A MULTI-COUNTRY PERFORMANCE ASSESSMENT OF HEALTH SYSTEMS IN ADDRESSING THE HEALTH AND ECONOMIC CONSEQUENCES OF COVID-19

Abstract

Objectives: This study aimed to assess performance health systems in the United Kingdom, France, Italy, Germany, and Spain in managing the health and economic consequences of the pandemic.

Setting: The analysis focused on quarterly data from the first quarter of 2020 to the fourth quarter of 2022 for the five selected European countries.

Methods: A panel dataset was constructed, and three regression models were employed: pooled OLS, panel fixed effects (FE), and panel FE with country dummy variables. The explained variable was a composite health system performance index, while explanatory variables included indicators of pandemic response effectiveness, health consequences, and economic consequences.

Results: The panel FE model revealed significant relationships between health system performance and various indicators, such as tests per confirmed case, fully vaccinated population, case fatality rate, ICU occupancy, unemployment rate, and consumer confidence index. Germany demonstrated the highest performance, followed by Italy, Spain, the UK, and France.

Conclusions: Effective pandemic management requires a comprehensive approach, combining public health measures with economic support policies. Testing efforts, vaccination campaigns, government measures, ICU capacity, social and economic security, and consumer confidence contribute to better health system responses. Cross-border cooperation and societal factors are also crucial for an effective response.

1. Introduction

The novel coronavirus disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has emerged as one of the most devastating global health crises in recent history [1]. The rapid and widespread global transmission of the COVID-19 virus has resulted in significant health and economic repercussions on an unparalleled scale, which has highlighted the crucial role of effective health systems in managing public health crises. Given the scarcity of data for certain countries and variations in reporting data methods, there is a need for improved comprehension of the ways to evaluate and compare the efficacy of national health systems in addressing the impacts of COVID-19 across different nations [2]. Developing a better understanding of these assessment methods can be invaluable for improving health systems, adopting best practices from countries that have successfully managed the pandemic, and ultimately serve as a foundation for developing effective policy implications and enhancing preparedness for future public health emergencies.

The severity of the impact caused by the Covid-19 pandemic varied significantly from one nation to another. The motivation for this study is to provide insights into the reasons for that and the factors contributing to greater health systems outcomes. The objective of this study is to conduct econometric analyses to assess relative performance in managing the health and economic consequences of the pandemic, specifically for health systems in the United Kingdom, France, Italy, Germany, and Spain based on the construction of a cross-country dataset from available sources.

2. Conceptual approach to analyzing health system performance during the COVID-19 pandemic

Various international organizations have differing perspectives on what constitutes a health system. The main point of contention is whether to include health promotion efforts and socio-economic factors that influence health outcomes within the scope of a health system definition. According to the World Health Organization (WHO), health systems encompass all organizations, institutions, and resources, related to service provision, financing, and stewardship, which are devoted to producing health actions [3]. This study will employ the WHO's approach to assessing health systems, taking into account the wide range of entities and activities that contribute to improving population health and considering the roles and responsibilities of various stakeholders and sectors in addressing the health and economic consequences of COVID-19.

Healthcare system performance indicators typically align with six primary domains: safety, effectiveness, efficiency, timeliness, patient-centeredness, and equity, as outlined by the Institute of Medicine (IOM) [4-5], and related to the three components of the healthcare system: structures, processes, and outcomes, following Donabedian's conceptual model [6-7]. Drawing upon the aforementioned sources and considering the need for internationally comparable indicators that capture the primary domains and components of healthcare systems, some metrics were selected as suitable measures for assessing health system performance during the COVID-19 pandemic.

Indicators for health system performance were divided into 3 groups: pandemic response effectiveness, addressing the health consequences of COVID-19, and addressing the economic consequences of COVID-19.

2.1 Pandemic response effectiveness indicators

COVID-19 testing level can indicate the ability of the healthcare system to detect and monitor the spread of the virus, which is crucial for controlling the pandemic. ***Tests per confirmed case*** was chosen as an indicator, which directly measures the extent of testing relative to the number of positive cases identified:

$$\boldsymbol{Tests\ per\ confirmed\ case} = \frac{\boldsymbol{Tests\ per\ confirmed\ case}}{\boldsymbol{Total\ number\ of\ confirmed\ COVID19\ cases}}$$

In contrast, metrics like total tests or tests per thousand population do not consider that. The chosen indicator gives a more direct sense of whether a country is conducting adequate testing to track the outbreak [8].

This indicator encompasses the domains of effectiveness (by identifying infected individuals and preventing further transmission), efficiency (by optimizing resource allocation for testing and contact tracing), and equity (by ensuring access to testing for all populations), while capturing the structural (testing facilities and resources) and process (testing protocols and contact tracing) components of the healthcare system.

Moreover, the speed and coverage of vaccination campaigns can reflect the efficiency and effectiveness of the healthcare system in protecting the population [9]. The indicator ***fully vaccinated population per 100*** represents the total number of people who have received all the doses prescribed by the initial vaccination protocol per 100 people in the total population and provides a standardized measure of the population's complete vaccination coverage. While other indicators like "total vaccinations" or "new vaccinations" don't differentiate between those who have only received one dose versus those who are fully vaccinated, chosen indicator standardizes this information per 100 people, allowing for easy comparisons between countries with different population sizes. A higher percentage suggests that a larger proportion of the population is well-protected against the virus, thus reducing the burden on the healthcare system.

This indicator encompasses the domains of safety (by ensuring the administration of safe and approved vaccines), effectiveness (by preventing infections, hospitalizations, and deaths), efficiency (by optimizing vaccine distribution and administration), timeliness (by rapidly vaccinating priority groups and the general population), and equity (by ensuring equal access to vaccines for all eligible individuals), while capturing the structural (vaccine supply and distribution systems), process (vaccination protocols and campaigns), and outcome (population immunity) components of the healthcare system.

However, vaccination campaigns can be greatly influenced by the policies adopted by governments. These policies may include prioritizing certain population groups, securing vaccine supply, and promoting vaccine uptake. The variation in vaccination policies and preferences across countries can lead to differences in the efficiency and effectiveness of their vaccination efforts. Therefore, the indicator ***government response stringency index*** was incorporated into the analyses. It is a composite measure that aggregates various policy responses to the COVID-19 pandemic, including not only vaccination policy but also containment and closure policies, economic policies, and health system policies, which could greatly affect the health system's performance [10]

Containment and closure policies can directly impact the health system's capacity to manage COVID-19 cases by reducing the spread of the virus and preventing a surge in hospitalizations. Economic policies, such as financial support for businesses and individuals, indirectly influence the health system's performance by mitigating the pandemic's negative impacts on livelihoods and mental health, which can reduce the long-term burden on the health system. Health system policies, such as investments in hospital capacity, workforce, and medical supplies, are directly linked to the health system's ability to respond effectively to COVID-19 cases and maintain its resilience.

2.2 Addressing the health consequences of COVID-19

The health repercussions of COVID-19 encompass a wide range of direct and indirect consequences, including increased morbidity and mortality from the virus itself, as well as the impact on non-COVID-19 health outcomes due to disruptions in healthcare services, delayed diagnoses, and deferred treatments for chronic conditions. Additionally, the pandemic has led to a surge in mental health issues, such as anxiety, depression, and stress-related disorders, arising from social isolation, economic hardships, and the overall psychological toll of the crisis [11-12].

Excess mortality is considered a more comprehensive and objective measure of the pandemic's impact compared to official COVID-19 death counts. Public health authorities may overcount COVID-19 deaths by including people who died from other causes shortly after a positive test. However, undercounting is more common, as many COVID-19 deaths are missed due to lack of testing before the person succumbed to the disease [13]. Excess mortality is defined as the difference between the observed number of deaths and the expected number based on historical data. Therefore, it estimates the additional deaths, surpassing the limitations of relying solely on confirmed COVID-19 fatalities and capturing deaths directly attributed to COVID-19 that were not accurately diagnosed or reported, as well as indirect deaths resulting from the broader societal and healthcare disruptions caused by the pandemic crisis [14-15].

Excess mortality is represented in ***P-scores for all ages***. The P-score is the percentage difference between the reported number of deaths and the projected number of deaths for the same period based on previous years. P-scores are standardized, allowing for cross-country comparisons of excess mortality during the pandemic [16]:

$$\boldsymbol{P-score} = \frac{\boldsymbol{Reported\ Deaths - Projected\ Deaths}}{\boldsymbol{Projected\ Deaths}} * \mathbf{100}\%$$

The excess mortality indicator captures the domains of effectiveness (preventing and managing COVID-19 cases, maintaining essential health services), equity (revealing disparities in healthcare access and outcomes), and safety (accounting for deaths caused by unsafe practices or lack of appropriate care), as well as the outcome (quantifying the impact of the pandemic on population health) and process (the ability to accurately diagnose, report, and manage COVID-19 cases) components of the healthcare system.

However, the concept of excess mortality may have some limitations as the accuracy of excess mortality figures can be compromised by delays in reporting deaths, lack of adherence to established reporting guidelines, and variations in reporting practices across different geographical areas.

In order to assess the impact and severity of COVID-19 cases this study employs ***case fatality rate (CFR)***. CFR is the ratio of confirmed deaths attributed to COVID-19 to the total number of confirmed cases:

$$\boldsymbol{CFR = \frac{Number\ of\ confirmed\ COVID-19\ deaths}{Number\ of\ COVID-19\ cases} * 100\%}$$

CFR captures the domains of effectiveness (assessing the lethality of the virus and the effectiveness of clinical management strategies), safety and the outcome component of the healthcare system. The monitoring the CFR over time can provide valuable insights into the evolving health consequences of COVID-19. However, it can be influenced by factors such as age distribution, healthcare quality, and case detection rates, and may be overestimated if mild cases are underreported or underestimated if there is a lag between case confirmation and death [17].

The infection fatality rate (IFR) was also considered for analyses. IFR is the ratio of deaths attributed to COVID-19 to the total number of infected individuals, including both confirmed and undetected cases [18]. It provides a more accurate estimate of the virus's lethality but is more difficult to calculate, as it requires estimating the total number of infections through methods like seroprevalence studies, and for this reason, it wasn't exploited in this study.

Intensive care unit (ICU) bed occupancy per million was chosen as the third indicator to estimate health repercussions. It represents the number of COVID-19 patients in ICUs on a given day per million people and provides a snapshot of the current burden on the healthcare system, specifically intensive care units, relative to the population size. It helps to understand the capacity of the healthcare system to handle severe cases and meet the demand for critical care [19-20]. This indicator encompasses the domains of safety (by ensuring adequate resources to provide safe and effective critical care), effectiveness (by managing severe cases and reducing mortality), efficiency (by optimizing ICU bed allocation and resource management), and patient-centeredness (by providing timely and appropriate care to critically ill patients), while capturing the structural (ICU bed capacity and staffing) and process (triage and admission protocols) components of the healthcare system.

2.3 Addressing the economic consequences of COVID-19

The economic consequences of COVID-19 are far-reaching and multifaceted, affecting various sectors and aspects of the economy. The pandemic has led to significant disruptions in global trade, supply chains, and consumer behavior, resulting in reduced economic activity, job losses, and financial instability [21]. The immediate economic repercussions include a sharp decline in GDP growth, increased unemployment, and sectoral impacts on industries such as tourism, hospitality, and aviation. The pandemic has also exacerbated pre-existing economic inequalities, disproportionately affecting vulnerable populations and small businesses [22].

It is important to note that the economic consequences of the COVID-19 pandemic can indirectly impact the healthcare system. For example, a severe economic slowdown or recession may lead to reduced government revenue and healthcare spending (e.g., funding for healthcare facilities and resources) and processes (e.g., the ability to provide timely and effective care). Additionally, economic hardship may also influence population health outcomes, as individuals may face challenges in accessing healthcare services or maintaining healthy lifestyles.

The ***GDP growth rate*** was chosen as the primary measure for assessing the economic consequences of COVID-19 in this analysis. It measures the change in the GDP of the country in comparison to an earlier period (in percentages):

$$\boldsymbol{GDP\ Growth\ Rate} = \left(\frac{\boldsymbol{Ending\ Value}}{\boldsymbol{Beginning\ Value}} - \mathbf{1} \right) \times \mathbf{100}\%$$

GDP represents the total value of all goods and services produced within a country's borders during a specific period. It is a widely used and standardized measure, enabling easy comparison of economic performance across different countries. While GDP can be measured in various ways, such as GDP per capita, nominal GDP, real GDP, and change in GDP [23], the GDP growth rate's main advantage is that it provides a more interpretable measure of economic growth and clearly shows whether the total economic output is accelerating or decelerating. However, the GDP growth rate has limitations. It does not account for income distribution or social welfare, potentially not fully reflecting the economic well-being of all individuals in a society. Furthermore, it does not capture the specific sectoral impacts of the pandemic, such as the disproportionate effects on certain industries [24-26].

The ***unemployment rate*** is a crucial indicator because it directly captures the impact of the pandemic on the labor market. COVID-19 has led to widespread job losses due to lockdowns, reduced economic activity, and changes in consumer behavior. Many businesses have been forced to lay off workers or reduce their hours [27]. Moreover, high unemployment can have long-lasting effects on the economy, as it reduces consumer spending and can lead to a slower recovery. Nevertheless, it may not fully capture individuals who are underemployed, not officially employed or working part-time involuntarily and underestimate the true extent of labor market distress.

The unemployment rate can affect the health system in several ways. Unemployment can lead to loss of employer-sponsored health insurance, increasing the burden on public health systems; may strain healthcare resources, as more people rely on public health services and emergency care. Also, financial stress and reduced access to healthcare due to unemployment can negatively impact mental and physical health outcomes.

The consumer confidence index *(**CCI**)* is another indicator to consider, it measures the overall sentiment of consumers towards the economy and their personal financial situation, capturing also psychological and emotional dimensions. During the pandemic, consumer confidence has been heavily impacted by factors such as job security concerns, health risks, and uncertainty about the future. The CCI captures these sentiments and can provide valuable insights into consumer spending patterns, which are a key driver of economic growth. When consumer confidence is low, people are more likely to save money and reduce their spending, which can further slowdown the economy. On the other hand, when consumer confidence improves, it can indicate that people are more willing to spend, leading to increased economic activity and a faster recovery.

When comparing the CCI to the inflation rate and the consumer price index (CPI) as indicators, the CCI emerges as a more suitable choice. Inflation and CPI are lagging indicators, reflecting changes in economic conditions with a delay, while the CCI is a more forward-looking and responsive indicator that captures consumer sentiment in real-time [28]. However, it is important to note that the independent information provided by the CCI may predict a relatively modest amount of additional variation in future consumer spending [29].

2.4 Evaluating the quality of selected indicators

Bojke et al. identified the key criteria that an exemplary performance indicator should possess to be considered for inclusion in a measure of health output [30]. The adequacy of the chosen indicators for analysis according to these criteria can be found in *Table 1*. After careful consideration, it was determined that all the selected indicators met Bojke criteria satisfactorily.

Table 1. Quality Criteria of Key Performance Indicators

Indicator	Clarity	Validity	Measurability	Consistency	Attribution	Data Availability
Tests per Confirmed Case	Specific. Unidirectional. Clearly defined as the number of tests conducted per new confirmed case of COVID-19.	Measures the testing capacity and effectiveness in identifying COVID-19 cases. Discriminates between higher and lower testing rates relative to confirmed cases.	Quantifiable. Has a clear unit enabling tracking over time and cross-country comparisons of testing capacity and effectiveness.	Repeatable across time periods if COVID-19 testing and reporting standards are maintained.	Attributable to government interventions and healthcare system policies aimed at increasing testing capacity and accessibility.	Available from multiple sources
Fully Vaccinated Population per 100	Specific. Unidirectional. Clearly defined as the total number of people who received all doses prescribed by the initial vaccination protocol per 100 people in the total population	Measures the proportion of the population that is fully vaccinated, indicating the level of protection against COVID-19. Discriminates between higher and lower vaccination coverage.	Quantifiable. Has a clear unit (enabling tracking over time and cross-country comparisons of vaccination progress and coverage.	Repeatable across time periods if vaccination reporting standards are maintained.	Largely attributable to government policies, healthcare system capacity, and public health efforts aimed at increasing vaccine availability, accessibility, and uptake.	Available from multiple sources
Government Response Stringency Index	Specific. Clearly defined as composite index based on 24 policy indicators including containment and closure, economic, health system and vaccination policies	Measures the overall stringency of government responses to the COVID-19 pandemic across various policy dimensions. Discriminates between more and less stringent responses.	Quantifiable. Has a clear scale, enabling tracking over time and cross-country comparison. However, it does not directly measure the effectiveness of policies, is complex to calculate and interpret.	Repeatable across time periods if the methodology for calculating the index remains consistent.	Directly attributable to government policies and action. However, does not capture the implementation or enforcement of these policies	Available

Indicator	Clarity	Validity	Measurability	Consistency	Attribution	Data Availability
Excess Mortality (in P-scores)	Specific. Unidirectional. Clearly defined as the percentage difference between reported and estimated deaths during a specific period, compared to the expected number of deaths had COVID-19 not occurred.	Measures the overall impact of the pandemic on mortality, capturing both direct and indirect deaths. Discriminates between higher and lower mortality consequences.	Quantifiable. Has a clear unit, enabling tracking over time and cross-country comparisons of the pandemic's mortality impact. However, the calculation relies on the accuracy of reported deaths and the estimation of expected deaths	Repeatable across time periods if COVID-19 death reporting standards are maintained.	Partially attributable to government interventions aimed at curbing viral transmission, healthcare system capacity and population demographics.	Available from multiple sources
Case Fatality Rate (CFR)	Specific. Unidirectional. Clearly defined as the ratio of the number of deaths attributed to COVID-19 to the total number of confirmed COVID-19 cases, expressed as a percentage.	Measures the proportion of confirmed COVID-19 cases that result in death, indicating disease severity. Discriminates between higher and lower fatality rates.	Quantifiable. Has a clear unit, enabling tracking over time and cross-country comparisons. However, the accuracy of the CFR depends on the completeness and reliability of case and death reporting.	Repeatable across time periods if COVID-19 death reporting standards are maintained.	Influenced by various factors such as health policies, healthcare resources, and population health characteristics.	Available from multiple sources
ICU Occupancy per million	Specific. Unidirectional. Clearly defined as the number of COVID-19 patients in intensive care units (ICUs) on a given day per million people in the population.	Measures the severity of COVID-19 cases and the burden on healthcare systems. Discriminates between higher and lower occupancy rates, indicating the strain on critical care resources.	Quantifiable. Has a clear unit, enabling tracking over time and cross-country comparisons of the pandemic's impact on critical care services. However, the accuracy depends on the reliability of hospital reporting.	Repeatable across time periods if COVID-19 hospitalization and ICU reporting standards remain consistent.	Influenced by various factors such as government policies, healthcare system capacity, population demographics	Available

Indicator	Clarity	Validity	Measurability	Consistency	Attribution	Data Availability
GDP Growth Rate	Specific. Unidirectional. Clearly defined as the percentage change in a country's Gross Domestic Product (GDP) from one period to another.	Measures the overall economic performance and growth, capturing the pandemic's impact on the economy. Discriminates between periods of economic expansion and contraction.	Quantifiable. Growth rate based on seasonally adjusted volume data, percentage change on the previous quarter. Has a clear unit, enabling tracking over time and cross-country comparisons	Consistently repeatable over time.	Influenced by government policies, external factors like the pandemic, geopolitical events, and global trade.	Widely available from multiple sources
Unemployment Rate	Specific. Unidirectional. Clearly defined as the percentage of the total labor force that is unemployed but actively seeking employment and willing to work.	Measures the pandemic's impact on the workforce and job losses. Discriminates between higher and lower levels of unemployment.	Quantifiable. Has a clear unit (percentage), enabling tracking over time and cross-country comparisons of labor market conditions.	Consistently repeatable over time.	Affected by government policies, employer decisions, and overall economic circumstances.	Widely available from multiple sources
Consumer Confidence Index	Specific. Unidirectional. Clearly defined as a measure of the degree of optimism that consumers have about the overall state of the economy and their personal financial situation, based on survey responses.	Measures consumer perceptions and spending intentions, reflecting the pandemic's impact on consumer confidence. Discriminates between higher and lower levels of consumer confidence.	Quantifiable. Has a clear scale, enabling tracking over time and cross-country comparisons of consumer confidence levels. However, the accuracy may be affected by the design and representativeness of the survey sample.	Consistently repeated over time using the same survey methodology.	Influenced by various factors, including government policies, media coverage, and personal experiences.	Available from multiple sources

3. Data and Methods

The study utilized a panel dataset consisting of quarterly data from the first quarter of 2020 to the fourth quarter of 2022 for five countries: the UK, France, Italy, Germany, and Spain. The dataset included 9 variables, most of which are time-variant and significantly influenced by temporal changes, making panel data an appropriate choice for analysis. There are no missing observations in the dataset.

The selection of countries to compare was based on their healthcare system similarity, similar approaches to COVID-19 policy, access to the same vaccines approved by the European Medicines Agency (EMA), comparable GDP (therefore, comparable financial resources available to invest in pandemic management), and similar socio-demographic factors, such as population size (countries with similar population sizes may face comparable challenges in terms of healthcare system capacity and resource allocation), age distribution (older people are at a higher risk of severe illness and mortality from COVID-19), and urbanization rates (which can influence the spread of the pandemic and the effectiveness of public health measures). Geographic proximity was also taken into consideration, as neighboring countries may have similar cultural, social, and economic ties, which can influence their approach to pandemic management. Further details on the selection criteria can be found in *Appendix A*.

3.1 The explained variable

The explained variable is the Health System Performance Index - a composite index that comprises aggregated excess mortality and GDP growth rate indicators. This index aims to measure the performance of health systems in managing the health and economic consequences of the pandemic.

A composite index was preferred over multivariate multiple regression due to the weak linear relationship between excess mortality and GDP growth rate (r = -0,148). To construct the index, min-max normalization was employed to scale both variables to a common range between 0 and 1, preserving their relative distribution:

$$\boldsymbol{GDP_{norm} = (GDP - GDP_{\min}) / (GDP_{max} - GDP_{\min})}$$

$$\boldsymbol{EM_{norm} = (EM - EM_{\min}) / (EM_{max} - EM_{\min})}$$

Since excess mortality is a negative indicator (higher values indicate worse performance), while GDP growth rate is positive, normalized EM variable was inverted:

$$\boldsymbol{EM_{inv} = 1 - EM_{norm}}$$

Assuming equal importance of addressing the health and economic consequences in determining overall health system performance, equal weights were assigned to the normalized variables using the equal weights method:

$$\boldsymbol{HS = \frac{(EM_{inv} + GDP_{norm})}{2}}$$

The resulting HS index ranges from 0 to 1 with a mean of 0.703, and higher values indicate better overall health system performance. The kernel density plot follows the normal density curve quite closely, suggesting that the distribution of HS is approximately symmetric and close to normal, with no major deviations (fig. 1).

Data on excess mortality was obtained from Our World in Data [31], while GDP growth rate is sourced from the Organisation for Economic Cooperation and Development (OECD) Data [32].

3.2 The Explanatory and Controlled variables

The explanatory variables comprise indicators of pandemic response effectiveness by health systems (tests per confirmed case and fully vaccinated population per 100), indicators of addressing health consequences (CFR and ICU occupancy per million), and indicators of addressing economic consequences of COVID-19 (unemployment rate and CCI). Data on tests per confirmed case, fully vaccinated population per 100, CFR, and ICU occupancy per million were sourced from Our World in Data, while unemployment rate and CCI were acquired from OECD Data [33-34].

Including government response stringency index as the controlled variable allow account for the potential effects of government interventions on the health system performance, while assessing the impact of the explanatory variables. This data was obtained from the Oxford COVID-19 Government Response Tracker [35]. Data sources for all variables are summarized in *Table 2*.

The high standard deviation of 57.73 for tests per confirmed case compared to its mean of 35.31 suggests a wide dispersion in testing rates for the given period 2020-2022. A similar trend is observed for the fully vaccinated population, CFR, and ICU occupancy, indicating substantial variability across the panel. In contrast, the unemployment rate and CCI have lower standard deviations of 2.13 and 2.39, respectively, indicating more consistent economic impacts (*Table 3*).

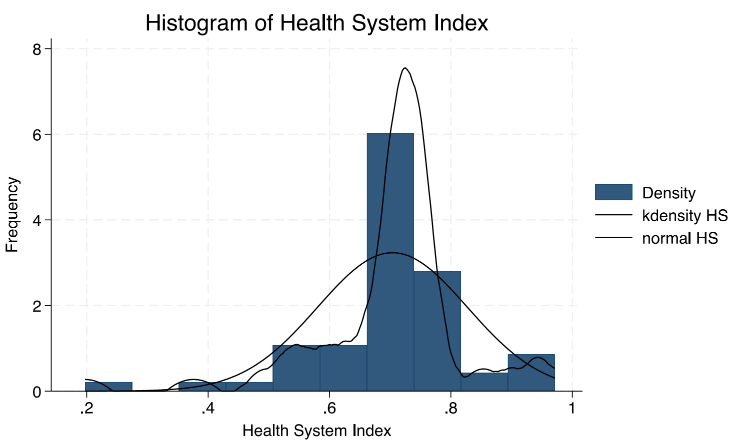

Figure 1. Histogram of Health System Index.

Table 2. Data Sources of the Variables

Variable	Data Sources	Unit
Tests per confirmed case	Our World in Data	Number
Fully Vaccinated Population per 100	Our World in Data	Number
Government Response Stringency Index	Oxford COVID-19 Government Response Tracker	Scale ranging from 0 to 100, where 100 is the strictest response
Excess Mortality	Our World in Data	Percentages (%)
Case Fatality Rate (CFR)	Our World in Data	Percentages (%)
ICU Occupancy per million	Our World in Data	Number
GDP Growth Rate	Organisation for Economic Cooperation and Development (OECD) Data	Percentages (%)
Unemployment Rate	OECD Data	Percentages (%)
Consumer Confidence Index (CCI)	OECD Data	Scale with a baseline value of 100 (above 100 – optimistic outlook, below 100 - negative)

Table 3. Summary Statistics of the Variables

Variables	Mean	Standard Deviation
Health System Performance Index (a)	0.703	0.12337
Tests per confirmed case	35.308	57.72612
Fully Vaccinated Population per 100	41.861	36.41589
ICU occupancy per million	21.835	21.84034
Case Fatality Rate (CFR), %	0.960	0. 84305
Unemployment Rate, %	7.768	2.12916
Consumer Confidence Index (CCI) (b)	98.792	2.39360
Government Stringency Index (c)	51.387	21.87122

Notes:
(a) The Health System Performance Index is unitless and ranges from 0 to 1, with higher values indicating better overall health system performance.
(b) The Consumer Confidence Index has a baseline value of 100. Values above 100 indicate an optimistic outlook, while values below 100 suggest a negative outlook.
(c) The Government Response Stringency Index ranges from 0 to 100, with higher values indicating more stringent government responses to the COVID-19 pandemic.

3.3 Methods

To identify the factors contributing to better health system performance in managing the health and economic consequences of COVID-19, three regression models were employed: a pooled OLS, a panel fixed effects (FE) model, and a panel FE model with country dummy variables.

The pooled OLS model assumes that the relationship between the explanatory variables and the HS Index is constant across countries and time and specified as [36]:

$$\boldsymbol{HS_{i,t} = \beta_0 + \beta_1 * tests_{i,t} + \beta_2 * fulvac_{i,t} + \beta_3 * CFR_{i,t} + \beta_4 * ICU_{i,t} + \beta_5 * unempl_{i,t} + \beta_6 * CCI_{i,t} + \beta_7 * govresp_{i,t} + \varepsilon_{i,t}}$$

Where i = 1-5, t = 1-12, β_0 is the intercept, β_1 to β_7 are the estimated coefficients for the explanatory variables, $HS_{i,t}$ is the Health System Performance Index for country i at quarter t, $\varepsilon_{i,t}$ is the error term.

However, the assumed homogeneity across countries and time periods may not be realistic given the diverse responses to the pandemic. Other limitations of this model include failure to account for unobserved country-specific factors and the potential violation of the independent and identically distributed (i.i.d.) error terms assumption.

Therefore, the panel FE model, which accounts for unobserved country-specific time-invariant heterogeneity such as cultural norms, historical events, and inherent response behaviors by allowing for country-specific intercepts and time-specific effects, was applied [36]:

$$\boldsymbol{HS_{i,t} = \alpha_{i,t} + \theta_t + \beta_1 * tests_{i,t} + \beta_2 * fulvac_{i,t} + \beta_3 * CFR_{i,t} + \beta_4 * ICU_{i,t} + \beta_5 * unempl_{i,t} + \beta_6 * CCI_{i,t} + \beta_7 * govresp_{i,t} + \varepsilon_{i,t}}$$

Where i = 1-5, t = 1-12, $\alpha_{i,t}$ – the country fixed effect, θ_t – the quarter fixed effect.

However, this model may still be limited by the assumption that the effects of the explanatory variables are constant across countries. To confirm that the FE model is indeed the most suitable choice for this study, a Hausman test will be conducted.

To further investigate each country's performance, the third model incorporates country dummy variables $\boldsymbol{country_{j,i}}$ alongside the explanatory variables [36]. This approach allows for the identification of countries that have performed exceptionally well or poorly in managing the pandemic's consequences, after controlling for the other factors:

$$\boldsymbol{HS_{i,t} = \beta_0 + \sum_{j=1}^{N} \gamma_j * country_{j,i} + \beta_1 * tests_{i,t} + \beta_2 * fulvac_{i,t} + \beta_3 * CFR_{i,t} + \beta_4 * ICU_{i,t} + \beta_5 * unempl_{i,t} + \beta_6 * CCI_{i,t} + \beta_7 * govresp_{i,t} + \varepsilon_{i,t}}$$

Where i = 1-5, t = 1-12, N = 5, and γ_j is the country-specific intercept for the jth country. However, this model may be limited by the potential multicollinearity among the dummy variables and the reduced degrees of freedom.

All three models will be diagnosed for normality and homoscedasticity of residuals, and multicollinearity of predictors to ensure the validity of the results.

4. Results

The results of a pooled OLS model, a panel fixed effects (FE) model, and a panel FE model with country dummy variables are presented in *Table 4*.

The pooled OLS model revealed positive and significant relationships between the health system performance index and tests per confirmed case, fully vaccinated population per 100 and consumer confidence index. A one-unit increase in the consumer confidence index, the most significant variable, is associated with a 0.0202 increase in the health system performance index, holding other variables constant. Conversely, the model showed negative and significant relationships between the health system performance index and CFR, ICU occupancy per million and unemployment rate. The government stringency Index does not show a statistically significant relationship with the performance index. The Breusch-Pagan test yielded a chi-square value of 9.52 with a p-value of 0.0020, indicating the presence of heteroskedasticity in the model. After adding robust standard errors to account for heteroskedasticity, the coefficients remained unchanged, maintaining their signs and significance levels.

The Q-Q plot reveals some deviations from the diagonal line, suggesting potential non-normality of the residuals. Moreover, the residual vs. fitted plot exhibits a non-random pattern, further confirming the presence of heteroskedasticity (*Appendix B*). Lastly, the variance inflation factors (VIF) for the explanatory variables range from 1.06 to 4.52, with a mean of 2.38, indicating that multicollinearity is not a severe concern in the model.

In the panel FE model the coefficients for fully vaccinated population per 100, ICU occupancy per million, and unemployment rate increase in magnitude and statistical significance. For instance, a one-unit increase in the fully vaccinated population per 100 is now associated with a 0.00127 increase in the performance index, significant at the 1% level, compared to a 0.000318 increase in the pooled OLS model. Similarly, the coefficient for unemployment rate increases from -0.00247 in the pooled OLS model to -0.0942 in the FE model, both significant at the 1% level. Moreover, the government stringency index becomes positive and significant at the 5% level. The relationships between the performance index and tests per confirmed case, CFR, and consumer confidence index remain significant but with slightly different magnitudes.

The Hausman test yielded a chi-squared value of 18.62 with a p-value of 0.0095, suggesting that the FE model is more suitable than the RE model, as the p-value is less than the conventional significance level of 0.05. This result confirms the initial assumption that the FE model would be more appropriate.

The diagnostic tests suggest that the residuals are approximately normally distributed. The Q-Q plot and the P-P plot show only slight deviations from the diagonal line, and the histogram of residuals exhibits a relatively symmetric distribution (*Appendix C*). Furthermore, the Shapiro-Wilk test for normality yields a p-value of 0.06826, which is above the conventional significance level of 0.05, indicating that we cannot reject the null hypothesis of normally distributed residuals. The Modified Wald test for groupwise heteroskedasticity suggests the presence of heteroskedasticity. The test result shows a chi-squared value of 19.45 with 5 degrees of freedom and a p-value of 0.0016. Therefore, the FE model with robust standard errors is employed. This model shows that the coefficients remain significant, and their magnitudes are similar to those in the FE model without robust standard errors.

Table 4. Coefficients of a pooled OLS, a panel fixed effects (FE) model, and a panel FE model with country dummy variables.

Variables	**Pooled OLS model**		**Panel fixed effects (FE) model**		
		Robust		**Robust**	**Country dummies**
Tests per confirmed case	0.000874** (0.00035)	0.000874** (0.00032)	0.000828** (0.00031)	0.000828*** (0.00011)	0.00102*** (0.00021)
Fully vaccinated population per 100	0.000318** (0.00072)	0.000318** (0.00081)	0.00127*** (0.000772)	0.00127*** (0.000692)	0.00996*** (0.00021)
Case Fatality Rate (CFR)	-0.0227** (0.00215)	-0.0227** (0.00232)	-0.0146** (0.00195)	-0.0146** (0.00240)	-0.00354** (0.00052)
ICU occupancy per million	-0.00374*** (0.00951)	-0.00374*** (0.00116)	-0.00417*** (0.00095)	-0.00417*** (0.00083)	-0.00237*** (0.00001)
Unemployment Rate	-0.00247** (0.00366)	-0.00247** (0.00399)	-0.09420*** (0.00245)	-0.0942*** (0.00226)	-0.0253*** (0.00173)
Consumer Confidence Index	0.0202** (0.00863)	0.0202** (0.00869)	0.00893** (0.00840)	0.00893*** (0.00188)	0.0330*** (0.00169)
Government Stringency Index	-8.07e-05 (0.00140)	-8.07e-05 (0.00135)	0.00108** (0.00148)	0.00108** (0.00101)	-0.0023** (0.00067)
Constant	-1.207 (0.805)	-1.207 (0.802)	-0.913** (0.745)	-0.913** (0.292)	-4.324*** (0.210)
Observations	60	60	60	60	60
R-squared	0.292	0.292	0.483	0.483	0.936

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The coefficients for the main explanatory variables in the model with country dummies and interaction terms represent the effects for the reference country (country_dummy1 – France). The direction and significance of the effects are generally the same as in the panel FE model, but the government stringency index has a negative and significant coefficient, which is different from the panel fixed effects model. The most significant coefficient among the main explanatory variables is for the fully vaccinated population per 100, with a value of 0.00996, indicating that a one-unit increase in the fully vaccinated population per 100 is associated with a 0.00996 unit increase in the health system performance index for the reference country.

Country dummy variables coefficients show that country 4 (Germany) has the best performance compared to the reference country (France), with a coefficient of 4.833, followed by country 2 (Italy) 4.254, country 5 (Spain) 4.118, and country 3 (the UK) 3.210. Among the interaction terms coefficients, some unusual trends can be observed. For example, the interaction term between CFR and country 3 (the UK) int_CFR_3 has a large negative coefficient of -0.117, indicating that the negative effect of CFR on the performance index is much stronger in the UK compared to France. Similarly, the interaction term between unemployment rate and country 4 (Germany) int_unempl_4 has a large negative coefficient of -0.149, suggesting that the negative impact of unemployment on the performance index is more pronounced. All coefficients for this model can be found in *Appendix C*.

In terms of the performance of each country Germany (country 4) has the highest performance index relative to France, but it is more negatively affected by unemployment and CFR. Italy (country 2) has the second-highest performance index and is positively influenced by tests per confirmed case and CCI. Spain (country 5) has the third-highest performance index and is more positively affected by tests per confirmed case, fully vaccinated population, and government stringency index compared to France. The UK (country 3) is more negatively impacted by CFR and unemployment rate. Compared to other countries, France (the reference country) had the lowest performance index, indicating that it faced significant challenges in managing the health and economic consequences of the COVID-19 pandemic. France's performance was negatively affected by factors such as high CFR, ICU occupancy, and unemployment rates.

The FE model with country dummy variables further improves the model's explanatory power, with an R-squared value of 0.936, compared to 0.292 in the pooled OLS model and 0.483 in the basic FE model.

The Q-Q plot and the P-P plot show that the residuals are approximately normally distributed, with only minor deviations from the diagonal line. The residual vs. fitted plot exhibits a more random pattern compared to the previous models, suggesting that the inclusion of country dummy variables and interaction terms has helped to capture some of the heterogeneity in the data. However, there is still some evidence of heteroskedasticity (*Appendix D*). Additionally, several variables, such as the unemployment rate, government stringency index, and CCI, have VIF values above 10, indicating strong multicollinearity. The mean VIF of 37.87 is extremely high, suggesting that multicollinearity is a severe issue in this model.

While this model provides a more comprehensive understanding of the country-specific effects and heterogeneity in the relationships between the explanatory variables and HS index, the high degree of multicollinearity raises concerns about the reliability of the coefficient estimates. Therefore, the basic FE model, which still accounts for unobserved time-invariant heterogeneity across countries is selected as the final model.

5. Critical Discussion and Conclusion

This study aimed to assess the performance of health systems in the United Kingdom, France, Italy, Germany, and Spain in managing the health and economic consequences of the COVID-19 pandemic. Pooled OLS, panel data with fixed effects, and panel data with country dummies were employed to analyze the factors influencing health system performance.

All three models found positive and statistically significant correlations between tests per confirmed case, fully vaccinated population per 100, and consumer confidence index and health system performance, while case fatality rate, ICU occupancy per million, and unemployment rate demonstrated negative and significant relationships. The results for the government stringency index varied across the models, with the preferred fixed effects panel model showing a positive and significant relationship with health system performance.

The findings are consistent with previous research. Baum et al. showed that GDP, government measures, and ICU occupancy affect the success of national responses to COVID-19 and pandemic preparedness [37]. Moolla and Hiilamo found that CFR is systematically negatively associated with health system performance, while vaccination has a positive effect [38].

The panel data model with country dummies evaluated Germany as having the highest performance, possibly due to its higher GDP and resources compared to the other analyzed countries. Italy ranked second, likely due to having a lower urbanization rate. Spain and the UK followed, with France demonstrating the lowest performance index, indicating significant challenges in managing the health and economic consequences of the pandemic. Although the country dummy model may be biased due to multicollinearity, the results align with Jamison et al. [39], who evaluated 35 countries based on the doubling time of cases and deaths. Their ranking differed only slightly, with Italy showing better performance than Germany.

In conclusion, effective pandemic management requires a comprehensive and coordinated approach, combining public health measures with economic support policies. Testing efforts, vaccination campaigns, and government measures, along with sufficient ICU capacity, social and economic security, and high levels of consumer confidence, contribute to better health system responses. Consumer confidence serves as an indicator of the population's trust in the government's handling of the pandemic and the overall economic situation, which can influence the effectiveness of public health measures and the resilience of the healthcare system. The need for cross-border cooperation is evident, as an effective response relies also on societal factors.

The study has several limitations. Different countries may have varying reporting practices, case definitions, and testing strategies, which can affect the comparability of data across countries. The data used in this study may be subject to inaccuracies or inconsistencies, such as delays in reporting, misclassification of cases, or data entry errors. The study creates an aggregated health system performance index that assumes equal importance of health and economic consequences, but the relative importance of these factors may vary across countries and stakeholders. The study focuses on only five European countries, which may not be representative of the diverse health systems and pandemic responses worldwide. The study covers a relatively short time frame, which may not capture the long-term impacts of the pandemic on health systems and economies. While the study includes several key indicators, it may not capture the full complexity and multidimensional nature of health system performance during a pandemic. The study does not fully address potential endogeneity issues or confounding factors that may influence the relationship between the explanatory variables and health system performance. Acknowledging these limitations is important for interpreting the study's findings and understanding the constraints and uncertainties associated with the analysis.

The findings of this study serve as a foundation for further research and a call to action for policymakers and health system stakeholders to prioritize investments in pandemic preparedness and response capabilities. Based on the limitations discussed, future research could expand the scope of the study to include a more diverse set of countries and collaborate with international organizations to develop standardized reporting guidelines, enhancing the generalizability and reliability of the findings. Exploring alternative weighting schemes for the health system performance index and extending the time frame of the analysis would capture the long-term impacts and different priorities of stakeholders. Incorporating a broader set of indicators, such as public trust, mental health, and social inequalities, would provide a more comprehensive assessment of health system performance. Employing advanced statistical techniques to address endogeneity and confounding factors would help establish more robust estimates. By addressing these limitations and incorporating these improvements, future research can provide a more comprehensive and reliable assessment of health system performance during the COVID-19 pandemic and beyond.

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Appendix A. Comparative Overview of Demographic, Economic, and Health System Characteristics of Selected European Countries in 2020

Table 1. Key characteristics of selected European countries in 2020

Characteristic	France	Italy	United Kingdom	Germany	Spain
Health system type	Universal, government-led (National Health Insurance)	Universal, government-led (National Health Service)	Universal, government-led (National Health Service)	Universal, multi-payer (public and private)	Universal, government-led (National Health System)
GDP millions $[1]	2,647.42	1,897.46	2,697.81	3,887.73	1,278.13
Population size, million[2]	67.57	59.44	67.08	83.16	47.36
Share of population aged 65+, %[3]	21	23	19	22	20
Urbanization rate, %[4]	80.97	71.04	83.90	77.45	80.81

[1] GDP (current US$). The World Bank
[2] Population, total. The World Bank
[3] Population ages 65 and above (% of total population). The World Bank
[4] Urban population (% of total population). The World Bank

Appendix B. Diagnostic Plots for the Pooled OLS Model

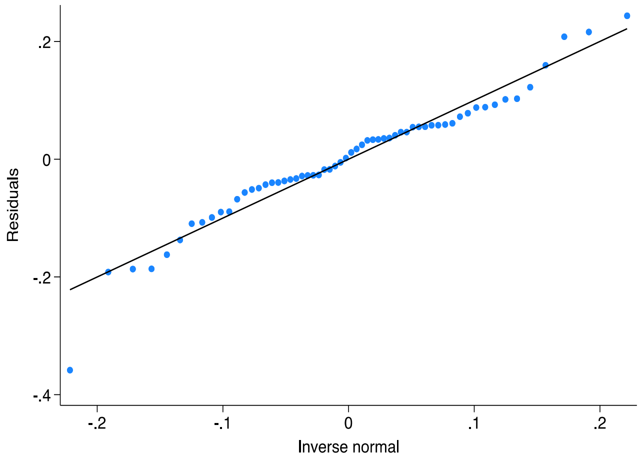

Figure B1. Quantile-Normal (Q-Q) Plot of Residuals for pooled OLS model.

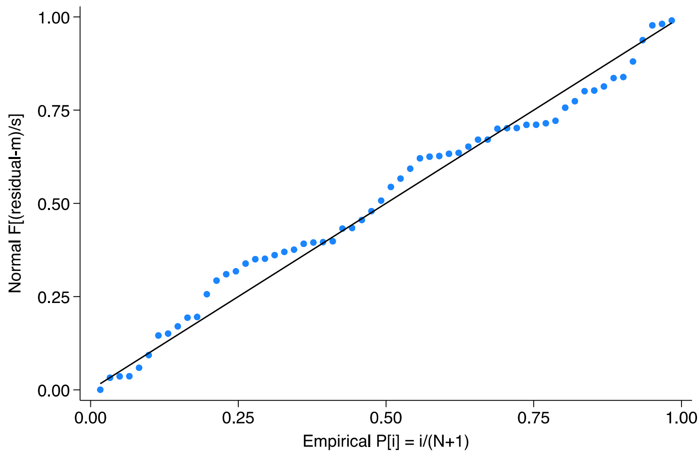

Figure B2. Probability-Probability (P-P) Plot of Residuals for pooled OLS model.

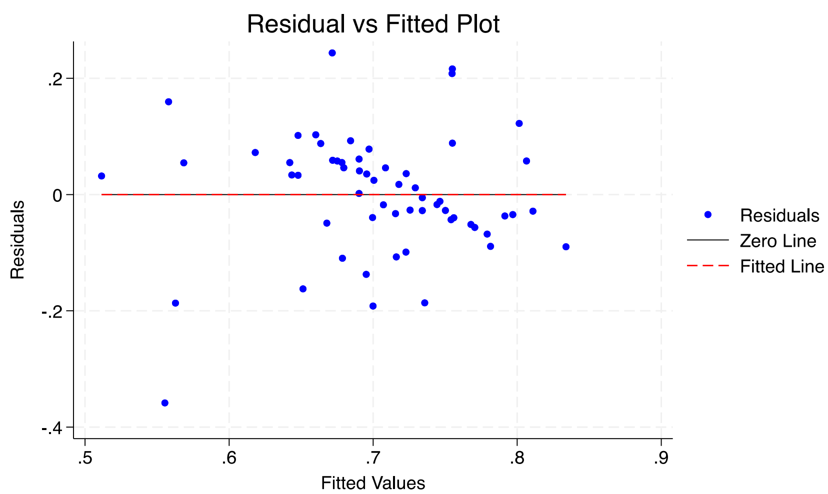

Figure B3. Residual vs. Fitted Plot for pooled OLS model.

Appendix C. Diagnostic Plots for the Panel Fixed Effects Model

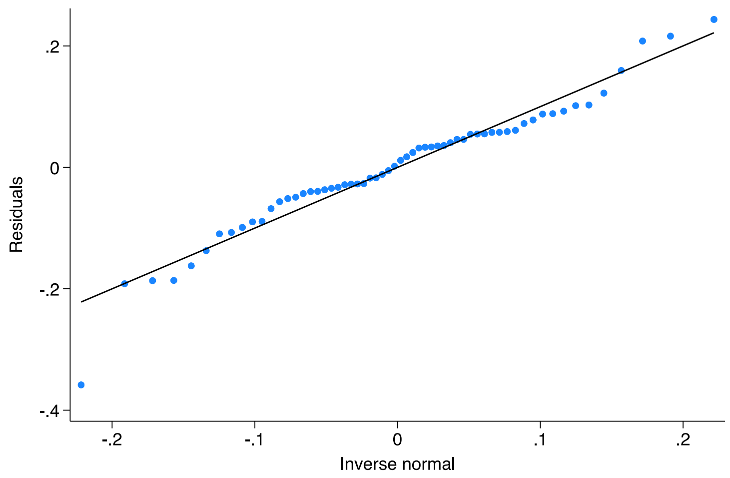

Figure C1. Quantile-Normal (Q-Q) Plot of Residuals for the Panel Fixed Effects Model.

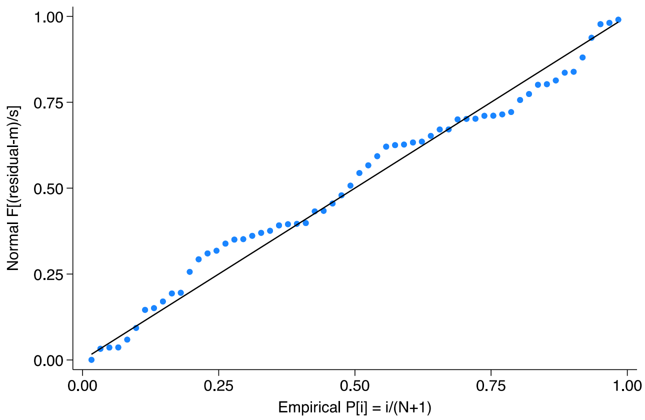

Figure C2. Probability-Probability (P-P) Plot of Residuals for the Panel Fixed Effects Model.

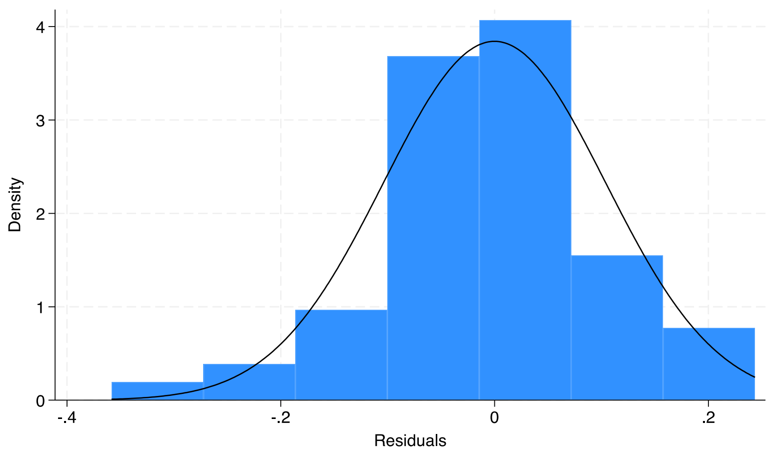

Figure C3. Histogram of Residuals for the Panel Fixed Effects Model.

Appendix D. Coefficients of the Panel FE Model with Country Dummy Variables

Table 4. Coefficients of a panel FE model with country dummy variables.

Variables	HS	Variables	HS
country_dummy2	4.254***	int_unempl_3	-0.106*
	(0.877)		(0.0592)
country_dummy3	3.210**	int_CCI_3	0.0214***
	(1.262)		(0.0147)
country_dummy4	4.833***	int_gov_resp_3	-0.00761*
	(1.056)		(0.00416)
country_dummy5	4.118**	int_test_per_case_4	0.000145***
	(1.645)		(0.000419)
test_per_case	0.00102***	int_ful_vac_4	0.00184***
	(0.00021)		(0.00111)
ful_vac	0.00996***	int_CFR_4	-0.142***
	(0.00021)		(0.0331)
CFR	-0.00354**	int_ICU_4	-0.00360**
	(0.00052)		(0.00162)
ICU	-0.00237***	int_unempl_4	-0.149*
	(0.00001)		(0.0804)
unempl	-0.0253***	int_CCI_4	0.0428***
	(0.00173)		(0.0132)
CCI	0.0330***	int_gov_resp_4	0.00130**
	(0.00169)		(0.00388)
gov_resp	-0.0023**	int_test_per_case_5	0.00270**
	(0.00067)		(0.00219)
int_test_per_case_2	0.000349**	int_ful_vac_5	0.00652***
	(0.000328)		(0.00317)
int_ful_vac_2	0.000487**	int_CFR_5	-0.0111***
	(0.000767)		(0.105)
int_CFR_2	-0.0292*	int_ICU_5	-0.00309**
	(0.0141)		
int_ICU_2	-0.00294*		(0.00527)
	(0.00148)	int_unempl_5	-0.0440*
int_unempl_2	-0.0440**		(0.0240)
	(0.0240)	int_CCI_5	0.0633***
int_CCI_2	0.0420***		(0.0272)
	(0.0106)	int_gov_resp_5	0.00123**
int_gov_resp_2	-0.000301		(0.00503)
	(0.00377)	Constant	-4.324***
int_test_per_case_3	0.000489**		(0.210)
	(0.000469)		
int_ful_vac_3	0.00456***	Observations	60
	(0.00109)	R-squared	0.936
int_CFR_3	-0.117***		
	(0.0404)		
int_ICU_3	-0.000467*		
	(0.00282)		

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
1 "France" 2 "Italy" 3 "UK" 4 "Germany" 5 "Spain"

Appendix E. Diagnostic Plots for the Panel FE Model with Country Dummy Variables

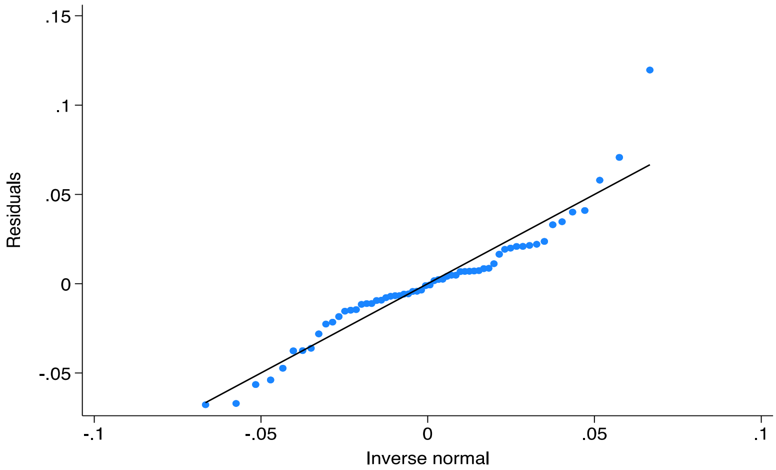

Figure E1. Quantile-Normal (Q-Q) Plot of Residuals for the Panel FE Model with Country Dummy Variables.

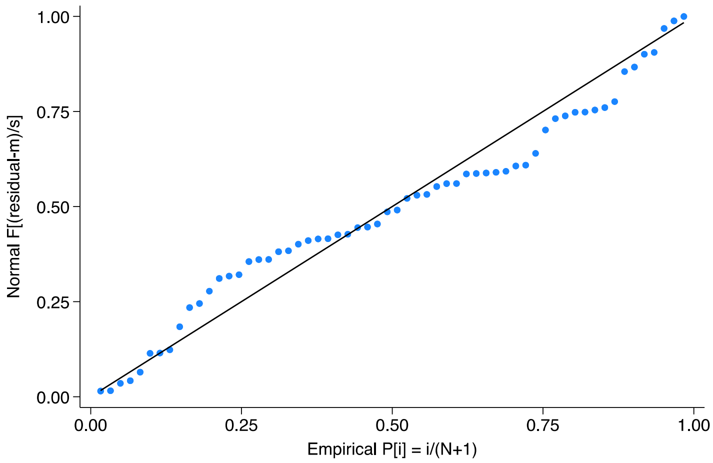

Figure E2. Probability-Probability (P-P) Plot of Residuals for the Panel FE Model with Country Dummy Variables.

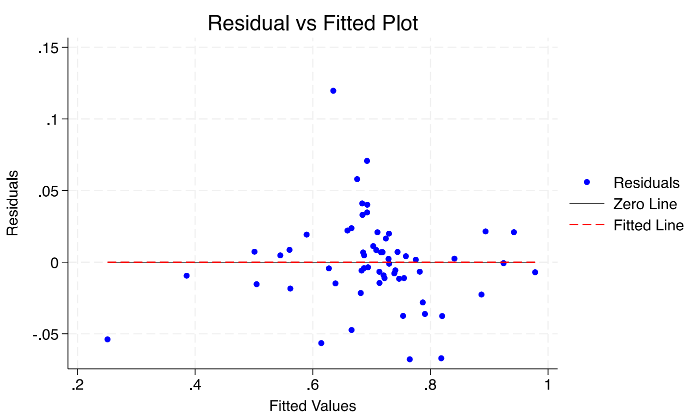

Figure E3. Residual vs. Fitted Plot for the Panel FE Model with Country Dummy Variables.

Appendix F. Additional Figures and Plots

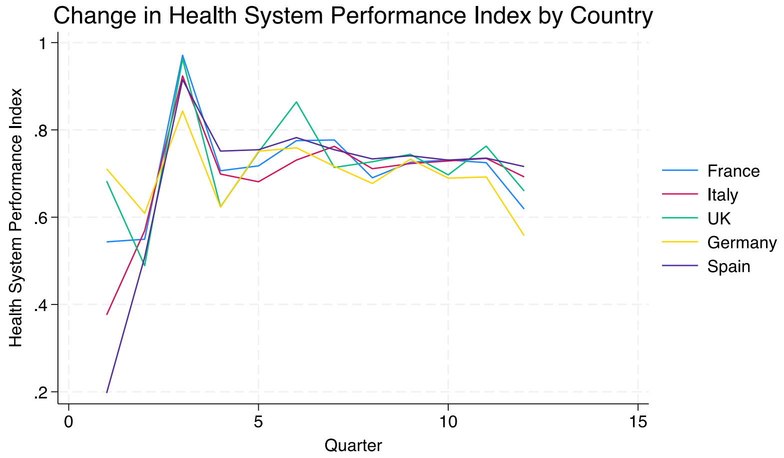

Figure F1. Change in Health System Performance Index by Country.

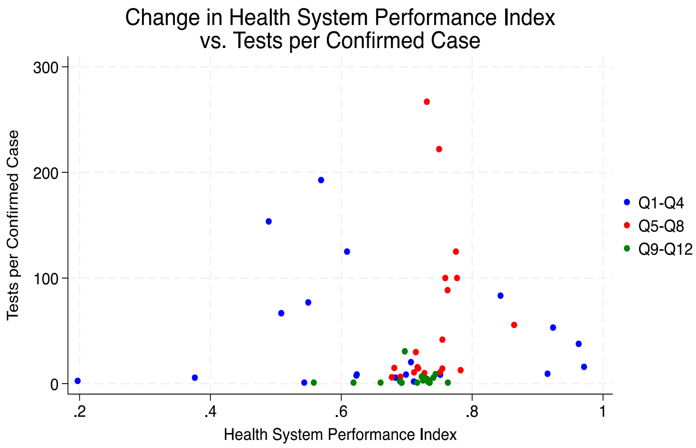

Figure F2. Scatter Plot of Tests per Confirmed Case against the Health System Performance Index.

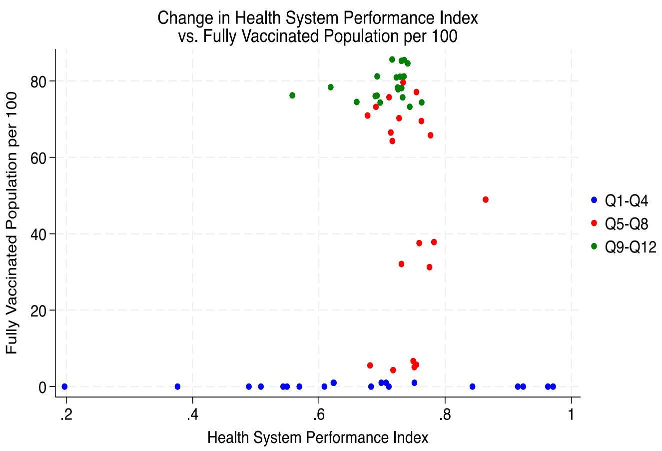

Figure F3. Scatter Plot of Fully Vaccinated Population per 100 against the Health System Performance Index.

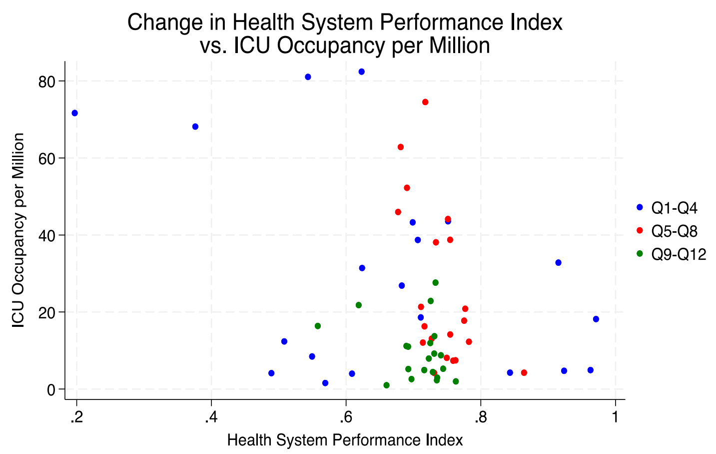

Figure F4. Scatter Plot of ICU Occupancy per Million against the Health System Performance Index.

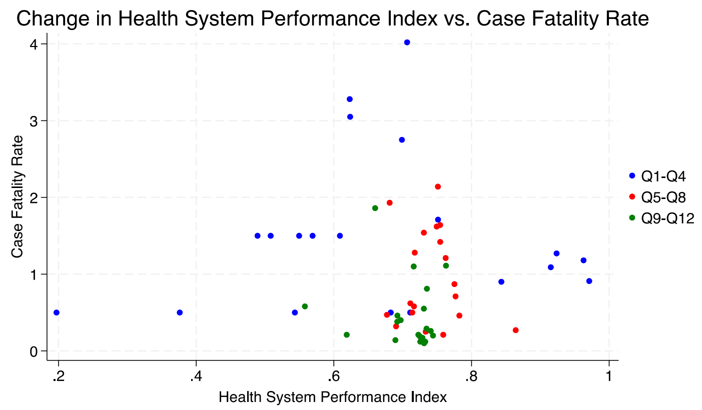

Figure F5. Scatter Plot of Case Fatality Rate (CFR) against the Health System Performance Index.

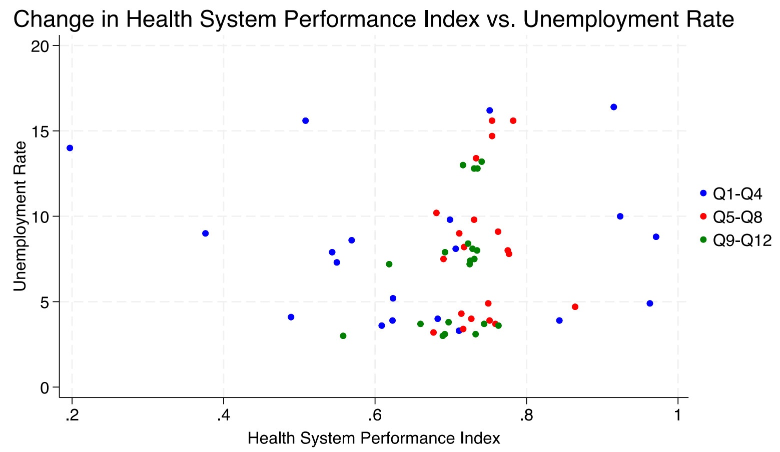

Figure F6. Scatter Plot of Unemployment Rate against the Health System Performance Index.

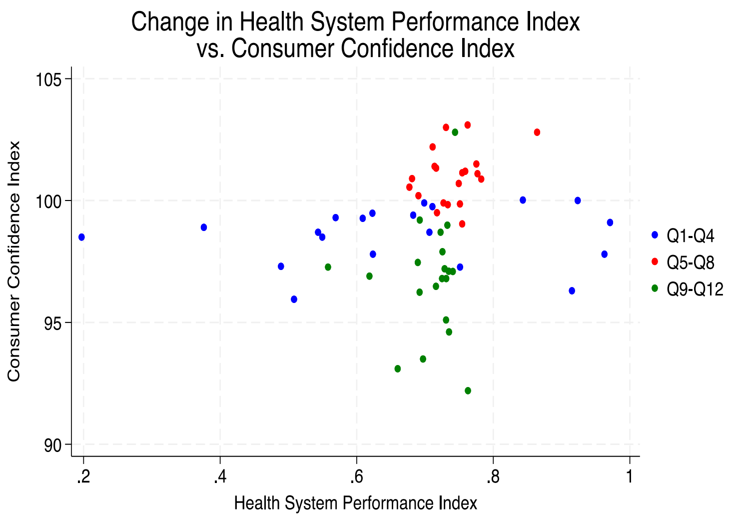

Figure F7. Scatter Plot of Consumer Confidence Index (CCI) against the Health System Performance Index.

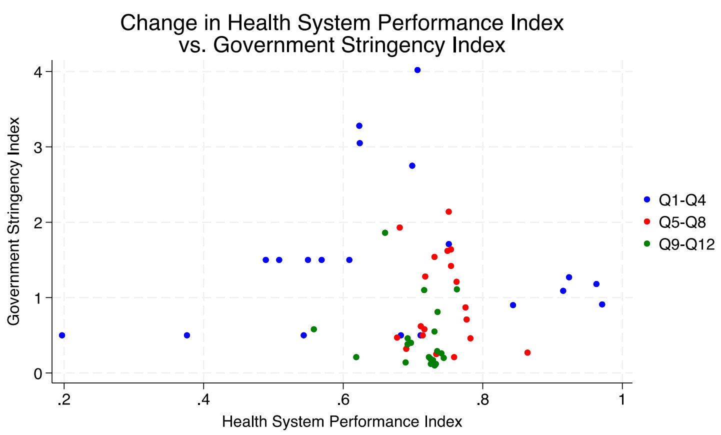

Figure F8. Scatter Plot of Government Stringency Index against the Health System Performance Index.

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