 report the point estimates of the coefficients of the expenditure function. Column 1 presents the results from the full specification, which serves as the benchmark model for all subsequent analyses. Columns 2 through 7 show the estimates obtained from various partial models, each excluding specific groups of explanatory variables. This allows for a clear assessment of the individual contribution of each category of covariates to the overall explanatory power of the model.

Table 12: Expenditure function by estimation model, dependent variable = current public health expenditure per inhabitant, years 1998 - 2022 - 1 part

Variable	Expenditure function (col. 1 - 7)						
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	OLS (5)	OLS (6)	OLS (7)
Technical inefficiency	5.647	1.822	3.459	2.901	0.388	6.438	1.397
Total number of years in spending cut plan for a region	[0.016]**	[0.398]	[0.046]**	[0.178]	[0.824]	[0.009]***	[0.504]
Technical inefficiency - squared	-0.0509	-0.0168	-0.0292	-0.0252	-0.00953	-0.0515	-0.0157
	[0.005]***	[0.256]	[0.023]**	[0.134]	[0.516]	[0.007]***	[0.260]
Output gap	218.1	245.5	252.8	252.9	208.2	263.5	232.4
	[0.005]***	[0.007]***	[0.003]***	[0.003]***	[0.008]***	[0.001]***	[0.008]***
	[0.004]***		[0.230]				
GDP per capita	1.851			2.232			
	[0.071]*			[0.200]			
Resident pop. 0-4 M+F - \% total pop	0.230				45.62		
	[0.996]				[0.500]		
Resident pop. 5-14 M+F - \% total pop	-58.21				-51.01		
	[0.043]**				[0.181]		
Resident pop. 15-24 M+F - \% total pop	24.67				30.72		
	[0.077]*				[0.270]		
Resident pop. 25-34 M+F - \% total pop	-32.08				-61.61		
	[0.044]**				[0.005]***		
Resident pop. 35-44 M+F - \% total pop	-2.816				-17.42		
	[0.854]				[0.343]		
Resident pop. 45-54 M+F - \% total pop	-58.15				-32.39		
	[0.046]**				[0.274]		

Table 13: Expenditure function by estimation model, dependent variable = current public health expenditure per inhabitant, years 1998 - 2022 - 2 part

Variable	Expenditure function (col. 1 - 7)						
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	OLS (5)	OLS (6)	OLS (7)
Resident pop. 55-64 M+F - \% total pop	10.22				28.65		
	[0.680]				[0.355]		
Discharge rates from traumas and poisoning	2.679					2.127	
	[0.000]***					[0.001]***	
Out-of-pocket household expenditure rate	-16.19						-4.481
	[0.002]***						[0.454]
Activity rate for over 15	-3.850						-4.155
	[0.374]						[0.378]
C.I. on discharge rates for illness related to pollution and social themes	55.58						41.30
	[0.116]						[0.542]
Life expectancy in good health at 65 years old	-9.306						3.384
	[0.045]**						[0.629]
COVID	1474.2	1197.1	1220.0	1191.6	916.6	1412.4	1175.5
	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***
N	359	359	359	359	359	359	359
R-sq	0.986	0.973	0.974	0.974	0.977	0.980	0.974
adj. R-sq	0.984	0.971	0.972	0.972	0.974	0.978	0.972

Number of observations = 383; s.e. clustered at region level, p-value reported in brackets.
* significance less than 10%, ** significance less than 5%, *** significance less than 1%.
Regional fixed effects and annual fixed effects from 1998 to 2022 are included in all models.

6 STREAM 2: MULTI-DIRECTIONAL COMPOSITE OUTPUT INDICATOR

6.1 INTRODUCTION

A widely recognised framework for classifying the dimensions of quality in health care is provided by Donabedian (1966), who identifies three key areas for measurement: outcome, process, and structure. Within these three domains, extensive efforts have been made to develop specific metrics adapted to various aspects of each category, the diversity of treatments, care settings, and differing health needs.

Although individual indicators in the quality assessment of health care offer valuable insights into specific elements, they often do not capture a comprehensive picture of overall performance. This limitation underscores the growing importance of developing composite measures that integrate multiple indicators to provide a holistic assessment of the quality of health care or the performance of specific services.

Beyond the variability in the weights assigned to individual indicators, an even more critical factor is the heterogeneity of the weights between different groups of units, such as health systems, providers, or regions. Prioritisation of health needs involves social value judgments at the system level - which may vary between countries - or reflects the unique composition of health needs within a specific geographical area. Consequently, each unit requires a customised improvement path to address its distinct challenges and priorities.

To address this need, a novel methodology called *Multi-directional robust Benefit of the Doubt* is applied in the health domain. This approach en-

ables the construction of endogenous composite indicators to produce a reliable overall measure to evaluate the performance of individual hospitals.

6.2 METHODOLOGY

The Multi-directional Benefit of the Doubt (`MD-BoD`) model (Fusco, 2023) represents an innovative approach to constructing noncompensatory composite indicators with endogenously determined weights.

The traditional `BoD` model (see subsection 5.2.1) maximises the score of each unit by assigning the most favourable weights to elementary indicators, operating under the assumption of full compensability (Cherchye *et al.*, 2007; Zhou *et al.*, 2010). Compensability reflects an implicit importance structure among indicators based on the actual trade-offs between them. In practice, a greater weight is assigned to indicators where a unit excels, rather than incentivising improvement in areas of weaker performance[1]. Building on this foundation, the Directional Benefit of the Doubt (`D-BoD`) model (Fusco, 2015; Vidoli *et al.*, 2015) introduces non-compensability by imposing an explicit, predefined importance structure among indicators. In this scheme, the direction of improvement is guided by priorities set by the decision maker.

The `MD-BoD` model extends the `D-BoD` by allowing distinct directions of improvement for each unit and indicator in an objective manner. It derives a unit-specific preference structure directly from the data, separating benchmark selection from efficiency measurement. The benchmark is determined by adjusting each elementary indicator proportionally to its potential for improvement (*"the weighting scheme is the «most favourable in the desirable direction»"* - Fusco, 2023). This methodology provides not only an overall composite score but also specific scores for each indicator, allowing the identification of strong and weak dimensions for each unit and facilitating customised improvement plans.

However, similar to `BoD` and `D-BoD`, the `MD-BoD` model is sensitive to outliers. Outliers can distort the efficiency frontier, leading to underesti-

1 *A preference relation is non-compensatory if no trade-offs occur and is compensatory otherwise. The definition of compensation therefore boils down to that of a trade-off* (Bouyssou, 1986).

mated performance scores for other units. To address this limitation, a robust version, termed Multidirectional robust Benefit of the Doubt, has been proposed (Vidoli *et al.*, 2024). This version is available in the Compind R package[2] and has been applied to assess the quality of acute healthcare services in 29 OECD countries.

As described in subsection 5.2.2, the fundamental concept of Order-m is to mitigate the influence of outliers and abnormal values by comparing each unit with subsets of observations of size $m < N$, rather than the entire dataset. This process yields a maximum expected frontier of the order m, representing the maximum achievable composite indicator (CI) level among m units drawn from the dataset.

In formal terms, consistent with the `BoD` literature, let us consider a matrix of q simple indicators treated as outputs ($Y_q \in \mathbb{R}_+, \forall q = 1, ..., Q$) and an input vector equal to one for all N observations i. To formalise the resampling process, a probabilistic production set Ψ, encompassing all feasible combinations of indicator values, can be defined as:

$$\Psi = \left\{ (\mathbb{1}, \mathbf{y}) \in \mathbb{R}_+^{1+Q} \;\middle|\; H(\mathbb{1}, \mathbf{y}) > 0 \right\},$$

where $H(\mathbb{1}, \mathbf{y}) = \text{Prob}(X \equiv \mathbb{1}, \mathbf{Y} \geqslant \mathbf{y})$ denotes the probability of observing a unit with indicator values that exceed those of $(\mathbb{1}, \mathbf{y})$.

Building on the work in Fusco (2023), the `MD-BoD` approach examines the maximal possible increase in a single indicator needed to reach the frontier, assuming that all other indicators remain constant. This process identifies specific directions by solving Q linear programming problems for each unit, maximising each indicator q while keeping the remaining indicators $\mathbf{y}_{-q}$ fixed:

$$\widehat{\mathbf{y}}_q = \sup \left\{ \mathbf{y}_q \;\middle|\; (\mathbb{1}, \mathbf{y}_q, \mathbf{y}_{-q}) \in \Psi \right\}, \; \forall q = 1, \ldots, Q,$$

where $\widehat{\mathbf{y}}_q$ is an N-dimensional vector containing the optimised values for all observations.

To introduce robustness and reduce the influence of outliers, each unit is compared to subsets of m observations ($m < N$) sampled with replacement. Let $S_m = \{\mathbf{Y}_i\}_{i=1}^{m}$ represent a random sample of size m, drawn

2 Accessible at https://cran.r-project.org/web/packages/Compind/index.html.

from the density of $\mathbf{Y}$. A corresponding random production set $\widetilde{\Psi}_m$ is defined as:

$$\widetilde{\Psi}_m = \bigcup_{j=1}^{m} \left\{ (\mathbb{1}, \mathbf{y}) \in \mathbb{R}_+^{1+Q} \mid X \equiv \mathbb{1}, \mathbf{Y}_j \geqslant \mathbf{y} \right\}.$$

For each iteration $b = 1, \ldots, B$, the maximum possible increment for a single indicator, based on subsets of size m, is obtained as:

$$\widetilde{\mathbf{y}}_{m;q}^{b} = \sup \left\{ \mathbf{y}_q \mid (\mathbb{1}, \mathbf{y}_q, \mathbf{y}_{-q}) \in \widetilde{\Psi}_m \right\}, \ \forall q = 1, \ldots, Q,$$

where $\widetilde{\mathbf{y}}_{m;q}^{b}$ is an N-dimensional vector.

Using the values obtained $\widetilde{\mathbf{y}}_{m;q}^{b}$, the potential improvement for each unit in iteration b is expressed as the directional vector:

$$\widetilde{\mathbf{g}}_m^{PI_b} = \widetilde{\mathbf{y}}_m^{b} - \mathbf{y}_m = (\widetilde{\mathbf{y}}_{m;1}^{b} - \mathbf{y}_{m;1}, \ldots, \widetilde{\mathbf{y}}_{m;Q}^{b} - \mathbf{y}_{m;Q}),$$

where $\widetilde{\mathbf{g}}_m^{PI_b}$ is an $N \times Q$ matrix, and $\widetilde{\mathbf{g}}_{m;q}^{PI_b}$ is the directional vector for indicator q. This framework penalises unbalanced indicator mixes, achieving non-compensability in a customised manner for each unit.

For each directional vector $\widetilde{\mathbf{g}}_m^{PI_b}$, the corresponding benchmarks are determined by solving:

$$\widetilde{D}_m^{b}(\mathbb{1}, \mathbf{y}; \widetilde{\mathbf{g}}_m^{PI_b}) = \sup \left\{ \beta \mid (\mathbb{1}, \mathbf{y} + \beta \widetilde{\mathbf{g}}_m^{PI_b}) \in \widetilde{\Psi}_m \right\},$$

where $\beta \in [0, 1]$ measures the proportion of improvement required to reach the frontier. The robust directions and benchmarks are obtained by averaging the results over B iterations:

$$\mathbf{g}^{PI} = E\left[\widetilde{\mathbf{g}}_m^{PI_1}, \ldots, \widetilde{\mathbf{g}}_m^{PI_B} \right],$$

$$D(\mathbb{1}, \mathbf{y}; \widetilde{\mathbf{g}}_m^{PI}) = E\left[\widetilde{D}_m^{b}\left(\mathbb{1}, \mathbf{y}; \widetilde{\mathbf{g}}_m^{PI_b} \right) \right].$$

The robust multi-directional scores for indicator q are computed as:

$$e_q = \frac{\mathbf{y}_q}{\mathbf{y}_q + \beta^* \mathbf{g}_q^{PI}}.$$

Finally, the overall CI score (CI_{MDir_RBoD}) aligns with the inefficiency index proposed by Bogetoft & Hougaard (1999):

$$CI_{MDir\_RBoD} = 1 - \frac{\beta^* \sum_{q=1}^{Q} \mathbf{g}_q^{PI}}{\sum_{q=1}^{Q} (\mathbf{y}_q + \beta^* \mathbf{g}_q^{PI})}.$$

Using B-order resampling, confidence intervals for CI scores can be constructed based on the t-distribution:

$$\bar{x} \pm t \cdot \left(\frac{s}{\sqrt{B}} \right),$$

where $\bar{x}$ is the sample mean, s the standard deviation and t the critical value for the desired confidence level.

6.3 DATA

To comprehensively evaluate the quality of hospital care in Italy, our analysis leverages data from the National Agency for Regional Healthcare Services (AGENAS), specifically the Programma Nazionale Esiti (PNE), which has been systematically collecting and publishing performance indicators for Italian hospitals since 2012. The dataset encompasses a comprehensive range of outcome measures, with 164 indicators reported in 2020, of which 71 pertain directly to care outcomes. Given the extensive nature of this dataset, we focus on a curated subset of outcome indicators spanning multiple clinical areas, selected based on AGENAS's criteria to ensure representativeness and relevance in capturing hospital performance.

The selected clinical areas and corresponding indicators include:

- **Cardiovascular**: 30-day mortality rates for acute myocardial infarction (AMI), percentage of AMI patients treated with percutaneous transluminal coronary angioplasty (PTCA) within 2 days, 30-day mortality after coronary artery bypass graft (CABG) surgery, congestive heart failure, valvuloplasty, and repair of intact abdominal aortic aneurysm.
- **Neurology**: 30-day mortality after ischemic stroke and craniotomy surgery.
- **Respiratory**: 30-day mortality for relapsed chronic obstructive pulmonary disease (COPD). General Surgery: Percentage of admissions with post-operative stay less than 3 days after laparoscopic cholecystectomy and 30-day complications following the procedure.
- **Surgical Oncology**: Percentage of breast cancer surgeries in high-volume wards, 90-day reoperation rate after breast preservation surgery, and 30-day mortality rates for lung, stomach, and colon cancer surgeries.
- **Pregnancy and Delivery**: Proportion of primary caesarean sections, readmissions after vaginal delivery, and complications during labour and puerperium for caesarean sections.
- **Musculoskeletal**: Surgery within 2 days for femoral neck fractures and 30-day readmissions after hip replacement surgery.

To ensure comparability across indicators with different units of measurement and to address the issue of polarisation—where higher values may indicate either better or worse performance—we utilize the normalised and polarised scores provided by AGENAS through their TREEMAP exercise. These scores standardize indicator values on a scale from 1 to 5, with higher scores consistently representing poorer performance, thereby facilitating accurate aggregation and interpretation within the composite indicator framework.

Our study period spans from 2015 to 2020, encompassing data from 1,377 accredited public and private hospitals across Italy. Due to data availability constraints and to capture a comprehensive view of healthcare delivery, we aggregate hospital-level data to the LHA level, resulting in an unbalanced panel dataset. Specifically, data are available for 80 LHAs in

2015, 98 in 2016, and 119 from 2017 to 2020. This aggregation allows us to assess the overall quality of healthcare services provided within each LHA, accounting for the collective performance of hospitals operating under their jurisdiction.

6.4 RESULTS

This section presents the results of the analysis conducted on healthcare performance indicators across the AGENAS clinical areas and over the six-year period (2015–2020).

Table 14 presents the yearly mean and standard deviation (SD) of the: *(i)* the first-level CIs scores for the seven clinical dimensions constructed in alignment with the TREEMAP methodology as implemented by AGENAS and *(ii)* the final second-level CI score obtained with robust `BoD` and robust `MD-BoD`.

Table 14: First and second level CI scores descriptive statistics

Dimension	2015		2016		2017		2018		2019		2020	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
First level CIs												
Cardiovascular	2.81	0.54	2.66	0.48	2.62	0.44	2.51	0.46	2.48	0.38	2.61	0.45
General surgery	2.97	0.88	2.74	0.88	2.45	0.83	2.33	0.88	2.32	0.74	2.32	0.83
Surgical Oncology	2.88	0.74	2.79	0.65	2.72	0.66	2.65	0.74	2.56	0.64	2.53	0.67
Neurology	3.01	1.02	2.77	1.04	2.87	0.99	2.57	0.96	2.53	0.89	2.85	0.98
Musculoskeletal	3.04	1.42	2.82	1.34	2.27	1.19	2.15	1.07	2.22	1.08	2.45	1.2
Pregnancy	2.93	0.89	2.77	0.8	2.59	0.74	2.66	0.65	2.62	0.63	2.49	0.67
Respiratory	3.28	0.75	2.99	0.75	3.07	0.76	3	0.82	3.06	0.81	3.63	0.86
Second level CI												
Robust `BoD`	0.81	0.15	0.85	0.13	0.89	0.12	0.91	0.1	0.9	0.1	0.9	0.1
Robust `MD-BoD`	0.64	0.2	0.71	0.18	0.76	0.16	0.79	0.14	0.79	0.14	0.76	0.15

Spearman ranking correlation Robust `BoD` - Robust `MD-BoD`: 0.813

From the first-level CIs, the Respiratory and Musculoskeletal dimensions show the highest average scores across most years, suggesting relatively better overall performance in these areas. For instance, Respiratory maintains a consistently high mean (e.g., 3.28 in 2015, 3.06 in 2020), though its standard deviation remains relatively high, indicating variability across facilities. Musculoskeletal starts with the highest variability in 2015 (SD

= 1.42), showing a decrease in mean values over time but also a reduction in variability.

Conversely, Cardiovascular and Neurology consistently exhibit lower average scores. Cardiovascular drops from a mean of 2.81 in 2015 to 2.61 in 2020, showing only modest variation (SDs ranging from 0.38 to 0.54), which may reflect persistent challenges in performance within this domain. Neurology remains relatively stable, but lower-scoring, with a slight decline in the later years (from 3.01 in 2015 to 2.85 in 2020).

Looking at second-level indicators, robust `BoD` scores remain consistently high (ranging from 0.81 to 0.92), suggesting strong aggregate performance due to the compensability among dimensions. robust `MD-BoD` values are lower, due to the imbalance performance with respect to the different dimensions and exhibit a similar trend, confirming the consistency between the two aggregation methodologies. The Spearman rank correlation of 0.813 between robust `BoD` and robust `MD-BoD` validates this alignment, indicating that both approaches yield similar rankings of healthcare performance.

Thanks to the robust `MD-BoD` model, it is possible to explore unit-specific and dimension-specific improvement trajectories within composite indicators. Unlike traditional DEA-based approaches, robust `MD-BoD` allows each unit to be evaluated against a tailored benchmark that reflects its own potential for improvement across multiple dimensions. This flexibility enables a more realistic and policy-relevant assessment of performance, as it accounts for the heterogeneity in strengths and weaknesses across units.

The Table 15 summarizes the average directional vectors across all ASLs, indicating the relative intensity of improvement efforts required in each clinical dimension. These values, derived from the robust `MD-BoD` model, reflect the average direction in which units are expected to improve, based on their current performance profiles.

The highest directional values across the years are consistently observed in the *Respiratory* dimension, which maintains values at or near 1.000 throughout 2015–2020. This stability suggests either consistently high efficiency or a ceiling effect where further improvements are limited, and aligns with literature highlighting respiratory care as both vital and under constant scrutiny, especially during health crises like the COVID-19

Table 15: Average directions by dimension and year

Year	2015	2016	2017	2018	2019	2020
Cardiovascular	0.966	1.000	0.898	0.877	0.785	0.689
Neurology	0.936	0.961	0.996	0.899	0.801	0.747
Respiratory	1.000	0.987	1.000	1.000	1.000	1.000
General surgery	0.918	0.921	0.736	0.762	0.667	0.559
Surgical Oncology	0.859	0.889	0.798	0.810	0.719	0.576
Pregnancy	0.844	0.848	0.740	0.754	0.693	0.507
Musculoskeletal	0.942	0.995	0.720	0.686	0.684	0.612

pandemic. In contrast, other dimensions exhibit varying degrees of decline, particularly noticeable in 2020. *Cardiovascular* care starts high in 2015 (0.966) and peaks in 2016 (1.000), but then steadily declines to 0.689 in 2020. A similar trend is seen in *Neurology*, which drops from a high of 0.996 in 2017 to 0.747 by 2020. *General surgery* and *Surgical oncology* both show significant reductions over time, with General surgery falling from 0.918 in 2015 to 0.559 in 2020, and Surgical oncology from 0.859 to 0.576. *Pregnancy* care also shows a downward trend, reaching the lowest score of all dimensions in 2020 (0.507), reflecting possibly increased vulnerabilities or resource reallocation during the pandemic. Finally, *Musculoskeletal* services decline from a peak of 0.995 in 2016 to 0.612 in 2020. These patterns suggest that while the *Respiratory* dimension remained a stable anchor, most other health service areas experienced notable efficiency challenges, particularly in 2020, likely due to systemic stress caused by the COVID-19 crisis. These directional averages provide a system-level view of where the most significant quality improvements are needed, and they can inform national or regional policy priorities in healthcare planning.

The radar charts in Figures 13 and 14 illustrate an example of direction and intensity of improvement efforts across seven clinical dimensions for three local health authorities.

Figure 13: Direction Radar plots examples - 2019

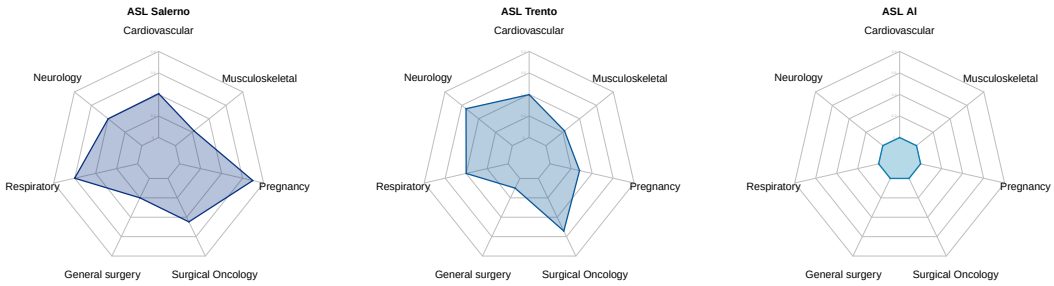
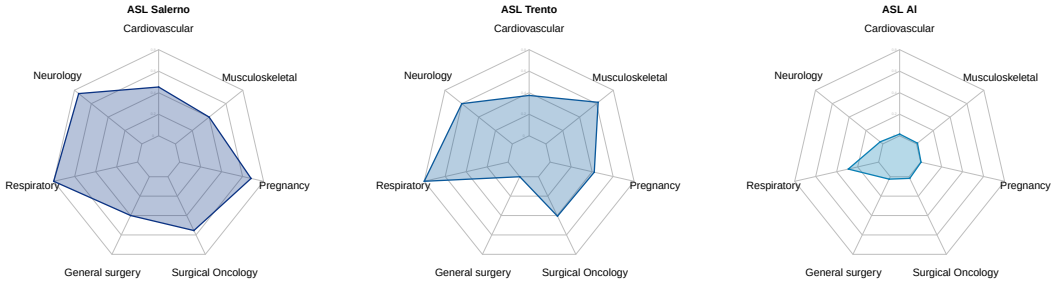


Figure 14: Direction Radar plots examples - 2020



The ASL of Salerno shows its highest directional values in *Neurology*, *Respiratory*, *Pregnancy*, and *Surgical Oncology* with a worsening in 2020. Lower values in *Cardiovascular*, *General Surgery*, and *Musculoskeletal* suggest relatively better positioning or lower priority for improvement.

The ASL of Trento displays a more selective improvement profile. The highest directional effort is required in *Respiratory* in 2020 (a worsening also in this case due to the COVID), followed by *Neurology* and *Musculoskeletal* (with a significant worsening in 2020). The remaining dimensions show lower directional values, indicating that Trento is closer to the frontier in those areas and may require only marginal improvements. There has been a slight improvement in *Surgical Oncology*.

The ASL of Alessandria appears to act as a benchmark unit, with consistently lower directional values across all dimensions. This suggests that it is already close to the efficiency frontier and serves as a reference for other units in the system.

Overall, the radar charts reflect the core strength of the robust MD-BoD approach: its ability to generate differentiated and context-sensitive improvement paths, enabling each unit to pursue efficiency and quality gains in a way that aligns with its unique performance profile.

7 STREAM 3: HEALTHCARE MOBILITY

The significant amount of resources caused by health mobility and the territorial consequences of these flows suggest analysing patient mobility in some detail. In this regard, we use (complex) network analysis to investigate monetary flows between regions, providing a complete picture of health mobility. Network analysis is a valuable tool to understand the concentration of monetary flows and to verify the direction of those flows over time. This analysis, indeed, has the advantage of clearly identifying - in the health mobility framework – the presence of persistent nodes (*i.e.*, regions) of attraction or - if any - how these nodes of attraction may have changed over the years. As will be explained in the following, complex network theory is a well-developed technique to identify relevant nodes in any kind of spatial relationship.

Our complex network is based on the interregional compensation schemes provided by the Ministry of Health (Table 16 provides a list of all Italian regions divided by macroregions - northern Italy, central Italy and southern and insular Italy – and their corresponding identification code). Our database includes the amount of (bilateral) exchanges between regions both in terms of the value generated by extraregional health services and in terms of the number of patients. The first database covers the period from 2002 to 2021, while the second database ranges from 2002 to 2022. Updated to the latest available year, both databases thus allow us to also examine the impact of the 2020 health crisis on the health mobility flows between regions.

Table 16: NUTS statistical regions of Italy

NUTS 1	NUTS 2	Code
Northern Italy	Piemonte	ITC1
	Valle d'Aosta	ITC2
	Liguria	ITC3
	Lombardia	ITC4
	Trentino-Alto Adige/Südtirol	ITH1 + ITH2
	Veneto	ITH3
	Friuli-Venezia Giulia	ITH4
	Emilia-Romagna	ITH5
Central Italy	Toscana	ITI1
	Umbria	ITI2
	Marche	ITI3
	Lazio	ITI4
Southern and Insular Italy	Abruzzo	ITF1
	Molise	ITF2
	Campania	ITF3
	Puglia	ITF4
	Basilicata	ITF5
	Calabria	ITF6
	Sicilia	ITG1
	Sardegna	ITG2

In terms of value, the first framework implies that an exporting (or debtor) region refunds money to the region that receives the foreign patient (importing or creditor region). The flow of money then corresponds to a flow of patients multiplied by the cost of specific healthcare services. In other words, being a creditor region in value terms is equivalent to importing patients from other regions. The latter will therefore be debtor regions, exporting patients to the rest of Italy. In numerical terms, the previous definitions remain valid, taking into account the number of patients treated rather than the total value of health services provided by an importing (or creditor) region. This means that exporting money or patients always qualifies a given region as an exporting (or debtor) region.

Over time, regional heterogeneity has fostered quality differences that have nourished high and persistent interregional patient mobility. Mobility patterns are traditionally characterised by patient flows from southern and insular regions toward hospitals located in very distant regions of central-northern Italy, despite the related costs of travelling. Our databases aim to deepen this characterisation applying the network theory which has become popular in the field of international trade (An *et al.*, 2014; Fan *et al.*, 2014; Zhang *et al.*, 2014; Tokito *et al.*, 2016; de Andrade & Rêgo, 2018; Cappelli *et al.*, 2023).

Generally speaking, a socioeconomic network is typically characterised by a directed graph, which consists of a collection of $N = 1, \ldots, n$ nodes that are interconnected by a set of directed links (or connections). This graph can be represented by an adjacency matrix G, whose elements define the presence or absence of a link between nodes. Formally,

$$G = [g_{ij}], (i, j) \in N \tag{23}$$

where $g_{ij} = 1$ indicates a link that goes from i to j, while $g_{ij} = 0$ indicates that such a link is not. Note that even if $g_{ij} = 1$, the reverse is not necessarily true. In other words, if there exists a directed link that goes from i to j, it is not automatically the case that node j also exports to node i. This implies that the adjacency matrix G is a nxn square matrix and is not bound to be symmetrical. Since we are interested not only in the number of connections but also in their intensity (*i.e.*, the monetary value and the number of patients), we consider the adjacency matrix of the resulting weighted directed graph W, which can be defined as follows:

$$W = [w_{ij}], (i, j) \in N \tag{24}$$

where $w_{ij} = 0$ when regions i and j do not trade with each other, while w_{ij} assumes a certain value (in monetary or numerical terms) when it exists a link between the two countries that goes from i to j. In a nutshell, the importance of a node can be assessed considering, on the one hand, the number of connections this node has to other nodes and, on the other hand, the related intensity of the linkage. In this regard, the weighted link represents the intensity of a region with other regions, taking into consideration not only the number of connections but also the related amount of money or patients. From a theoretical point of view, this

weighted adjacency matrix will not necessarily be symmetrical ($w_{ij} \neq w_{ji}$): as mentioned above, the order of the subscripts determines the direction of the exchange and the export of i to j is unlikely to match the export of j to i.

In this theoretical context, the interregional compensation scheme of the Italian NHS may be conceptualised using complex network theory, where Italian regions represent the nodes (or vertices) and monetary and numerical trade flows between regions the corresponding connections (or edges). In this way, we can use specific indicators to analyse the structural characteristics of our network. In traditional analysis of complex networks, one of the most important problems is related to the identification of the importance of nodes that, in our case, are represented by regions. Network centrality can be assessed through several methods that aim to capture different network structures. In our analysis, we concentrate on three prevalent centrality measures frequently employed in the economic literature: (weighted-)degree centrality, eigenvector centrality and the HHI (Newman *et al.*, 2006; Park & Yang, 2021). Degree centrality identifies the nodes with the highest number of incoming links, while eigenvector centrality evaluates the importance of a node based on the importance of its neighbours. Both measures help identify the pivotal nodes in the network architecture. The two centrality measures provide different information in relation to the network structure: on the one hand, a node with high-degree centrality but low eigenvector centrality may have many connections, but they might not lead to influential nodes in the network; on the other hand, a node with high-degree centrality but low-degree centrality might not have many connections, but it links influential nodes in the network. Finally, the HHI is a commonly used measure in economics and finance to gauge the level of competition or market concentration within a market. In recent research on the global trade network, weighted network indicators have been found to offer better perspectives than binary indicators (Minoiu & Reyes, 2013). Numerous scholars have contended that the assessment of the intensity of interactions between two nodes is central to understanding social and economic relationships. Adopting a binary undirected network approach to study such relationships would likely lead to the omission of significant information (Fagiolo *et al.*, 2010). For these reasons, we consider both a network approach, instead of a binary one, and a weighted perspective that takes into account the intensity of trade flows in addition to the number of connections.

Let us start by considering the first type of centrality. Degree centrality measures the direct connections between nodes in a network: in-degree centrality denotes the total number of inflow links, while out-degree centrality is computed based on outflow links. Degree centrality can also assign weights based on the importance of a node, as determined by the corresponding monetary value of the trade flow, as well as the number of patients. This element defines the size of the network link, with inflow or outflow indicating whether a node imports or exports healthcare services. In these cases, we are dealing with weighted degree centralities, where the term "*weighted*" refers precisely to the fact that we consider the monetary and numerical amount of trade flows between regions. This can also be described as the strength of the node. This distinction is applicable only to directed graphs. The definition of a directed graph (*i.e.* a graph made up of a set of vertices connected by directed links) coincides with the network under consideration. In- and out-degree centralities generally serve as fundamental indicators that are commonly used as an initial stage in network analysis (Wasserman & Faust, 1994).

There exists an exporting-based network, considering the outgoing edges, and an importing-based network, based on the incoming links. If we look at the outgoing edges, then we estimate the weighted out-degree centrality, representing the export side of the network. If n denotes the number of regions in our problem, the weighted out-degree centrality of region/node i can be defined as follows:

$$WeightedOutDegree_i = \sum_{j=1}^{n} w_{ij} = \sum_{j \neq i} w_{ij} \tag{25}$$

where w_{ij} is the weight of the link (i, j). The weighted out-degree centrality captures the outreach of a region to the community. A high weighted out-degree centrality indicates that region i exports a lot, aiming to reach all other regions with a certain pervasiveness (all regions are practically connected, but the weight indicates how pervasive the influence of i is). The weighted out-degree centrality, then, captures the level of engagement a region i initiates with members of the community. If a region is characterised by a high weighted out-degree, this implies that it is exporting a lot of money (*i.e.*, patients) to many regions. In this regard, the weighted out-degree centrality identifies those regions whose inhabitants are most dependent on other regions for healthcare. On the contrary, if we look at the incoming links, then we are analysing the weighted in-

degree centrality, which displays the import side of the network: importing money from one region is equivalent to importing patients. Consequently, the weighted in-degree centrality represents the regions that are attractive to patients from other regions in terms of healthcare. Formally, being n the overall number of regions, the weighted in-degree centrality of region/node j can be defined as follows:

$$WeightedInDegree_j = \sum_{j=1}^{n} w_{ij} = \sum_{j \neq i} w_{ij} \tag{26}$$

where w_{ij} is the weight of link (i, j). The weighted in-degree centrality measures the number of links – and their amounts – others have initiated with the region j. Regions with a high weighted in-degree centrality gain attention to their markets among the regions participating in the exchange. Weighted in-degree centrality, thus, captures the community's engagement with them. Those with high weighted in-degree centrality scores can be considered as market hubs since others have exported to them.

From a graphical point of view, the complex network can be visualised in various ways, one of which is the chord diagram. A chord diagram is a graphical tool that illustrates the relationships and interactions between different nodes—regions, in this case. Each node is represented by a circular segment arranged along the circumference of a circle, which serves as a reference frame for visualising interconnections. These connections are depicted as arcs, or chords, that link two or more segments, thereby representing interactions between the corresponding regions. The thickness of each chord is proportional to the magnitude or intensity of the relationship it signifies. In this context, we present the interregional compensation scheme within the Italian National Health Service (NHS), based on both patient numbers (Figure 15) and the absolute value of monetary flows between regions (Figure 15). To enhance the comprehensiveness of the visual representation, each figure incorporates both the import (weighted in_degree – panel a) and export (weighted out_degree – panel b) dimensions. Furthermore, macro-regions are distinguished by colour: northern regions are shown in dark grey, central regions in light grey, and southern regions and islands in light blue. It is important to emphasise that both dimensions represent the same network, highlighting the two facets of patient mobility. The length of each segment along the circle indicates the relative weight of a given region within the

overall network. The patterns of the interregional healthcare mobility do not change significantly when considering either the number of patients or the corresponding monetary value of the services provided. In this regard, it is noteworthy that value-based mobility from the South and Centre to the North tends to be more pronounced compared to mobility measured in terms of patient numbers. This may suggest a greater willingness to travel for more costly or complex medical procedure, as opposed to less invasive or lower-cost treatments. Generally speaking, from the export perspective, the southern macro-region emerges as the primary exporter of patients. The northern regions, conversely, serve as the principal destination for patients from across Italy, while also retaining most of their own patients within the same macro-regional boundaries. With regard to the import dimension, Lombardia (ITC4) has progressively enhanced its capacity to attract patients from other regions, often at the expense of the central regions and Liguria (ITC3). Southern regions and islands generally receive patients from neighbouring areas, with the notable exception of Abruzzo (ITF1), which attracts patients from Lazio (ITI4). A similar pattern is observed in the central regions, which predominantly exchange patients among themselves.

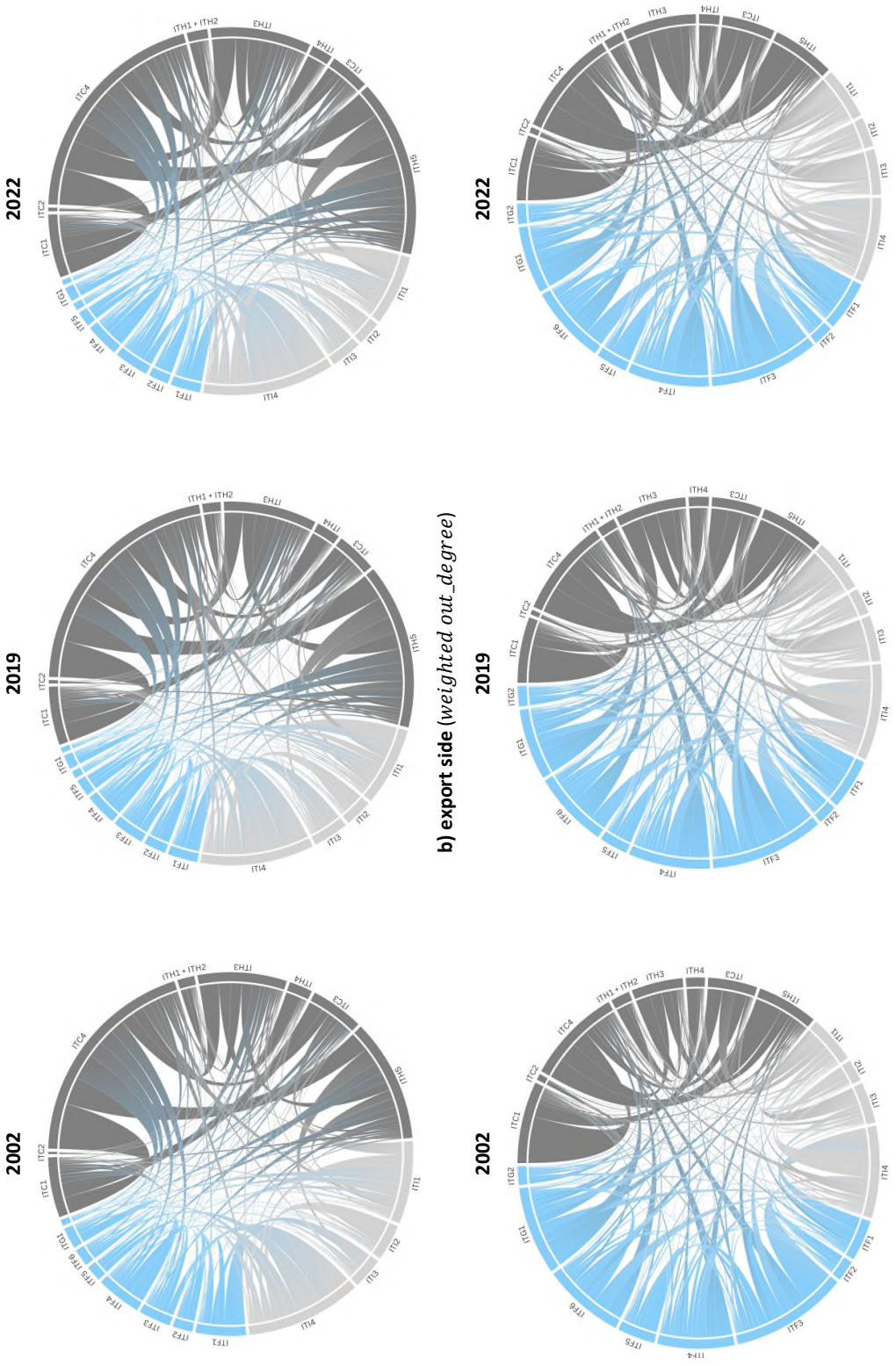


Figure 15: Chord diagram: Interregional compensation network of the Italian NHS in terms of the number of patients

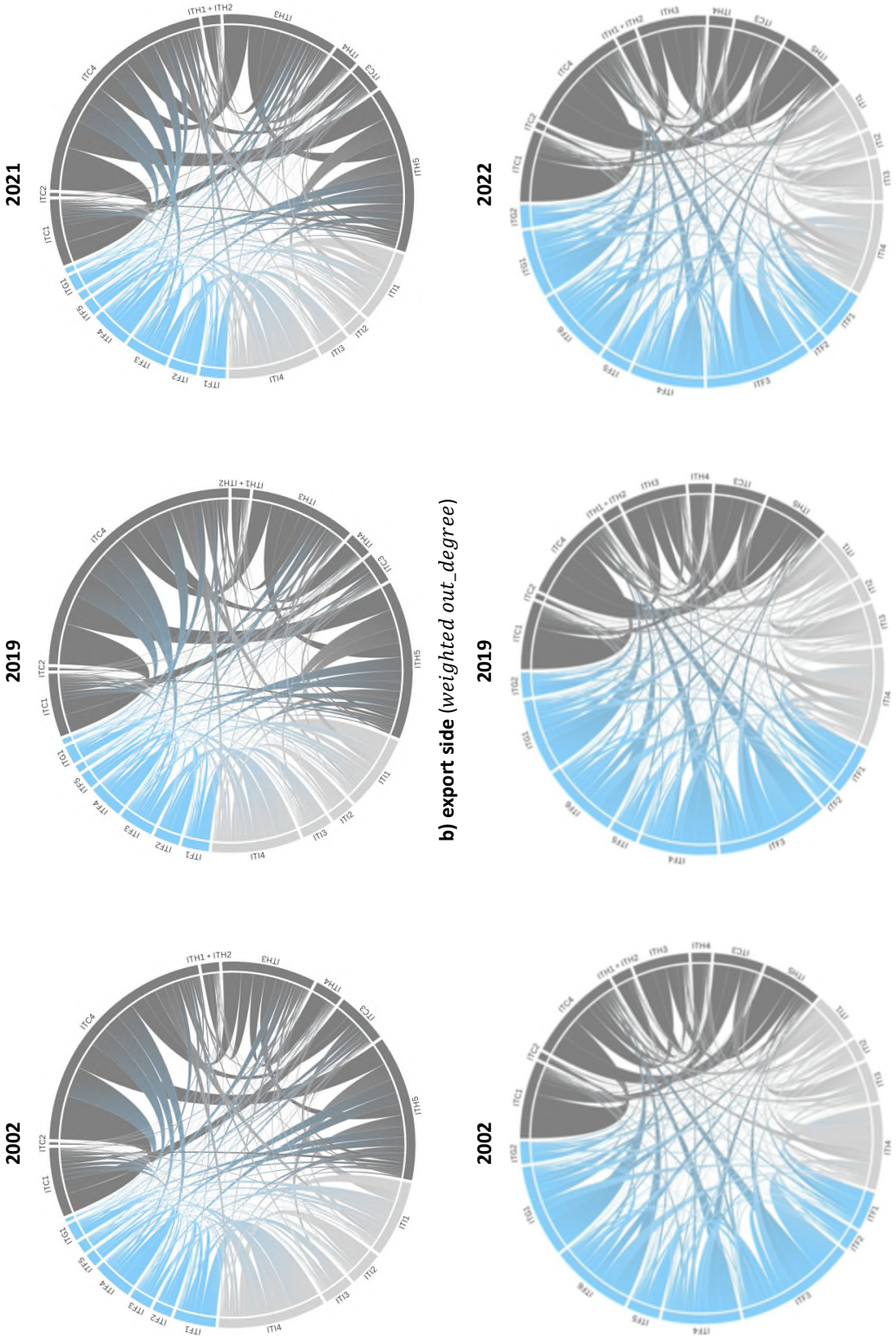


Figure 16: Chord diagram: Interregional compensation network of the Italian NHS in terms of value

Tables 17 to 20 provide a partial, year-by-year breakdown of the inter-regional healthcare mobility patterns previously illustrated in aggregate form through the chord diagrams. Specifically, Tables 17 and present the annual percentage share of each region in total healthcare mobility, respectively from the perspective of imports and exports, based on the number of patients. Tables and 20 display the same information but refer to the monetary value of interregional healthcare flows. Table 17 reveals that, when grouping regions into macro-areas, the North has gradually increased its role as an importer of patients over time, the Centre has remained relatively stable, while the South has experienced a decline in its ability to attract patients. Table , which depicts the same dynamics in value terms, confirms this overall trend. With regard to exports, the data consistently highlight the significant share of mobility originating from northern regions. However, it is important to clarify that this mobility largely reflects intra-regional flows within the North itself, rather than movements towards the Centre, South or islands.

Table 17: Interregional healthcare mobility in terms of the number of patients (% share of the annual total) from the import side

	Importing region	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
North	ITC1	5.7%	5.6%	5.6%	5.4%	5.4%	5.7%	5.7%	5.4%	5.3%	5.3%	5.4%	5.3%	5.3%	5.2%	5.3%	5.2%	5.3%	5.5%	5.7%	5.9%	5.9%
	ITC2	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.4%	0.4%	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
	ITC3	5.0%	5.0%	4.8%	4.7%	4.6%	4.6%	4.7%	4.6%	4.7%	4.6%	4.5%	4.3%	4.2%	4.2%	4.1%	4.0%	3.8%	3.8%	3.8%	3.8%	3.7%
	ITC4	20.7%	20.4%	20.2%	19.9%	19.7%	19.2%	18.9%	19.0%	18.3%	18.8%	18.7%	18.9%	19.5%	20.8%	21.8%	22.4%	22.6%	22.8%	19.1%	20.2%	21.3%
	ITH1 + ITH2	1.6%	1.6%	1.5%	1.6%	1.5%	1.6%	1.6%	1.5%	1.5%	1.5%	1.6%	1.5%	1.5%	1.6%	1.5%	1.6%	1.6%	1.7%	1.7%	1.7%	1.9%
	ITH3	8.4%	8.3%	8.2%	8.2%	8.0%	7.8%	7.6%	7.8%	7.7%	7.3%	7.1%	7.2%	7.5%	7.9%	8.1%	8.1%	8.1%	8.8%	9.8%	9.3%	9.4%
	ITH4	2.2%	2.1%	2.2%	2.2%	2.2%	2.3%	2.4%	2.5%	2.6%	2.7%	3.0%	2.9%	2.7%	2.4%	2.5%	2.4%	2.5%	2.3%	2.5%	2.0%	2.0%
	ITH5	11.6%	11.7%	12.0%	12.1%	12.6%	13.3%	13.7%	14.1%	14.3%	14.6%	14.6%	14.8%	14.7%	14.7%	14.6%	14.6%	14.9%	15.6%	15.5%	16.0%	16.5%
Centre	ITI1	7.8%	7.6%	7.7%	7.6%	7.7%	8.0%	8.2%	8.6%	8.7%	8.7%	9.2%	9.0%	9.1%	9.3%	9.2%	8.9%	8.8%	7.4%	7.2%	6.9%	6.6%
	ITI2	3.4%	3.4%	3.4%	3.0%	2.9%	3.0%	3.0%	3.1%	3.0%	3.1%	3.1%	3.2%	3.2%	3.0%	2.9%	2.7%	2.6%	2.6%	2.6%	2.3%	2.2%
	ITI3	2.9%	2.7%	2.9%	2.8%	2.9%	3.0%	3.4%	3.6%	3.5%	3.5%	3.2%	3.6%	3.4%	3.1%	3.1%	3.4%	3.4%	3.3%	3.5%	3.3%	2.9%
	ITI4	10.9%	11.9%	11.7%	12.5%	12.4%	12.1%	12.3%	12.5%	12.4%	11.8%	11.8%	11.5%	11.2%	10.6%	10.4%	10.7%	10.8%	10.7%	12.8%	12.5%	12.3%
South and islands	ITF1	4.7%	4.8%	5.2%	5.4%	5.5%	4.7%	3.9%	3.5%	3.3%	3.5%	3.4%	3.3%	3.2%	3.1%	3.1%	3.1%	2.9%	2.8%	3.0%	2.9%	2.8%
	ITF2	1.9%	1.9%	2.0%	2.1%	2.3%	2.5%	2.2%	2.2%	2.4%	2.2%	2.2%	2.3%	2.2%	2.2%	2.0%	1.9%	2.0%	2.1%	2.2%	2.2%	1.9%
	ITF3	3.0%	3.1%	3.1%	3.1%	3.0%	3.0%	3.0%	3.1%	3.0%	3.0%	3.2%	3.3%	3.3%	3.3%	3.2%	3.1%	3.0%	3.0%	3.1%	3.3%	3.2%
	ITF4	4.2%	3.9%	3.6%	3.2%	3.1%	3.3%	3.3%	3.2%	3.6%	3.4%	3.4%	3.5%	3.6%	3.4%	3.4%	3.2%	3.1%	3.0%	3.2%	3.2%	3.2%
	ITF5	1.5%	1.5%	1.5%	1.6%	1.6%	1.7%	1.8%	1.8%	1.9%	1.9%	1.8%	1.9%	2.0%	1.9%	1.8%	1.7%	1.7%	1.6%	1.5%	1.5%	1.4%
	ITF6	1.6%	1.5%	1.4%	1.3%	1.3%	1.2%	1.2%	1.0%	1.0%	1.0%	0.9%	0.8%	0.8%	0.8%	0.7%	0.6%	0.7%	0.7%	0.8%	0.7%	0.7%
	ITG1	2.0%	2.1%	2.3%	2.4%	2.3%	2.2%	2.2%	2.2%	2.0%	2.0%	2.0%	1.8%	1.7%	1.5%	1.4%	1.4%	1.4%	1.4%	1.2%	1.5%	1.3%
	ITG2	0.6%	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.0%	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
	Total (thousands)	849	852	871	880	885	865	852	820	806	792	754	738	732	738	740	732	723	711	499	581	636
	HHI (average)	2,094	2,056	2,090	2,128	2,141	2,176	2,219	2,223	2,244	2,235	2,249	2,216	2,218	2,242	2,255	2,247	2,253	2,235	2,215	2,292	2,270

Importing macroregion	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
North	55.3%	54.9%	54.7%	54.3%	54.3%	54.7%	55.0%	55.2%	54.7%	55.1%	55.1%	55.3%	55.9%	57.2%	58.3%	58.7%	59.1%	60.8%	58.4%	59.3%	61.1%
Centre	25.1%	25.7%	25.6%	25.9%	26.0%	26.2%	26.9%	27.7%	27.6%	27.1%	27.3%	27.2%	26.8%	26.0%	25.5%	25.7%	25.6%	24.1%	26.1%	24.9%	24.0%
South and islands	19.6%	19.4%	19.7%	19.8%	19.7%	19.1%	18.1%	17.1%	17.7%	17.7%	17.6%	17.5%	17.3%	16.8%	16.2%	15.6%	15.3%	15.1%	15.5%	15.8%	15.0%

Table 18: Interregional healthcare mobility in terms of the number of patients (% share of the annual total) from the export side

	Exporting region	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
North	ITC1	7.6%	7.4%	7.3%	7.1%	7.0%	6.6%	6.6%	6.4%	6.2%	6.1%	6.1%	6.3%	6.3%	6.4%	6.4%	6.3%	6.2%	6.1%	5.8%	6.1%	6.0%
	ITC2	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.5%	0.5%	0.5%
	ITC3	4.7%	4.7%	4.6%	4.5%	4.5%	4.8%	5.0%	4.8%	4.8%	5.0%	5.0%	4.9%	4.8%	4.8%	5.0%	5.0%	4.9%	4.7%	4.6%	4.9%	5.0%
	ITC4	9.0%	9.0%	8.8%	8.8%	8.8%	8.8%	8.8%	8.6%	8.6%	8.6%	8.6%	8.7%	8.7%	8.8%	8.7%	8.6%	8.7%	9.1%	10.2%	10.2%	9.8%
	ITH1 + ITH2	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.7%	1.8%	1.7%	1.7%	1.6%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.9%	1.8%	1.7%
	ITH3	4.9%	4.9%	5.1%	5.3%	5.4%	5.6%	5.7%	5.9%	6.0%	6.2%	6.4%	6.3%	6.3%	6.1%	6.2%	6.4%	6.7%	6.7%	6.9%	6.9%	6.9%
	ITH4	1.8%	1.8%	1.8%	1.8%	1.8%	1.7%	1.7%	1.7%	1.8%	1.7%	1.6%	1.6%	1.6%	1.8%	1.8%	1.7%	1.8%	1.9%	2.0%	1.9%	1.9%
	ITH5	5.7%	5.7%	5.8%	6.0%	6.0%	5.9%	5.9%	5.9%	5.7%	5.6%	5.6%	5.7%	5.8%	5.8%	5.8%	5.9%	5.9%	5.9%	6.0%	5.9%	5.9%
Centre	ITI1	4.4%	4.5%	4.5%	4.4%	4.4%	4.6%	4.7%	4.8%	4.9%	4.9%	4.7%	4.7%	4.7%	4.7%	4.6%	4.8%	4.9%	4.9%	4.8%	4.8%	4.8%
	ITI2	2.0%	2.1%	2.2%	2.3%	2.3%	2.4%	2.5%	2.5%	2.6%	2.5%	2.6%	2.6%	2.5%	2.5%	2.5%	2.5%	2.5%	2.4%	2.7%	2.7%	2.7%
	ITI3	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.9%	3.7%	3.8%	3.8%	3.9%	3.9%	4.0%	4.1%	4.1%	4.1%	4.2%	4.3%	4.3%	4.2%
	ITI4	8.5%	8.4%	8.6%	8.5%	8.5%	8.6%	8.4%	8.2%	8.4%	8.6%	8.8%	9.2%	9.5%	9.7%	9.8%	9.5%	9.3%	8.9%	8.8%	8.1%	7.9%
South and islands	ITF1	3.8%	3.8%	4.0%	4.2%	4.2%	4.3%	4.7%	5.2%	5.2%	5.3%	5.0%	5.1%	4.9%	4.7%	4.6%	4.7%	4.7%	4.7%	5.0%	4.8%	4.6%
	ITF2	2.0%	2.1%	2.0%	2.0%	1.9%	1.8%	1.7%	1.7%	1.7%	1.7%	1.7%	1.8%	1.8%	1.8%	1.9%	1.9%	1.8%	1.8%	1.9%	1.9%	1.9%
	ITF3	11.0%	11.0%	10.6%	10.6%	10.7%	10.9%	10.6%	10.8%	10.9%	10.7%	10.8%	10.6%	10.7%	10.6%	10.5%	10.7%	10.7%	10.7%	10.5%	10.4%	10.2%
	ITF4	7.3%	7.6%	7.9%	8.2%	8.2%	8.0%	7.8%	7.8%	7.7%	7.8%	7.7%	7.7%	7.8%	7.7%	7.5%	7.7%	7.7%	7.7%	7.2%	7.2%	7.6%
	ITF5	3.5%	3.4%	3.3%	3.1%	3.0%	3.0%	3.0%	2.9%	2.9%	2.9%	2.9%	2.9%	2.8%	2.7%	2.7%	2.6%	2.6%	2.7%	2.8%	2.9%	2.9%
	ITF6	7.7%	7.7%	7.9%	8.0%	7.8%	7.9%	8.0%	7.9%	7.8%	7.6%	7.8%	7.7%	7.6%	7.6%	7.5%	7.3%	7.2%	7.2%	6.6%	7.1%	7.3%
	ITG1	8.2%	7.9%	7.6%	7.3%	7.2%	7.0%	6.9%	6.9%	6.9%	6.8%	6.5%	6.3%	6.2%	6.2%	6.4%	6.4%	6.4%	6.6%	5.8%	5.9%	6.2%
	ITG2	1.7%	1.7%	1.8%	1.8%	1.9%	2.0%	2.0%	1.9%	1.9%	2.0%	2.0%	1.9%	1.9%	2.0%	2.0%	1.9%	1.8%	1.9%	1.7%	1.8%	1.9%
	Total (thousands)	849	852	871	880	885	865	852	820	806	792	754	738	732	738	740	732	723	711	499	581	636
	HHI (average)	2,349	2,356	2,374	2,389	2,393	2,360	2,361	2,388	2,357	2,338	2,310	2,310	2,345	2,368	2,401	2,393	2,370	2,378	2,429	2,430	2,459

Exporting macroregion	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
North	36.0%	36.0%	35.7%	35.8%	35.9%	35.8%	36.0%	35.6%	35.3%	35.5%	35.7%	35.7%	35.7%	35.9%	36.0%	36.0%	36.2%	36.5%	37.9%	38.2%	37.8%
Centre	18.8%	18.8%	19.1%	19.0%	19.0%	19.4%	19.5%	19.4%	19.6%	19.8%	19.9%	20.4%	20.6%	20.9%	21.0%	20.9%	20.8%	20.4%	20.7%	19.9%	19.6%
South and islands	45.2%	45.2%	45.2%	45.2%	45.1%	44.8%	44.6%	45.0%	45.1%	44.7%	44.4%	44.0%	43.7%	43.2%	43.0%	43.2%	43.0%	43.1%	41.4%	41.9%	42.7%

Table 19: Interregional healthcare mobility in terms of value (% share of the annual total) from the import side

	Importing region	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
North	ITC1	6.5%	6.5%	6.6%	6.6%	6.6%	6.7%	6.6%	6.6%	6.5%	6.5%	6.2%	5.9%	5.5%	5.4%	5.4%	5.6%	5.7%	5.9%	6.2%	6.3%
	ITC2	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
	ITC3	4.8%	4.6%	4.4%	4.4%	4.4%	4.2%	4.1%	3.9%	3.8%	3.6%	3.4%	3.5%	3.3%	3.2%	3.1%	3.1%	3.1%	2.9%	2.9%	2.7%
	ITC4	22.7%	22.8%	23.1%	22.3%	22.4%	22.5%	22.3%	21.9%	22.1%	23.0%	22.8%	23.6%	23.9%	24.2%	25.3%	25.8%	25.8%	25.7%	21.7%	22.7%
	ITH1 + ITH2	1.7%	1.7%	1.6%	1.6%	1.6%	1.7%	1.6%	1.6%	1.6%	1.6%	1.7%	1.6%	1.5%	1.5%	1.5%	1.7%	1.6%	1.7%	1.7%	1.7%
	ITH3	8.8%	9.0%	9.0%	9.1%	8.9%	8.8%	8.6%	8.7%	8.8%	8.6%	8.6%	8.6%	8.7%	8.9%	8.9%	9.0%	9.2%	9.9%	11.1%	10.9%
	ITH4	2.6%	2.4%	2.3%	2.3%	2.3%	2.3%	2.4%	2.5%	2.5%	2.7%	2.7%	2.7%	2.5%	2.3%	2.3%	2.2%	2.2%	2.2%	2.5%	2.3%
	ITH5	13.6%	14.1%	14.5%	14.8%	15.3%	15.8%	15.9%	16.1%	16.0%	15.7%	15.5%	15.4%	15.3%	15.3%	14.9%	14.4%	14.5%	14.9%	15.2%	15.7%
Centre	ITI1	7.1%	7.4%	7.7%	7.6%	7.7%	7.8%	7.8%	8.1%	8.2%	8.2%	8.4%	8.4%	8.5%	8.5%	8.3%	8.3%	8.3%	7.0%	7.3%	6.7%
	ITI2	3.2%	3.1%	3.0%	2.7%	2.6%	2.7%	2.7%	2.7%	2.7%	2.7%	2.6%	2.7%	2.9%	2.8%	2.7%	2.5%	2.3%	2.3%	2.4%	2.1%
	ITI3	2.8%	2.6%	2.5%	2.6%	2.5%	2.6%	2.7%	2.9%	2.9%	2.9%	2.9%	3.1%	2.9%	2.7%	2.7%	2.9%	2.9%	2.9%	3.1%	2.9%
	ITI4	10.1%	9.7%	9.5%	9.9%	10.0%	9.5%	9.5%	9.8%	9.1%	8.7%	8.5%	7.9%	8.0%	7.8%	8.1%	8.2%	8.4%	8.4%	9.2%	8.7%
South and islands	ITF1	3.9%	4.0%	4.1%	4.2%	4.1%	3.8%	3.3%	2.9%	2.9%	2.9%	2.8%	2.7%	2.6%	2.7%	2.7%	2.8%	2.6%	2.6%	2.6%	2.5%
	ITF2	1.8%	2.0%	1.8%	2.0%	2.3%	2.2%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.3%	2.3%	2.4%	2.4%	2.8%	2.7%
	ITF3	2.1%	2.2%	2.4%	2.4%	2.2%	2.3%	2.3%	2.4%	2.5%	2.4%	3.1%	3.2%	3.5%	3.6%	3.6%	3.5%	3.3%	3.3%	3.3%	4.1%
	ITF4	3.7%	3.4%	3.0%	2.8%	2.7%	2.9%	3.0%	2.9%	3.0%	2.9%	3.0%	3.1%	3.2%	3.4%	3.4%	3.2%	3.2%	3.2%	3.5%	3.6%
	ITF5	1.2%	1.2%	1.2%	1.3%	1.4%	1.4%	1.5%	1.5%	1.7%	1.8%	1.7%	1.8%	2.0%	2.1%	1.8%	1.6%	1.6%	1.5%	1.5%	1.4%
	ITF6	1.1%	1.0%	0.8%	0.9%	0.9%	0.8%	0.9%	0.9%	0.8%	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%	0.7%	0.6%	0.7%	0.9%	0.8%
	ITG1	1.6%	1.5%	1.7%	1.6%	1.6%	1.5%	1.6%	1.6%	1.6%	1.8%	1.9%	1.9%	1.9%	1.8%	1.7%	1.6%	1.7%	1.7%	1.5%	1.5%
	ITG2	0.3%	0.3%	0.4%	0.4%	0.4%	0.4%	0.4%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.4%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
	Total (nominal - billion €)	2.89	2.99	3.14	3.25	3.31	3.37	3.45	3.50	3.48	3.55	3.59	3.68	3.79	3.86	3.97	4.02	4.08	4.12	3.13	3.66
	Total (real - billion €)	3.65	3.66	3.74	3.79	3.78	3.75	3.75	3.74	3.70	3.71	3.69	3.74	3.82	3.86	3.93	3.94	3.96	3.96	2.96	3.41
	HHI (average)	2,017	2,015	2,015	2,025	2,013	2,051	2,073	2,093	2,087	2,068	2,062	2,054	2,001	2,114	2,102	1,978	2,111	2,537	2,139	2,179

Importing macroregion	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
North	60.9%	61.4%	61.7%	61.5%	61.7%	62.1%	61.8%	61.5%	61.6%	62.0%	61.3%	61.5%	61.0%	61.1%	61.6%	62.0%	62.5%	63.5%	61.5%	62.7%
Centre	23.3%	22.9%	22.8%	22.9%	22.8%	22.6%	22.8%	23.5%	23.0%	22.6%	22.4%	22.1%	22.3%	21.9%	21.7%	21.8%	21.9%	20.6%	22.0%	20.4%
South and islands	15.8%	15.7%	15.5%	15.6%	15.5%	15.3%	15.4%	14.9%	15.4%	15.5%	16.3%	16.3%	16.8%	17.0%	16.6%	16.2%	15.7%	15.8%	16.5%	17.0%

Table 20: Interregional healthcare mobility in terms of value (% share of the annual total) from the export side

	Exporting region	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
North	ITC1	7.2%	7.2%	7.2%	7.0%	7.0%	6.7%	6.7%	6.5%	6.5%	6.5%	6.5%	6.8%	6.6%	6.6%	6.7%	6.6%	6.4%	6.3%	6.1%	6.6%
	ITC2	0.7%	0.7%	0.7%	0.8%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.5%	0.5%	0.5%	0.4%	0.5%	0.5%	0.6%	0.6%
	ITC3	4.7%	4.9%	5.0%	4.9%	4.9%	5.0%	5.1%	5.0%	5.2%	5.2%	5.2%	5.1%	4.9%	4.8%	4.9%	5.0%	4.9%	4.8%	4.8%	4.9%
	ITC4	9.0%	9.2%	9.2%	9.3%	9.4%	9.2%	9.2%	9.3%	9.1%	9.0%	9.0%	8.9%	8.7%	8.6%	8.5%	8.5%	8.7%	8.8%	10.0%	10.2%
	ITH1 + ITH2	1.9%	1.9%	1.9%	1.9%	2.0%	2.0%	1.9%	1.9%	1.9%	1.8%	1.8%	1.8%	1.7%	1.7%	1.8%	1.7%	1.7%	1.7%	1.9%	1.8%
	ITH3	5.3%	5.3%	5.3%	5.5%	5.5%	5.8%	5.8%	5.9%	6.0%	6.2%	6.2%	6.2%	6.1%	5.9%	5.9%	6.0%	6.1%	6.3%	6.4%	6.5%
	ITH4	1.9%	1.9%	1.8%	1.9%	1.9%	1.9%	1.8%	1.8%	1.9%	1.9%	1.9%	1.9%	1.9%	2.0%	1.9%	1.9%	2.1%	2.2%	2.3%	2.2%
	ITH5	5.6%	5.7%	5.8%	5.9%	6.0%	6.0%	6.1%	6.0%	6.1%	6.2%	6.2%	6.3%	6.5%	6.2%	6.1%	6.3%	6.2%	6.1%	6.1%	6.1%
Centre	ITI1	4.6%	4.6%	4.4%	4.4%	4.5%	4.6%	4.8%	4.7%	4.7%	4.6%	4.5%	4.6%	4.7%	4.6%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%
	ITI2	2.0%	2.0%	2.1%	2.2%	2.2%	2.2%	2.2%	2.4%	2.4%	2.3%	2.3%	2.3%	2.2%	2.2%	2.2%	2.3%	2.3%	2.2%	2.4%	2.3%
	ITI3	3.8%	3.8%	4.0%	3.9%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.9%	3.8%	3.8%	3.9%	4.0%	4.0%	4.0%	3.8%	3.9%	3.9%
	ITI4	7.9%	8.0%	8.2%	8.0%	7.9%	8.2%	8.2%	7.9%	8.1%	8.4%	8.6%	8.9%	9.4%	9.7%	9.8%	9.7%	9.5%	9.2%	9.2%	8.5%
South and islands	ITF1	3.6%	3.5%	3.6%	3.8%	3.8%	3.9%	4.1%	4.6%	4.7%	4.6%	4.6%	4.5%	4.4%	4.4%	4.3%	4.5%	4.5%	4.6%	4.7%	4.6%
	ITF2	1.9%	1.9%	1.8%	1.8%	1.7%	1.6%	1.5%	1.5%	1.4%	1.4%	1.5%	1.5%	1.5%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%
	ITF3	11.4%	11.1%	10.7%	10.7%	10.8%	10.7%	10.6%	11.0%	10.6%	10.5%	10.5%	10.3%	10.4%	10.4%	10.4%	10.5%	10.5%	10.4%	10.2%	10.1%
	ITF4	7.5%	7.7%	7.9%	8.1%	8.2%	8.1%	7.8%	7.9%	7.7%	7.7%	7.7%	7.8%	7.9%	7.8%	7.7%	7.7%	7.6%	7.5%	7.1%	7.0%
	ITF5	3.1%	3.0%	2.9%	2.8%	2.6%	2.5%	2.6%	2.6%	2.5%	2.6%	2.6%	2.6%	2.6%	2.6%	2.6%	2.6%	2.5%	2.6%	2.7%	2.8%
	ITF6	7.6%	7.5%	7.5%	7.5%	7.4%	7.5%	7.4%	7.2%	7.4%	7.2%	7.3%	7.4%	7.7%	7.6%	7.5%	7.3%	7.2%	7.1%	6.8%	7.1%
	ITG1	8.5%	8.3%	7.9%	7.7%	7.6%	7.4%	7.3%	7.4%	7.3%	7.2%	6.8%	6.6%	6.6%	6.5%	6.7%	6.7%	6.7%	6.9%	6.2%	6.2%
	ITG2	2.1%	2.0%	2.0%	2.0%	2.2%	2.3%	2.2%	2.1%	2.2%	2.1%	2.2%	2.0%	2.1%	2.1%	2.1%	2.1%	2.3%	2.3%	2.1%	2.1%
	Total (nominal - billion €)	2.89	2.99	3.14	3.25	3.31	3.37	3.45	3.50	3.48	3.55	3.59	3.68	3.79	3.86	3.97	4.02	4.08	4.12	3.13	3.66
	Total (real - billion €)	3.65	3.66	3.74	3.79	3.78	3.75	3.75	3.74	3.70	3.71	3.69	3.74	3.82	3.86	3.93	3.94	3.96	3.96	2.96	3.41
	HHI (average)	2,358	2,015	2,381	2,383	2,376	2,374	2,370	2,394	2,384	2,375	2,346	2,365	2,402	2,397	2,428	2,438	2,452	2,471	2,489	2,477

Exporting macroregion	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
North	36.2%	36.7%	37.0%	37.2%	37.3%	37.3%	37.3%	37.1%	37.2%	37.5%	37.4%	37.6%	36.8%	36.5%	36.2%	36.5%	36.5%	36.9%	38.1%	39.0%
Centre	18.3%	18.4%	18.7%	18.5%	18.3%	18.9%	19.0%	18.8%	18.9%	19.1%	19.3%	19.6%	20.0%	20.4%	20.8%	20.6%	20.5%	20.1%	20.3%	19.4%
South and islands	45.5%	44.9%	44.3%	44.3%	44.3%	43.9%	43.7%	44.1%	43.8%	43.4%	43.3%	42.8%	43.2%	43.1%	43.0%	42.9%	43.0%	43.1%	41.5%	41.6%

Finally, we quantify the level of import diversification through the HHI, which represents our last centrality measure. The identification of specialisation in international trade is comparable to a similar issue in industrial organisation, that is, the need for a theoretical and empirical measure of market power. In this regard, the HHI represents a typical example. In a trade framework, the HHI can be applied both on the export and import side (Magee & Magee, 2008). In our network, link weights now represent the market shares (MS). By definition, this implies that the sum of the outgoing and incoming links to country i is equal to 100%. More precisely, let n be the number of all the Italian regions, the HHI concerning the diversification of export of patients (and the relative amount of money) of a certain region i (HHI export) and the diversification of import of patients (and the relative amount of money) of a certain region j (HHI import) are calculated by squaring and summing the markets shares exported and imported by partner regions j and i respectively as follows:

$$\mathrm{HHIexport}_i = \sum_{j \neq i} MS_j^2 \tag{27}$$

$$\mathrm{HHIimport}_j = \sum_{j \neq i} MS_i^2 \tag{28}$$

where MS_j represents the market shares of importing countries j, while MS_i the market shares of exporting countries i (i.e., 5%=5). The HHI gives much heavier weight to countries with large market shares than to countries with small shares as a result of squaring the market shares. This feature of the HHI corresponds to the theoretical notion in economics that the higher the import concentration in a small number of countries (a high HHI), the greater the likelihood that, other things equal, competition in a market will be weak. In contrast, if concentration is low, reflecting a large number of countries with small market shares (low HHI), competition will tend to be significant. The HHI ranges from a maximum value of 10,000 in which one country has 100% of the market (monopolistic situation) to the minimum value of 0 which occurs when there is a purely competitive market with infinite countries with small market shares. The US merger guidelines classify market concentration as follows: (i) a HHI_i below 1,000 indicates absence of concentration; (ii)

a HHI_i between 1,000 and 1,800 indicates moderate concentration; (iii) a HHI_i above 1,800 indicates high concentration.

Let us now analyse the results, starting with the Piedmont region (ITC1). This region is characterised by a high concentration of exports (towards other northern regions) and a high degree of diversification in imports, confirming the northern area's strong attractiveness in terms of inbound healthcare mobility. This attractiveness is further confirmed across all northern regions.
Among them, Emilia-Romagna (ITH5) stands out as the region with the highest degree of inbound diversification in the entire country. In any case, this level of diversification is a defining feature of the entire macro-area, which is in turn characterised by substantial internal mobility – effectively excluding central and southern regions as well as the islands from such dynamics. By contrast, the central regions present a more varied and balanced situation regarding the relationship between export and import diversification. This is largely due to their intermediate geographical position: on the one hand, central regions tend to attract patients from the south; on the other, patients from the centre often seek better healthcare in the north. As for the southern regions, they tend to exhibit a medium level of export diversification, mainly directed towards the northern regions (and to a lesser extent towards the centre).

Figure 17: Diversification of interregional healthcare mobility in terms of the number of patients (HHI) - North

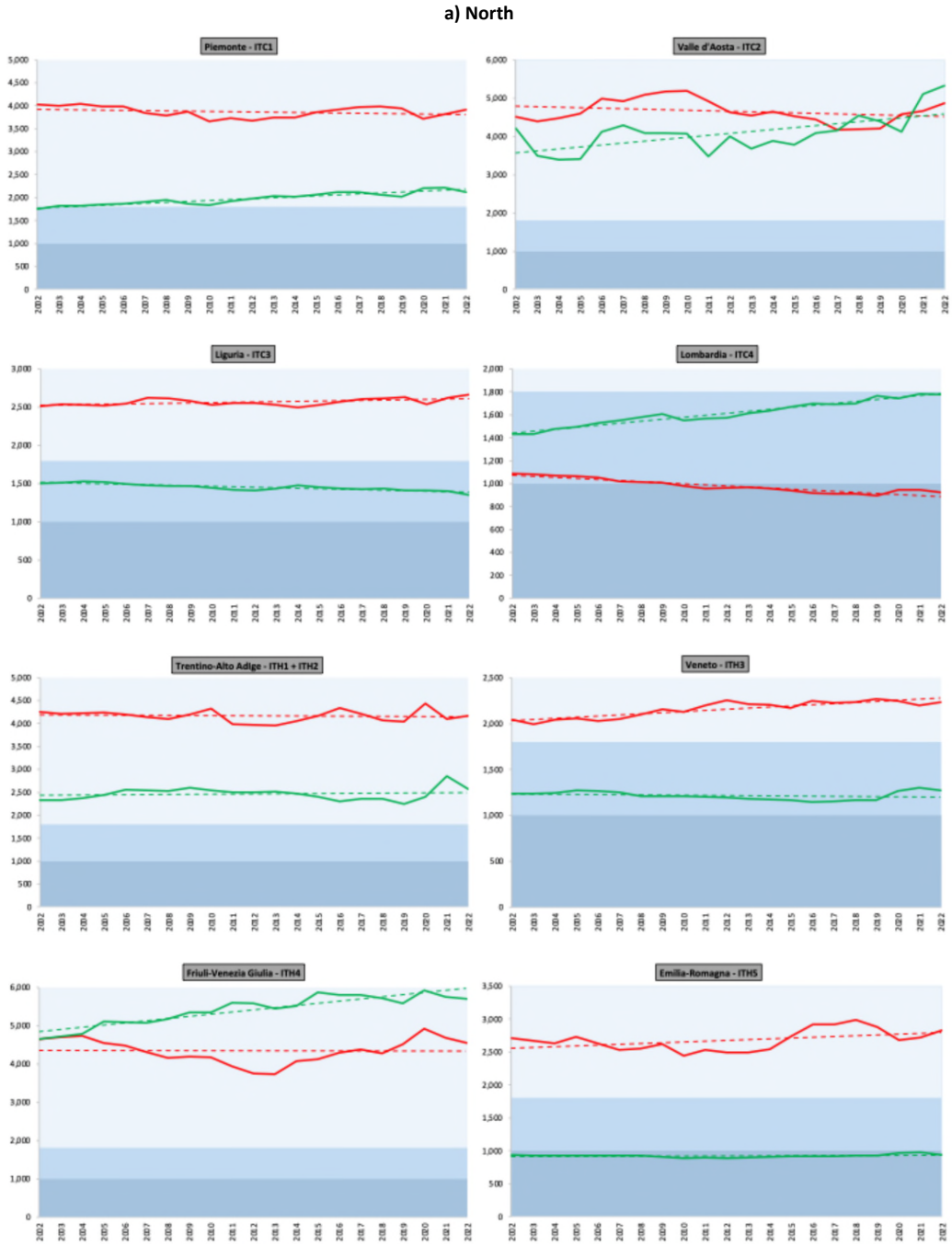


Figure 18: Diversification of interregional healthcare mobility in terms of the number of patients (HHI) - Centre & South and Islands

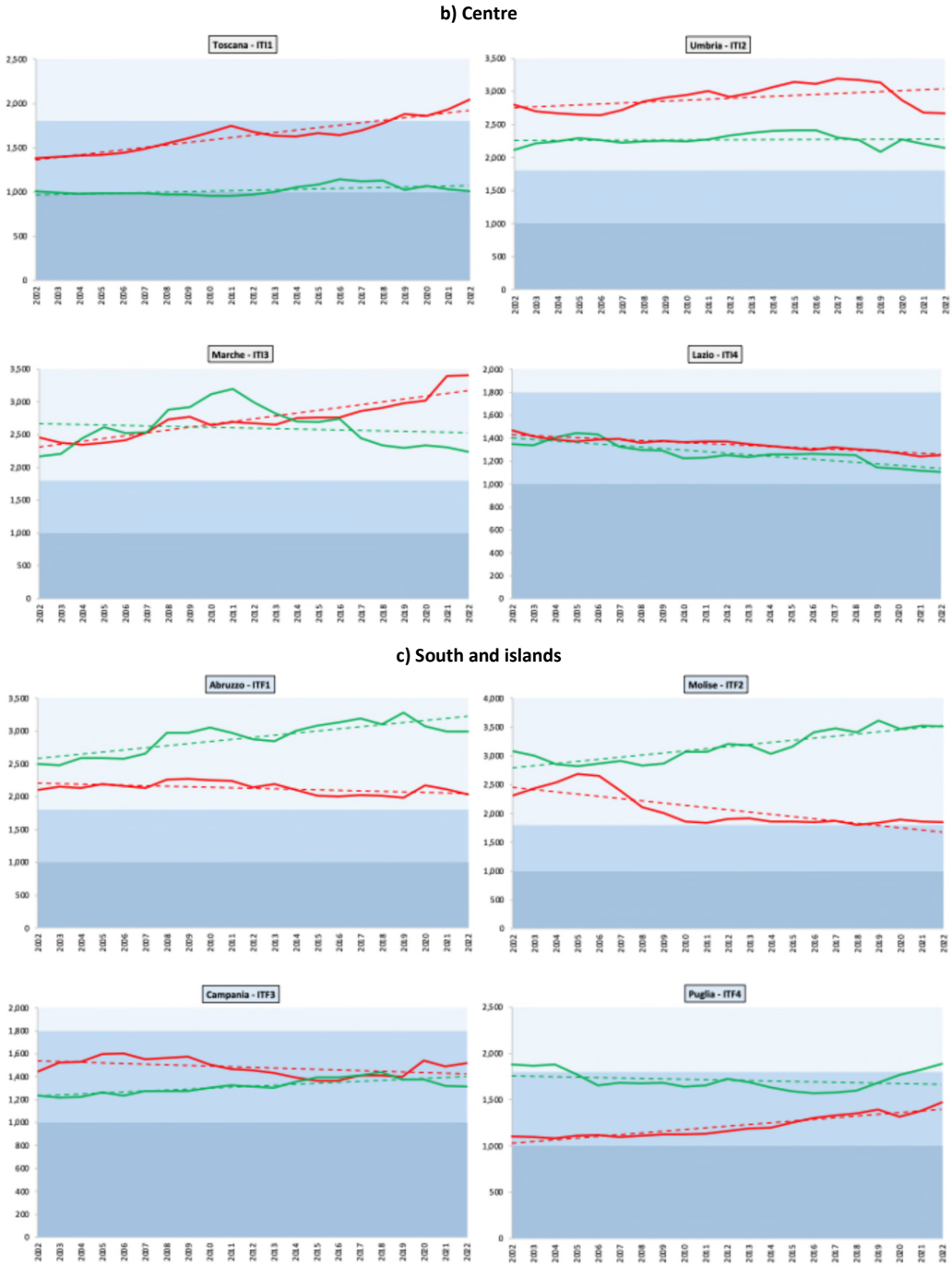


Figure 19: Diversification of interregional healthcare mobility in terms of the number of patients (HHI) - South and Islands

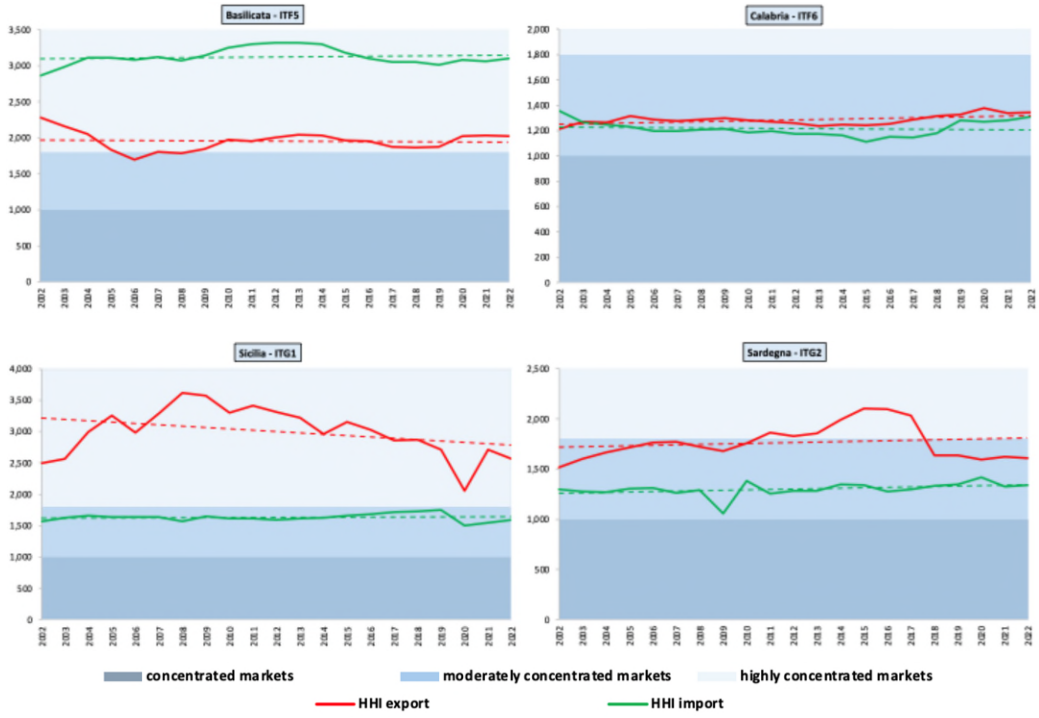


Figure 20: Diversification of interregional healthcare mobility in terms of value (HHI) - North

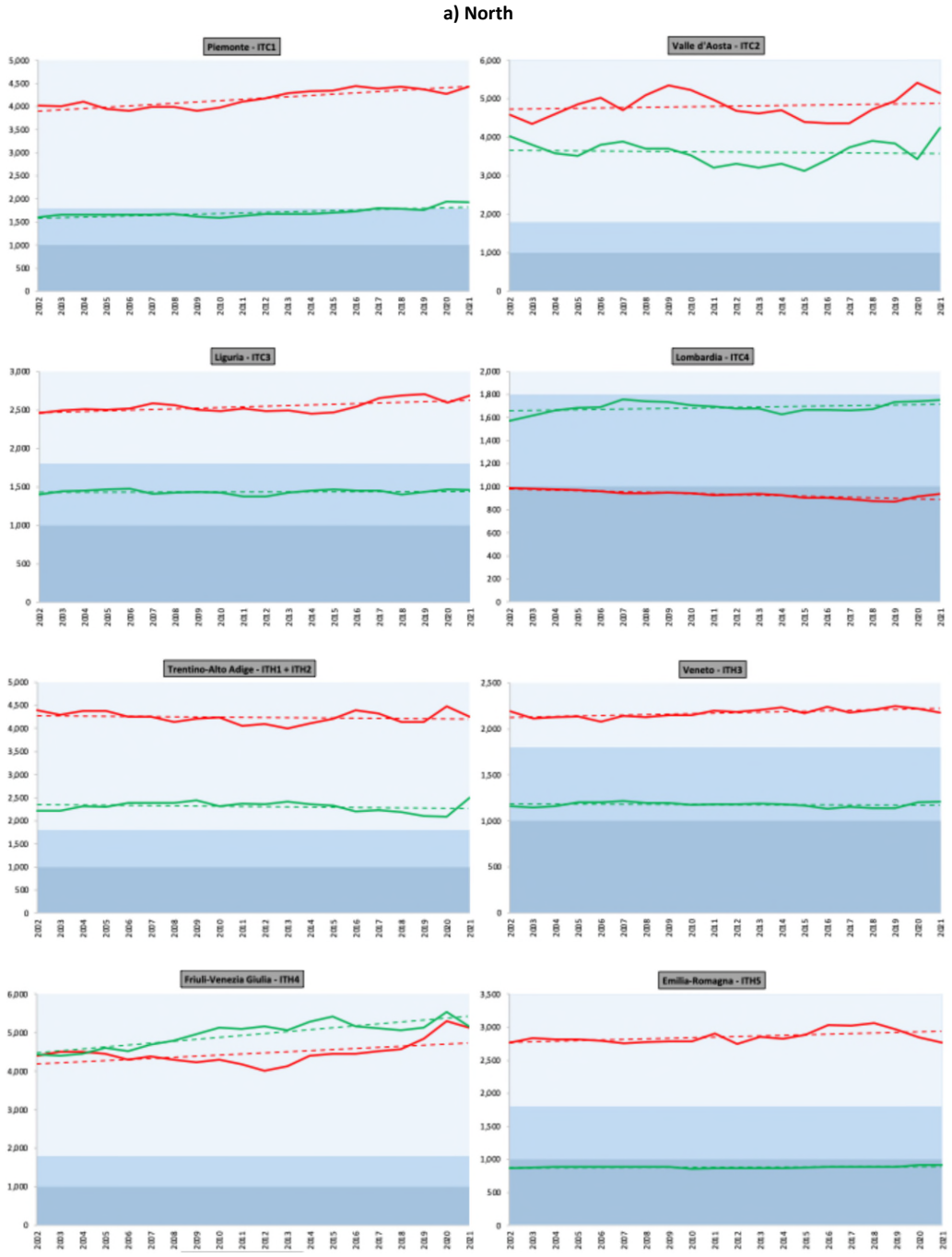


Figure 21: Diversification of interregional healthcare mobility in terms of value (HHI) - Centre & South and Islands

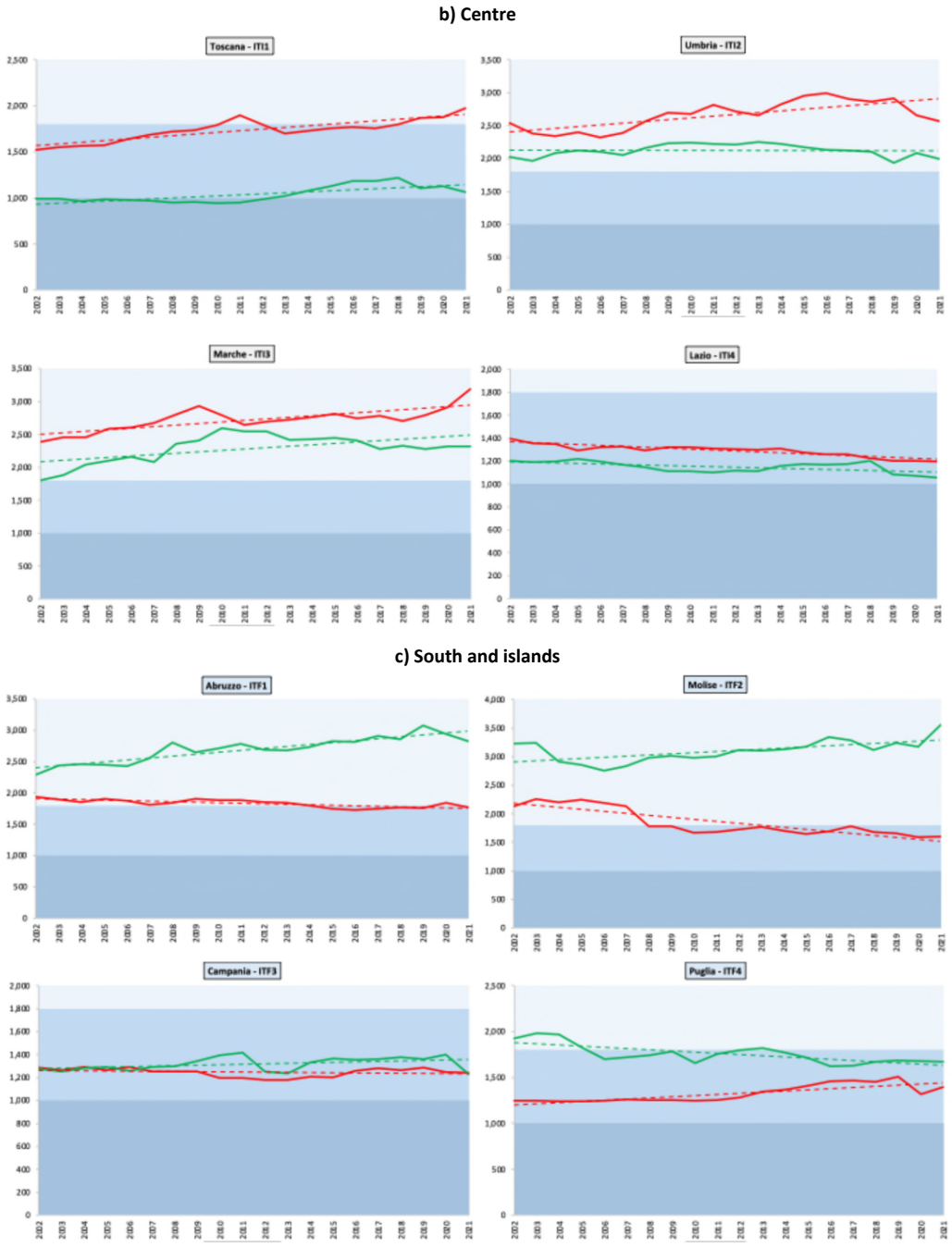
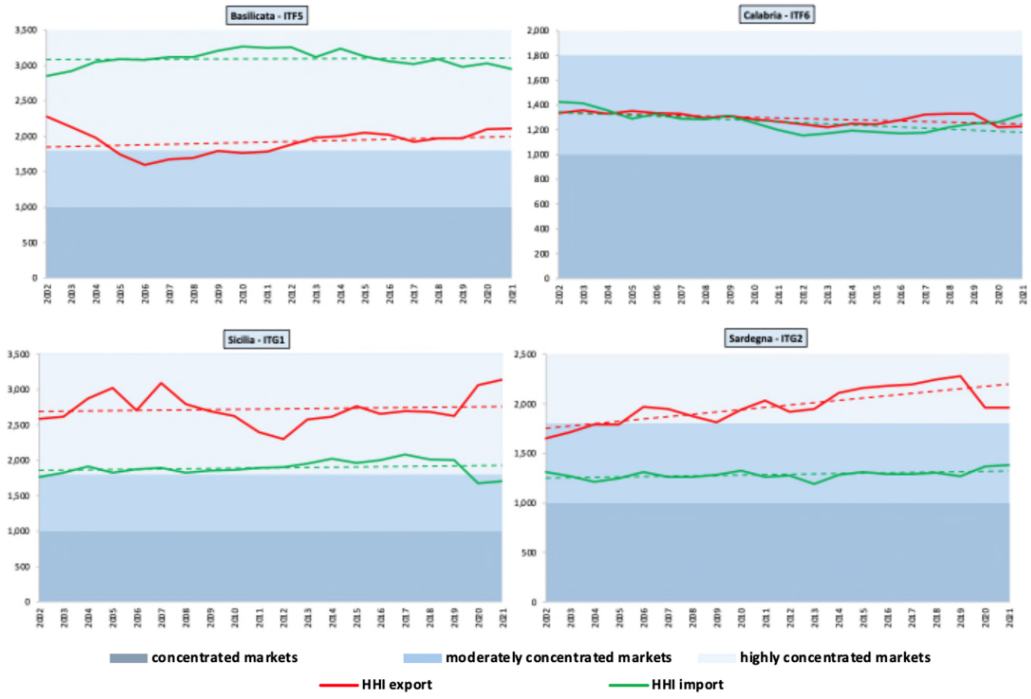


Figure 22: Diversification of interregional healthcare mobility in terms of value (HHI) - South and Islands



8 STREAM 4: ENVIRONMENTAL CONDITIONS

The relationship between environmental degradation and human health has become increasingly evident in recent years, as the accumulation of scientific evidence underscores the profound implications of ecological conditions on well-being. Localized pollution, stemming from soil degradation, poor air quality (World Health Organization, 2016; Burnett *et al.*, 2018), compromised water resources, and inefficient waste management (Mudu *et al.*, 2014), constitutes a complex set of stressors that collectively shape health outcomes at the population level. Each of these environmental dimensions independently and synergistically contributes to the deterioration of both physical and mental health, exacerbating chronic conditions, infectious disease exposure, and general health inequities (Prüss-Üstün *et al.*, 2016).

Soil degradation, for instance, entails the erosion, contamination, and depletion of essential nutrients, which not only affects agricultural productivity and food security but also increases human exposure to toxic substances such as heavy metals (El Mujtar *et al.*, 2019). Air pollution—particularly particulate matter (PM2.5, PM10) and gases like NO_2 and SO_2, has been consistently associated with respiratory and cardiovascular morbidity and mortality, especially in urban contexts (Manisalidis *et al.*, 2020). Similarly, degraded water quality, as indicated by ecological and chemical imbalances in freshwater bodies, poses substantial risks for gastrointestinal diseases, developmental disorders, and reproductive health (Albert *et al.*, 2021). Lastly, high levels of unsorted urban waste are symptomatic of environmental neglect and are linked to increased vermin populations, air and soil contamination, and the marginalization of communities in proximity to waste facilities.

The cumulative impact of these environmental stressors is here captured in composite indices that quantify local pollution levels and help identify areas of heightened vulnerability. These indices offer crucial insights for public health policy and spatial epidemiology, enabling the design of targeted interventions to mitigate environmental risks and promote sustainable urban and rural development (World Health Organization, 2022; Young *et al.*, 2017).

8.1 SOIL DEGRADATION INDEX

The map of *Soil degradation indicators in EU* (produced by the European Soil Data Centre (ESDAC) of the Joint Research Centre) shows areas where scientific evidence indicates a high likelihood of soil degradation (Panagos *et al.*, 2024). The multi-band dataset includes 20 bands (one per soil degradation indicator, plus a summary of all indicators), and covers the whole Europe, exhibiting a ground resolution of 500 m pixels. The following Tables 21 and 22 shows the soil degradation processes, the indicators used, the thresholds, and the data sources.

Table 21: Soil Degradation Index - 1st part

Soil degradation	Indicator	Threshold used	Data used (reference)
Soil erosion	Water erosion	Erosion rate >2 tonnes ha-1year-1	Panagos et al., 2020
	Wind erosion	Erosion rate >2 tonnes ha-1year-1	Borrelli et al., 2017
	Tillage erosion	Erosion rate >2 tonnes ha-1year-1	Borrelli et al., 2023
	Harvest erosion	Erosion rate >2 tonnes ha-1year-1	Panagos et al., 2019
	Post-fire recovery	Recovery rate <1	Vieira et al., 2023
Soil pollution	Copper excess	Cu concentration >100 mg kg-1	Ballabio et al., 2018
	Mercury excess	Hg concentration >0.5 mg kg-1	Ballabio et al., 2021
	Zinc excess	Zn concentration >100 mg kg-1	Van Eynde et al., 2023
	Cadmium excess	Cd concentration >1 mg kg-1	Ballabio et al., 2024
	Arsenic excess	Probability of high as (>45 mg kg-1) >5%	Fendrich et al., 2024

Table 22: Soil Degradation Index - 2nd part

Soil degradation	Indicator	Threshold used	Data used (reference)
Soil nutrients	Nitrogen surplus	Agricultural areas where N surplus >50 kg ha-1	Grizzetti et al., 2022; Lugato et al., 2018
	Phosphorus deficiency	P deficiency <20 mg kg-1	Ballabio et al., 2019
	Phosphorus excess	P excess >50 mg kg-1	Ballabio et al., 2019
Loss of soil organic carbon	Distance to maximum SOC level	Distance from 'maximum' SOC >60%	De Rosa et al., 2024
Loss of soil biodiversity	Potential threat to biological functions	⩾Moderately high level of risk	Orgiazzi et al., 2016
Soil compaction	Soil packing density	High packing density (>1.75 g cm-3)	De Rosa, et al., 2024
Salinisation	Secondary salinisation	Areas in Mediterranean biogeographical region where >30% is equipped for irrigation	Siebert et al., 2010
Loss of organic soils	Peatland degradation	Peatlands under hotspots of cropland	UNEP, 2022
Soil sealing	Built-up areas	No threshold applied (all built-up areas)	Copernicus, 2018

For our purposes, only band 20 was used, as this is an overall index of soil health, calculated by summing all the other indicators.
The values of indicators 1 to 19 can be either 0 (healthy) or 1 (unhealthy). Consequently, the values of the soil degradation index range from 0 (healthy soil, where all indicators have a value of 0) to a theoretical maximum of 19 (all indicators have a value of 1), a value that has never been recorded in Italy. The highest recorded value is 8, that is a pixel in which eight indicators are simultaneously in a poor state. Pixels dominated by sealed soil were not included in the study and were therefore assigned to a new class with a value of 9, as the absence of soil — due to man-made sealing — represents the highest possible level of resource degradation. At this stage, the information was re-aggregated at municipal level using zonal statistics, and the average value at municipal level was extrapolated. As a result, the index has a national extension with basic aggregation at the municipal level. Its dimensionless value can theoretically varies between 0 and 9. In our dataset values range between 0.029 and 9.

8.2 AIR QUALITY INDEX

The Copernicus Atmosphere Monitoring Service produces daily concentration data for various air pollutants across Europe (Hamer *et al.*, 2024). The 2023 data is the latest fully reanalysed and is currently available for download and use (Copernicus Atmosphere Monitoring Service, 2021). For our purposes, we downloaded suspended particulate matter and gas concentration data for each of the indicators shown in the table on the first day of each month.

The ground resolution of CAMS products is a raster, covering the entire European continent, with cells of 0.1° width. For each cell, the monthly concentration value of each indicator was selected and summed in order to calculate the annual value. Subsequently, the annual concentration values of the pollutants were reported to the municipalities, being the analysis spatial base layer. In a few cases, to avoid data redundancy, an interpolation of data at municipality centroid level was preferred to zonal statistics over its entire territory. The various indicators were normalised and then summed to obtain the total atmospheric quality index.

Table 23: Air Quality Indicators (Copernicus Atmosphere Monitoring Service, 2021)

Type	Indicator	Units	Sources
Particulate Matter	PM10	$\mu g\ m^{-3}$	Heating, vehicles
	PM2.5	$\mu g\ m^{-3}$	Industry, fires
Gases	SO_2	$\mu g\ m^{-3}$	Fossil fuel
	CO	$\mu g\ m^{-3}$	Vehicles
	NO, NO_2	$\mu g\ m^{-3}$	Fossil fuel

8.3 WATER STATUS INDEX

WISE-Freshwater is an information platform by the European Environment Agency providing data on the state of Europe's rivers, lakes, and groundwater (European Environment Agency, 2024). It highlights the pressures affecting these water bodies and the measures taken to protect and conserve them. The platform offers insights into key challenges such as pollution, habitat degradation, and climate change impacts on freshwater resources. (Néry, 2023). Data on the status and quality of Italian waters is limited to surface waters, as the available data on groundwater is not continuous throughout the country. Although there are several gaps in certain territories regarding the condition of surface water bodies, it is possible to use the available data to assess the ecological and chemical status of principal rivers, lakes, and brackish water. Surface water bodies are categorized into five classes (high, good, moderate, poor, bad) or unknown.

Table 24: WISE Freshwater Indicators

Indicator	Type	Location	Class (1-6)
Ecological status	Structural/functional	Rivers, Lakes	1–6
Chemical status	Priority substances	Rivers, Lakes	1–6

The average value of the status of water bodies in the municipality, our spatial reference layer, is calculated for each of the two indicators using the most recent data (2022). Subsequently, they are normalised and then

summed to obtain the total water quality index. Some municipalities do not have any main water bodies and therefore the index could not be calculated (e.g. Tavoliere delle Puglie). Furthermore, as previously mentioned, the water status data is unknown for some territories. For these two reasons, the index is not calculated for all Italian municipalities.

8.4 URBAN WASTE INDEX

Municipal waste production and separate collection data aggregated at the municipal level were downloaded from the *Catasto Nazionale dei Rifiuti Urbani* (National Urban Waste Database), produced by the Italian Institute for Environmental Protection and Research (ISPRA, 2024). As the database is not spatial, the waste information had to be linked to the geographical information contained in the official ISTAT polygonal shapefile of Italian municipalities. As several municipalities have formed consortia for waste management and separate collection, all of these were aggregated to ensure continuous information throughout the country. Two indicators at the municipal level were produced from the available data of 2023:

- Sorted waste: Total_SW / Total_UW
- Waste per capita: Total_UW / Population

Where Total_SW is the total amount of waste sorted in a municipality and Total_UW is the total amount of urban waste produced. These indicators were then normalized and combined into an overall waste index.

8.5 ENVIRONMENTAL INDEX

The soil degradation, air quality, water status and municipal solid waste indices are first normalised and then combined into a cumulative index, known as the Environmental Index (EI).

$$EI = \frac{1}{n} \sum_{i=1}^{n} I_i \tag{29}$$

Where EI is the Environmental Index, n is the number of the single indices, and I_i is the normalised value for air, soil, water, and waste indices. For municipalities where the water status index is unknown, $n = 3$; for all others, $n = 4$.

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