




Adjusting hospital reimbursements to the onset of a new disease: Lesson from Covid-19

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ABSTRACT

The COVID-19 pandemic represented a significant shock to healthcare systems, which faced substantial challenges on multiple fronts. In addition to organizational and clinical issues, one important challenge that required attention was adapting hospital service reimbursement systems to address a new disease with initially unknown costs and consequences. In this paper, we quantify the gap between DRG tariffs and the actual hospitalization costs of COVID-19 cases, through a comparison with pre-COVID-19 cases of respiratory tract infections, at San Martino Polyclinic Hospital, Genoa, Italy. We collected and analyzed a unique administrative dataset comprising Hospital Discharge Records (HDRs). We used propensity score matching to compare health outcomes and hospitalization costs of patients with confirmed SARS-CoV-2 pneumonia and patients in a control group of pre-COVID-19 patients with similar characteristics. We found that COVID-19 infection leads to a higher probability of being admitted to the Intensive Care Unit (ICU) and death, fewer days of hospitalization, increased hospital services, and increased costs of these services. Factors that increased hospitalization costs included female gender, age group 65–74 years, being admitted to ICU, death, increased length of stay (LOS), and the association between mechanical respiration DRGs and COVID-19 infection. In the period examined, DRG reimbursements were underestimated in severe COVID-19 cases requiring mechanical respiration. Knowledge of the factors that influence COVID-19 hospitalization costs may lead to a more comprehensive DRG tariff and, overall, to more effective management of financial resources in the event of future similar outbreaks.

1. Introduction

Since December 2019, the world has been navigating the consequences of the Coronavirus disease (COVID-19), which had a considerable economic impact on global healthcare systems, requiring additional resources and sizeable financial investments [1,2]. The resultant crisis led to significant changes in society and challenged national and local governments to become more innovative in their solutions to new problems including infection control, staff shortages, and limited equipment and supplies [3,4]. Hospital activity was one of the healthcare sectors most affected during the early stages of the pandemic, with intensive care unit (ICU) capacity expanded,¹ elective admissions temporarily suspended, and patient care pathways reorganized to manage COVID-19 services alongside non-COVID-19 services.

In addition to the challenges related to patient management and

healthcare needs, a series of significant administrative and accounting issues have also emerged. The costs of treating COVID-19 patients were high due to prolonged hospital stays, isolation, and intensive care needs. Additionally, stricter hygiene measures, physical distancing, increased PPE use, and widespread testing made it more expensive and time-consuming to treat non-COVID patients [5]. Moreover, health providers in countries with activity-based payment systems faced revenue losses, especially in the early stages of the pandemic, due to the suspension of elective procedures and patients avoiding care.

Italy has been profoundly affected by the pandemic, becoming one of the countries with the highest death toll outside Hubei Province and mainland China. This positioned Italy as an early epicenter for the spread of the epidemic, with the severity of the outbreak soon surpassing that of China's neighbor, South Korea [6]. As of April 1, 2020, 110,574 cases and 13,155 deaths related to severe acute respiratory syndrome

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¹ "Data on hospital and ICU admission rates and current occupancy for COVID-19," *European Centre for Disease Prevention and Control*, Apr. 15, 2021. <https://www.ecdc.europa.eu/en/publications-data/download-data-hospital-and-icu-admission-rates-and-current-occupancy-covid-19>.

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COVID-19 infection were documented in Italy [7]. These issues were further exacerbated by Italy's demographic landscape, marked by a high percentage of elderly patients with comorbidities. As the first European country seriously affected by the pandemic, Italy was the first to face the clinical, organizational, and managerial challenges associated with it.

In the Italian context, characterized by a universal healthcare system, one of the issues that arose concerned the reimbursement of hospital services related to COVID-19 hospitalizations. As will be further detailed in the next section, since the 1990s (L.438, D.L.502 of 1992), hospital service reimbursements have been based on Diagnosis-Related Group (DRG) rather than on historical expenditure (cost reimbursement). The DRG system is described as "resource-equivalent": it categorizes the complexity of care provided based on the principle that similar illnesses, treated in comparable hospital departments, generally require the same level of human and material resources. This approach makes it possible to predict the quantity and type of resources needed for patient care. However, the determination of DRG tariffs is a complex and intricate process that requires detailed and timely data on the resource utilization of homogeneous patient groups. It is evident that, during the urgency of the pandemic period, the system was unprepared to accurately determine reimbursements for COVID-19 patients in a timely manner. Therefore, as will be further detailed later, hospitalized patients with COVID-19-related issues were initially assigned DRG codes associated with respiratory conditions deemed most consistent with COVID-19 symptoms.

Within this paper, we aim to quantify the gap between the DRG reimbursements applied during the pandemic and the actual costs incurred by hospitals treating COVID-19 patients. Our analysis is based on hospital discharge records from a large hospital located in the Northwest region of Italy and uses cost data calculated by the hospital's management control system through an activity-based costing approach for a sample of patients hospitalized for COVID-19 and related respiratory issues. The ultimate aim of this study is to measure the extent of the mismatch between reimbursements and actual costs, while also evaluating the factors driving higher or lower hospitalization costs. This analysis provides insight into how the DRG-based hospital financing system could be revised to better reflect the real costs of COVID-19 cases. The rest of the paper is organized as follows. Section 2 presents the literature review and the Italian institutional setting; Section 3 describes the material and methods used in this study. Section 4 illustrates the results. Finally, Section 5 discusses and concludes the paper.

2. Background

2.1. The determinants of hospital costs for COVID-19 patients

From the early stages of the pandemic, it became clear that the prognosis and resource consumption of COVID-19 patients were heavily influenced by their underlying clinical conditions [8]. Comorbidities have also been found to affect the treatment process and the resources needed as they may result in a longer length of stay (LOS) or admission to Intensive Care Unit (ICU) [9,10]. As the COVID-19 pandemic spread rapidly worldwide, costs associated with hospitalization of patients with COVID-19 and their corresponding reimbursement merits some investigation. The literature on direct healthcare costs associated with the use of hospital resources for patients with COVID-19 is limited. Consequently, economic models estimating the impact of COVID-19 have used cost inputs from other diseases, such as pneumonia and influenza [11,12]. We posit that, specific data outlining the hospitalization costs related to patients with COVID-19 is needed to better understand the economic impact of COVID-19 and support future policy in this regard [13].

There are already some significant studies from China, Brazil, Turkey, and Iran that explore direct medical hospitalization costs for COVID-19. In the Brazilian study, average direct medical costs of inpatients with COVID-19 who were admitted to general wards was

4,767€; costs for inpatients with severe and critical COVID-19 who were admitted to ICU was 15,255€ [14].

In Turkey the lowest costs were found, both for non-serious COVID-19 patients and for those in ICU. They turn out to be on average 842€ and 2,795€ respectively. [15].

An Iranian study reported an average hospitalization cost for non-severe COVID-19 patients of 2,845€ and for patients at ICU of 12,684€. [16].

An early Chinese national report highlighted that the mean hospitalization costs of confirmed COVID-19 cases was 2,882€, and the mean costs of severe COVID-19 cases was more than 20,000€. [17].

All four studies discussed the COVID-19 direct medical hospitalization costs. Analyzing the cost drivers of COVID-19 patients at ward, the most dominant was service care (58 % to 88 %). For patients at ICU, there was no consensus among studies that reported either service care (54 % to 87 %) or treatment (72 % to 81 %) as key drivers of total cost. [18].

Few European studies have reported such information. A recent Italian national report revealed that the mean costs of hospitalization for confirmed COVID-19 cases was 11,730€, and that of severe cases was more than 39,000€ [19]. This would result in 41 % lower Diagnosis Related Group (DRG) rates than for the costs of an ordinary hospitalization and 86 % of an ICU hospitalization. A recent study that tracked and compared the costs of healthcare services in 60 countries found that the cost of an ICU bed for COVID-19 treatment in Italy cost seven times less than the same bed in the United States [20].

However, these studies did not provide comprehensive descriptions of the sample patients as they were conducted during March to August 2020, when knowledge of the virus was scant. Research shows that factors such as demographic and clinical characteristics can have considerable impact on the course of COVID-19 [21]. Consequently, these factors can be strong predictors of high use of health resources and costs.

2.2. Institutional setting

The Italian healthcare system is based on the Beveridge model, and public healthcare is funded through general taxation. Secondary health care is remunerated through a prospective payment system [22–24] based on Diagnosis-Related Groups (DRGs). These are homogeneous groupings of diagnoses whose uniformity relates to economic aspects, specifically the resources required for patient care. DRGs are guided by a primary diagnosis, but the same diagnosis can have different remuneration levels depending on factors such as the patient's age (e.g., over 65 or under 18) or clinical condition (e.g., with complications or without complications). DRG reimbursement is intended to reflect the average cost incurred for a patient with that diagnosis. The reimbursement amount is determined by the assigned DRG and covers the cost of the patient's care for the entire hospital stay.

When the costs of treatment exceed the standard tariff for a specific DRG, additional payments may be made. These additional payments are triggered when the treatment exceeds a certain threshold, known as the "over-threshold" value. This value represents the point at which the costs for the care provided go beyond the usual amount covered by the fixed DRG tariff, and extra reimbursement is needed to cover these higher costs.

Inherent variability within a single DRG is unavoidable. However, in theory, the reimbursement rate for a given DRG should reflect the average cost—some patients may incur higher costs and others lower, but on average, this cost should be accurately recognized by the hospital.

With the reforms introduced in recent decades, Italy transitioned from a retrospective reimbursement system based on historical expenditure to a prospective system using predefined tariffs (DRGs). Two significant changes accompanied this shift. On one side accredited private hospitals were allowed to offer services within the National Health

Service (NHS). To obtain accreditation, these hospitals must meet specific quality requirements and accept the same DRG-based remuneration as public hospitals. This effectively equates accredited private hospitals to public ones. In addition, citizens were granted the freedom to choose their hospital, whether public or accredited private, for hospitalization [25]. Since the service is provided free at the point of use, patients base their choice on the perceived quality of care rather than cost, except for potential mobility costs [26]. This introduces competition among hospitals, encouraging them to improve service quality [27–29]. In Italy, the DRG classifications are numbered from 1 to 579, although the actual number is 538, since the numbering is not continuous.

This study focuses on DRGs associated with respiratory diseases and septicemia, which were notably frequent during the COVID-19 pandemic (a detailed description of these DRGs is provided in the next section and in Table A1). In detail, we select all patients including mechanical respiration DRGs (codes: 542, 565, 566), respiratory infection DRGs (codes: 79, 80, 87, 89, 90, 99); septicemia DRG (code: 576).

Accurately defining reimbursement rates is essential for proper resource allocation. Incorrect tariffs can lead to inefficiencies. If the tariff is lower than the cost an efficient hospital incurs, providing the treatment will inevitably result in a deficit. Conversely, excessive remuneration will create strong incentives to produce those services, benefiting the hospital. Assuming that tariffs are incorrectly calculated and exceed the actual cost of providing a treatment, hospitals could exploit profit margins [30,31]. This might lead to strategic behaviors, such as specializing in high-margin areas or disengaging from services with inadequate remuneration [32,33]. This issue has been extensively studied in the literature and includes phenomena such as dumping [34–36], where unprofitable patients are refused or transferred without clinical justification.

3. Material and methods

3.1. Identification strategy

To quantify the gap between DRG reimbursements and actual hospital costs during the COVID-19 pandemic, we collected and analyzed administrative data obtained from the hospital discharge records (HDRs) of patients hospitalized at San Martino polyclinic hospital in Genoa, Italy. The San Martino polyclinic hospital in Genoa is the largest hospital in Liguria and the one most heavily involved in the hospitalization of COVID-19 patients during the early stages of the pandemic.

The target population was represented by all consecutive patients hospitalized from October 19, 2018, to May 31, 2020, with a range of different respiratory problems. In detail, starting from the San Martino Hospital Discharge Records (HDRs) database, two patient groups were identified:

- Adult patients with a confirmed SARS-CoV-2 pneumonia who were in the hospital from February 24 to May 31, 2020 (i.e. COVID-19 patients, also defined as “treated patients”);
- Adult patients with comparable respiratory problems, hospitalized between October 19, 2018, and December 30, 2019 (i.e. Pre-COVID-19 patients, also defined “control patients”). To identify the control group, we extracted a sample of patients hospitalized in a pre-COVID period with DRGs equal to those used for COVID-19 positive patients. In detail, we select all patients including mechanical respiration DRGs (codes: 542, 565, 566), respiratory infection DRGs (codes: 79, 80, 87, 89, 90, 99); septicemia DRG (code: 576).

A total of 2,836 patients were included in our analysis; 2,114 were hospitalized prior to COVID-19 in Italy, while 722 tested positive for COVID-19. The two groups of patients will be compared on the basis of a selection of outcome variables, with the aim of detecting the difference in resource absorption by patients suffering from Pre-COVID-19 respiratory infection and COVID-19 infection. Table 1 shows the hospital care

service tariffs for the most relevant DRG attributed to COVID-19 patients in the Liguria region, along with their respective threshold values. As shown in the table, the DRGs with the highest reimbursements are those that involve mechanical ventilation (DRGs 565 and 566). These DRGs were assigned to 12 % and 5 % of the patients hospitalized for COVID-19, respectively.

3.2. Covariates and outcome variables

The final dataset includes, for each patient, a selection of demographic, clinical and use of resources variables.

In detail, patients are characterized by gender (Male-Female) and age group (<65; 65–74; 75–84; 85+). For what concerns clinical status we computed the Charlson Comorbidity Index, an indicator of patient comorbidities based on the International Classification of Diseases (ICD-9-CM) diagnosis codes. By exploiting the primary and secondary diagnosis of hospitalization in HDR database, each comorbidity (e.g. diabetes; cardiovascular diseases) is weighted (in the range of 1–6) according to the risk of mortality or resource use. The score for each patient is obtained by summing up all the weights. The higher is the score, the higher will be the probability of mortality and higher resource use [37].

As outcome variables we consider five main variables connected to the clinical pathway: number and the costs of hospital services; likelihood of being hospitalized in ICU; death; number of days of hospitalization (Length of Stay – LOS).

The number and cost of the services received during hospitalization were calculated using an Activity-Based Costing (ABC) methodology which allows to allocate hospitalizations costs incurred based on services associated with patient care, which can be procedural or time-based [38]. In our context, costs are computed using a time-driven Activity-Based Costing including all direct costs (human resources, consumables, diagnostic tests). By applying this micro-analytic approach, we were able to quantify the cost of all resources utilized in treating the medical conditions of COVID-19 patients. This analysis allowed us to map the care delivery value chain, encompassing all activities performed throughout the entire care cycle. Specifically, the evaluation covered the full duration of the hospital stay, from the confirmation of COVID-19 positivity to patient discharge. Intermediate services include a wide range of services performed during hospitalization, ranging from lower-cost services (e.g., blood and urine tests) to high-cost services (among which the most common for COVID patients were continuous venovenous hemodiafiltration and abdominal CT scans). Therefore, as outcome variables related to the use of healthcare services and the associated resource absorption, we constructed a variable reporting the total number of services performed and a variable reflecting their estimated cost.

In addition, the proposed analyses will also evaluate the following health outcome measures: the length of hospitalization expressed in days (calculated as the number of days between the admission and discharge/death dates), the hospitalization outcome (a dichotomous variable equal to 1 for deceased patients and 0 for discharged patients), and a dichotomous variable related to the probability of being admitted to the ICU (a variable equal to 1 for patients admitted to intensive care and 0 otherwise). Table 2 provides a detailed description of the variables used.²

3.3. Methodological approach

This section describes the econometric approach adopted to test the

² It should be noted that the data at our disposal did not allow us to obtain information on the socio-economic status of the patients, as the field related to educational level (although present in the data) was characterized by a persistent share of missing values and was therefore not usable.

Table 1
Most frequent DRGs for COVID-19 patients hospitalized in 2020.

DRG	Group	Description	Freq.	%	Tariff (in €)	Threshold	Tariff for days
79	Respiratory infection	Respiratory and inflammatory infections, age > 17 years with CC	191	27 %	5,744	79	148
565	Mechanical respiration	Diagnosis related to the respiratory system with assisted breathing ≥ 96 h	81	12 %	15,595	50	283
89	Respiratory infection	Simple pneumonia and pleurisy, age > 17 years with CC	76	11 %	3,558	38	141
80	Respiratory infection	Respiratory and inflammatory infections, age > 17 years without CC	75	11 %	4,422	98	133
87	Respiratory infection	Pulmonary edema and respiratory failure	72	10 %	3,802	31	146
566	Mechanical respiration	Diagnosis related to the respiratory system with assisted breathing < 96 h	33	5 %	6,764	46	198
421	Other	Diseases of viral origin, age > 17 years	28	4 %	2,184	21	147

Note: Mechanical respiration DRGs (codes: 542, 565, 566); Respiratory infection DRGs (codes: 79, 80, 87, 89, 90, 99); Septicemia DRG (code: 576) Other DRGs (codes: 9, 12, 76, 127, 249, 421, 572).

Table 2
Description of the variables used in the analysis. Note s.e. = standard error.

Domain	Variable name	Description	% of patients	Mean		
Demographic variables	Age classes	Categorical variable: 1 if the patient’s age is between 0 and 64 years old; 2 if the patient’s age is between 65 and 74 years old; 3 if the patient’s age is between 75 and 84 years; 4 if the patient’s age is above 85 years old	<64 65–74 75–84+85	20.36 17.53 32.0330.08	– – –	
		Clinical variables	Female	Binary variable = 1 if the patient is female, 0 otherwise	44.36	–
			Charlson Comorbidity Index	Charlson Comorbidity Index score	–	1.12(s.e. 0.02)
DRG classes	Mechanical respiration DRGs	Covid	Binary variable = 1 if the patient has COVID-19 infection	25.46	–	
		Respiratory infection DRGs	DRGs codes: 79, 80, 87, 89, 90, 99	8.11	54.94	
	Septicaemia DRGs	DRG codes: 576	30.50	–		
	Other DRGs	DRG codes: 9, 12, 76, 127, 249, 421, 572	6.45	–		
	Outcome deceased	Dummy variable = 1 if the patient is deceased, 0 otherwise	28.81	–		
	Intensive care	Dummy variable = 1 if the patient has been in the intensive care unit, 0 otherwise	8.53	–		
	Length of Stay	Days of hospitalization (LOS)	–	17.21(s.e. 0.27)		
	Hospital services	Amount of hospital services	–	182.97 (s.e.6.04)		
Hospital costs	Overall hospital services costs	–	1150.37 (s.e. 60.21)			

effect of COVID-19 status on outcome variables (Outcome deceased; Intensive care; Length of Stay; Number and cost of hospital services). As a preliminary analysis, Tables 3 and 4 present descriptive statistics aimed at assessing differences in the outcome variables of interest between COVID and Non-COVID patients. To evaluate the statistical significance of these differences, t-tests were employed. We first used a propensity score matching approach. Here the goal is to permit reliable comparisons between a treatment group and a matched control group when random allocation to condition is not possible. In our context, the treated group consists of patients diagnosed with COVID-19, while the control group comprises patients hospitalized during the Pre-COVID-19 period for respiratory issues similar to those associated with COVID-19. This is accomplished by matching patients in the treatment group (those with confirmed SARS-CoV-2 pneumonia), to similar patients taken from a larger control sample on demographic factors. The treatment effect is computed by taking the average of the difference between the observed and potential outcomes for each subject. We use a logistic model to predict each subject’s propensity score. With reference to the variables used in the matching process, given the information available in our dataset, we utilized a selection of demographic variables (gender and age group) and clinical variables (Charlson Comorbidity Index, DRG Group). Additionally, the following clinical pathway variables were included: Death; Admission to intensive care.³ Therefore, the differences observed between the two groups are more likely to result from the

³ When the dependent variable was either Death or Admission to Intensive Care, the corresponding variable was excluded from the matching procedure.

treatment effect (i.e. COVID Infection) rather than from other confounding factors.⁴ The resulting Average Treatment Effect is obtained by matching each subject to a single subject with the opposite treatment whose propensity score is closest.

To better understand the role of various determinants (demographic and clinical) on the outcome variables, we will also conduct a multivariate analysis. Given the different nature of the dependent variables analyzed (binary for mortality and intensive care utilization, count data for the number of hospitalization days and the number of services, and lower-bounded for cost data), various types of nonlinear models will be applied. Specifically, a logistic specification was used to model the probability of ICU and mortality (binary variables), a Poisson distribution to model the LOS, and number of services (countable outcomes) and a Tobit regression to model costs.

The models are formally specified as:

$$y_i^* = \beta_0 + \beta_1 X_i + \beta_2 Z_i + \delta COVID_i + u_i$$

where y_{it}^* represents the outcome variable, X_i includes the demographic covariates (age class, sex), $COVID_i$ indicates the “treatment” (i.e. the presence of a diagnosis for COVID-19), Z_i includes a selection of covariates connected to the clinical outcome (i.e. and Charlson Index; death; DRG class; ICU) and u_i is the idiosyncratic error term.

⁴ As previously mentioned in the section on the dataset, unfortunately, the database at our disposal does not include variables related to the socio-economic context of the patients.

Table 3

Age distribution of COVID and Non-COVID patients across the total admissions, deceased cases, and ICU admissions. Frequencies and percentages are reported for each age class within both patient groups.

Age classes	Total admissions		Non Covid patients		Deceased Covid patients		Non Covid patients		ICU Covid patients		Non Covid patients	
	Freq.	Perc.	Freq.	Perc.	Freq.	Perc.	Freq.	Perc.	Freq.	Perc.	Freq.	Perc.
<64	220	33 %	345	16 %	16	8 %	42	7 %	70	48 %	37	37 %
65–74	133	20 %	357	17 %	39	19 %	58	10 %	48	33 %	26	26 %
75–84	182	27 %	708	34 %	74	35 %	191	31 %	24	16 %	26	26 %
+85	134	20 %	704	33 %	80	38 %	317	52 %	4	3 %	11	11 %
Tot.	669	100 %	2114	100 %	209	100 %	608	100 %	146	100 %	100	100 %

Table 4

Average number of hospital services and average costs for COVID-19 and Pre COVID-19 patients Note: * = p-value < 0.05; ** = p-value < 0.01; *** = p-value < 0.001.

Number of hospital services		Pre Covid patients	Covid patients	Significance of the difference
	Age_classes	160.6	353.9	***
	<64	142.9133.4	212.5146.9	***
	65–74			
	75–84+85			
	Sex	152.2144.8	309.8212.5	***
	MaleFemale			
	DRG_classes	257.2183.4	649.5143.2	***
	DRG_pulm_inf			
	DRG_mech_respDRG_septic			
Costs of hospital services	Admitted to ICU	5287.1	7186.7	*
	DeceasedBeyond DRG threshold	1239.13090.5	2677.14121.2	***

4. Results

4.1. Descriptive statistics

Regarding the demographic characteristics of the two patient groups, it is noted that gender distribution is fairly similar: the percentage of women is 40 % among COVID-19 patients and 46 % among pre-COVID-19 patients. However, with respect to age, the proportion of elderly patients (over 65) is higher in the pre-COVID population (84 % compared to 67 % among hospitalized COVID-19 patients).

Tables 3 and 4 provide some initial descriptive insights into the trends of the outcome variables, stratified by group membership (“COVID-19 patients” and “Pre-COVID-19 patients”). Analysis revealed (Tables 3) that the percentage of deaths increased with an increase in the patient’s age and the percentage of patients in ICU was inversely proportional to their age. Patients hospitalized for COVID-19, compared to those with respiratory conditions unrelated to COVID-19, experienced worse clinical outcomes on average. Specifically, 22 % of COVID-19 patients required intensive care (compared to 5 % in the control group), and mortality reached 31 % (versus 29 %). Stratifying the analysis by age reveals that COVID-19-related deaths affected significant proportions even among individuals under 85 years old, while the use of intensive care was markedly lower for COVID-19 patients over 85.

Table 3 reports a comparison of the number of hospital services and their associated costs between COVID-19 and Non-COVID patients. A t-test is used to assess whether the differences in these outcomes between the two groups are statistically significant. It becomes evident that, overall, COVID-19 patients had a significantly higher number of services and associated costs compared to Non-COVID patients (p-value < 0.001). Notably, the most pronounced differences in the number of services are observed in the younger population (345 services versus 190 for those under 65), while no significant differences are found among patients over 85 (p-value > 0.05). The largest difference in the average number of services was noted among patients who were assigned a DRG that involved mechanical respiration, at 650 hospital services (against 257). The average hospital cost for a patient with COVID-19 admitted to ICU or who died was also higher. The cost for a patient admitted to ICU with COVID-19 was approximately 1,900€ more than that for a non-

COVID-19 patient; a deceased COVID-19 patient cost nearly 1,400€ more (see Fig. 1). For COVID-19 patients who were hospitalized for many days above the threshold value, hospital services costs were approximately 1,000€ higher than for non-COVID-19 patients.

4.2. Multivariate analysis

The propensity score matching results presented in Table 5 provide evidence supporting these findings. After matching patients on age group, gender, Charlson Comorbidity Index (CCI), and DRG, COVID-19 patients demonstrated a significantly higher likelihood of ICU admission and mortality compared to patients with non-COVID-19 respiratory conditions. Interestingly, COVID-19 was negatively associated with the length of stay (LOS), suggesting that COVID-19 patients had shorter hospital stays, potentially due to their elevated mortality risk or to the shortness of beds during the pandemic, and the pressure of the demand.

Further, the results indicate a substantial relationship between COVID-19 positivity and increased hospital resource use. Hospital costs and services provided were notably higher for COVID-19 patients, with ATE estimation reaching 207 and 39, respectively. These figures underline the resource-intensive nature of COVID-19 care, driven by more complex clinical needs and the use of specialized interventions.

To deepen the analysis, non-linear regressions were employed to explore the role of covariates, with results summarized in Table 6. The models demonstrated consistent estimations across the five outcomes examined, reinforcing the strong influence of COVID-19 on ICU admission, death, services provided, and overall costs. The inclusion of the COVID-19 variable significantly enhanced the explanatory power of these models, emphasizing its critical role in understanding outcome variations.

Age-specific trends were also noteworthy. Patients under 65 were more likely to require ICU admission, while those over 85 had a markedly higher risk of mortality (O.R. = 10.669). However, the non-significant interactions between age groups and COVID-19 suggest that ICU admission trends have not shifted drastically due to the pandemic. Instead, COVID-19 appears to reduce LOS (I.R.R. = 0.880), a trend attributable to the increased mortality among infected patients.

The combined effects of ICU admission, mortality, and LOS

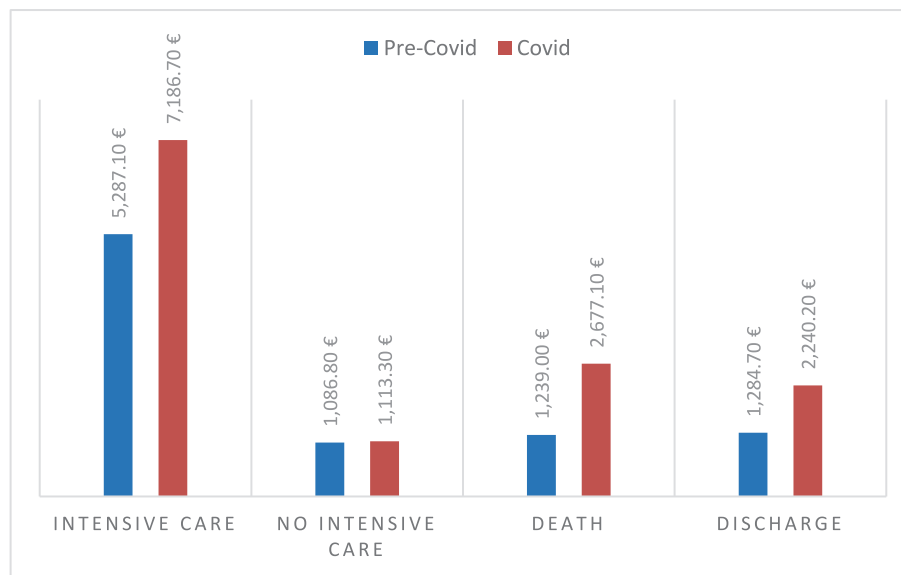


Fig. 1. Average hospitalization costs (€) by outcome in COVID-19 and Pre-COVID-19 patients.

Table 5

Average treatment effect (ATE) estimated by propensity score matching. Standard errors in parenthesis.

	ICU	Outcome deceased	Days	Hospitalcosts	Hospitalservices
ATE					
Covid (1 vs 0)	0.085*** (0.015)	0.121*** (0.025)	-1.861** (0.693)	206.987* (104.193)	39.416*** (12.055)

significantly drive hospital service use and costs. For instance, ICU admission increased service utilization and costs substantially (I.R.R. = 2.842), as did mortality (I.R.R. = 1.138) and LOS (I.R.R. = 1.027).

Moreover, interactions between DRG classifications and COVID-19 revealed striking disparities in resource use, particularly for patients requiring mechanical ventilation or those categorized in the “other” DRG class. Costs for COVID-19 patients in these categories were substantially higher, reflecting the intensive care and specialized resources necessary for managing severe cases.

After fitting a Poisson regression model to evaluate the effect of an intervention in a cohort study, we estimated the number of events and costs for different groups of patients. This can be calculated by comparing the predicted number of events under the intervention (factual) and no intervention (counterfactual) scenarios. In our context we computed the predictive margins at fixed values of some covariates (DRG group and COVID-19 treatment) and at median value over the remaining covariates.

The predictive margins shown in Fig. 2 allow us to highlight the key factors contributing to the higher costs for COVID-19 patients compared to the control group. It is evident that the gap in the number of hospital services and their associated costs is significant across all DRGs, albeit to varying degrees. In particular, DRGs related to mechanical ventilation show the largest differentials, suggesting that the DRG reimbursement applied to COVID-19 patients requiring mechanical ventilation should be considered misaligned with the costs incurred. The increased cost connected to increased complexity has been documented also in [39].

5. Discussion and policy implications

In the early stages of the COVID-19 pandemic, DRG reimbursements were initially calculated based on pre-existing respiratory conditions, as there were no DRG codes tailored to COVID-19. This led to an underestimation of the real costs incurred by hospitals, particularly in severe cases requiring intensive care and mechanical ventilation. Our results

indicate that the costs for COVID-19 patients in ICU were significantly higher than those for non-COVID-19 patients, yet the reimbursement rates did not reflect these differences.

This discrepancy underscores a critical limitation in the DRG-based reimbursement system: its inherent inflexibility during emergencies. The delay in adapting reimbursement schemes to account for the unique cost drivers of COVID-19, such as prolonged ICU stays, specialized treatments, and extensive use of personal protective equipment (PPE), placed additional financial strain on healthcare providers.

To address these gaps, some countries introduced temporary measures to adjust hospital reimbursements during the pandemic. Waitzberg et al. [5] examine how 20 countries adapted healthcare provider payment systems during the COVID-19 pandemic to address financial challenges and ensure service continuity. Indeed, countries affected by the pandemic faced two pressing challenges: on one hand, a decline in revenue due to reduced delivery of routine services, and on the other, the need to reimburse COVID-19-related services in a context of uncertainty. In particular, countries with activity-based payment systems faced indeed significant revenue drops as elective services were suspended. To address this, nations like Belgium and Germany introduced new budgets or adjusted payment rates to compensate for lost income. Some, like England and Israel, transitioned to broader payment mechanisms, such as salaries or capitation, ensuring financial stability. For COVID-19-specific costs, new payment mechanisms were created. Early in the pandemic, countries introduced new payment mechanisms to address COVID-19-related costs, revising them as the situation evolved. For example, Germany introduced per-diem payments for unused hospital beds, and France implemented fees for COVID-19 testing and treatment. Many nations also provided personal protective equipment (PPE) and hygiene materials either in-kind or reimbursed their costs.

In Italy, the Ministerial Decree of August 12, 2021 [40] introduced supplemental tariffs for COVID-19 hospitalizations, with maximum increases of €3,713 for medical area stays and €9,697 for ICU admissions. While these measures were an essential step forward, they were reactive

Table 6
Regression results.

	ICU(O.R.)	Outcome deceased (O.R.)	LOS(I.R.R.)	Hospital costs(I.R.R.)	Hospital services (I.R.R.)
Female	0.615** (0.097)	0.837* (0.076)	1.000 (0.009)	1.023*** (0.001)	1.013*** (0.003)
Charlson Comorbidity Index	0.663*** (0.058)	1.184*** (0.036)	1.007* (0.003)		
Age 65–74	0.701 (0.195)	2.292*** (0.420)	1.063*** (0.016)	1.059*** (0.001)	1.017*** (0.004)
Age 75–85	0.315*** (0.089)	4.587*** (0.757)	1.128*** (0.015)	0.889*** (0.001)	0.994 (0.004)
Age > 85	0.149*** (0.055)	10.669*** (1.781)	1.124*** (0.016)	0.684*** (0.001)	0.984*** (0.005)
Covid	2.955*** (0.679)	1.429** (0.156)	0.880*** (0.010)	1.714*** (0.004)	1.977*** (0.014)
Age 65–74#Covid	1.820 (0.658)				
Age 75–85#Covid	1.150 (0.442)				
Age > 85#Covid	0.552 (0.354)				
ICU		2.632*** (0.445)	1.737*** (0.026)	2.493*** (0.004)	2.842*** (0.013)
Outcome_deceased			0.711*** (0.008)	1.248*** (0.001)	1.138*** (0.004)
Days				1.028*** (0.000)	1.027*** (0.000)
DRG_resp_inf				0.823*** (0.002)	0.948*** (0.007)
DRG_septic				1.032*** (0.002)	1.141*** (0.008)
DRG_others				1.116*** (0.007)	1.027 (0.020)
DRG_resp_inf#Covid				0.651*** (0.002)	0.601*** (0.005)
DRG_septic#Covid				0.503*** (0.005)	0.559*** (0.014)
DRG_others#Covid				0.813*** (0.005)	0.768*** (0.015)
Constant	0.190*** (0.035)	0.068*** (0.011)	16.669*** (0.207)	703.473*** (1.790)	68.892*** (0.530)
Number of Obs	2829	2829	2829	2829	2816

Note: Given the different nature of the dependent variables analyzed (binary for mortality and intensive care utilization, count data for the number of hospitalization days and the number of services, and lower-bounded for cost data), various types of nonlinear models will be applied. Specifically, a logistic specification was used to model the probability of ICU and mortality (binary variables), a Poisson distribution to model the LOS, and number of services (countable outcomes) and a Tobit regression to model costs.

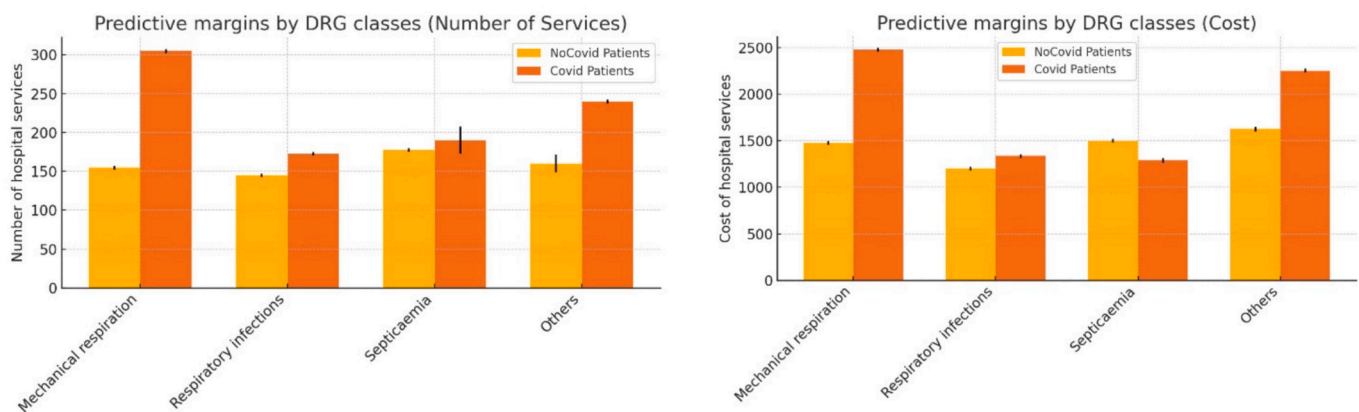


Fig. 2. Predictive margins by DRG classes – Number of hospital services and cost of hospital services.

rather than proactive, highlighting the need for more agile and pre-emptive policy frameworks. The rates would on average be higher than the average costs we found.

Given the difficulties encountered in correctly defining the reimbursement, these findings can assist in policy planning by the government. Considering that COVID-19 is the latest in zoonotic pandemic to

occur in the last 20 years (Ebola, Severe Acute Respiratory Syndrome, Zika, Middle East Respiratory Syndrome, Avian influenza), whose spread from animal hosts to human populations has been intensified by anthropogenic pressures, it is likely that similar outbreaks will occur [41]. Examining the hospital costs related to the treatment of hospitalized patients with COVID-19, as well as the main cost components and

related clinical factors, can assist health policymakers in better managing a comparable future situation by optimizing the use of financial resources.

The COVID-19 pandemic has demonstrated the urgent need for flexible and adaptive reimbursement frameworks capable of addressing the financial demands of health emergencies [5]. To prepare for future crises, policymakers should prioritize the development of reimbursement systems that can be rapidly adjusted to reflect the resource intensity and specific cost drivers of emerging diseases. For instance, establishing emergency DRG codes or a modular tariff structure could enable more precise and timely alignment between actual costs and hospital reimbursements.

Real-time data collection and cost monitoring are also critical in this context. By implementing advanced systems for tracking resource utilization during emergencies, health authorities and hospitals can gain immediate insights into financial needs. These insights would allow for swift adjustments to reimbursement policies, minimizing delays and ensuring that hospitals remain adequately funded throughout a crisis. This study has two main limitations. The data were obtained from one hospital and second, the analysis period was relatively short. These limitations are partly counteracted by the fact that the San Martino hospital was a main reference center for COVID-19 in Italy and experienced the most serious COVID-19 cases in 2020.

CRedit authorship contribution statement

Francesco Copello: Supervision, Data curation, Conceptualization. **Michela Dattaro:** Writing – original draft, Formal analysis, Data curation. **Lucia Leporatti:** Writing – original draft, Methodology, Conceptualization. **Marcello Montefiori:** Writing – original draft, Validation, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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