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ORIGINAL RESEARCH ARTICLE

The Association between COVID-19 Status and Economic Costs in the Early Stages of the COVID-19 Pandemic: Evidence from a UK Symptom Surveillance Digital Survey

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Abstract

Introduction In the absence of a vaccination programme, the coronavirus disease 2019 (COVID-19) pandemic had substantial impacts on population health and wellbeing and health care services. We explored the association between COVID-19 status, sociodemographic, socioeconomic and clinical factors and economic costs during the second wave of the COVID-19 pandemic.

Data The study used patient-reported digital survey and symptom surveillance data collected between July and December 2020, in collaboration with a primary care computerised medical record system supplier, EMIS Health, in the UK. The study included 11,534 participants.

Methods Generalised linear models (GLM) and two-part regression models were used to estimate factors associated with economic costs (£sterling, 2022 prices) estimated from two perspectives: (i) a UK National Health Service (NHS) and personal social services (PSS) perspective and (ii) a societal perspective.

Results Experience of the onset of COVID-19 symptoms started more than 3 months ago was associated with significantly higher NHS and PSS costs (GLM: £319.8, two-part: £171.7) ($p < 0.001$) and societal costs (GLM: £776.9, two-part: £675.6) ($p < 0.001$) in both models. A positive test result within the previous 14 days was associated with significantly higher NHS and PSS costs (two-part: £389.1) ($p < 0.05$) and societal costs (GLM: £470.7, two-part: £439.2) ($p < 0.01$). Age between 31 and 55 years was associated with significantly higher societal costs than age between 16 and 30 years.

Conclusion This study identifies and quantifies factors associated with the economic costs incurred during the second wave of the COVID-19 pandemic in the UK. The results of our study can inform cross-country comparisons and other cost comparisons.

1 Introduction

The outbreak of the coronavirus disease 2019 (COVID-19) pandemic had substantial impacts on population health and wellbeing and health care services. As of December 2023, the cumulative total number of infected cases in the UK was 21,017,576 and the cumulative number of attributable deaths was 161,224 [1]. The UK government's total spending on COVID-19 measures is estimated to be between £310 billion and £410 billion. This translates to a cost of roughly £4600–6100 per person in the UK [2]. It was reported in December 2022 that approximately 544,592,771 COVID tests had been conducted in the UK [3]. Moreover, the pandemic substantially reduced capacity to provide routine health care treatments and check-ups for conditions unrelated to COVID-19. In March 2020, after the introduction of the first lockdown, only one-third of those who needed inpatient care managed to use hospital inpatient services [4]. The National Health Service (NHS) in England and Wales rapidly reorganised health care services to manage the growth of COVID-19 cases, and this transformation included cessation of routine treatment and face-to-face appointments for many conditions to reduce the risk of infection to at-risk groups and secure extra bed capacity [5]. These delays significantly increased demand for critical care and thereby increased administration costs such as those resulting from hiring temporary staff to manage referrals to critical care [6].

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Key Points for Decision Makers

This study found that the experience of COVID-19 symptoms was associated with an increased economic burden from (a) a UK National Health Service and personal social services perspective, and (b) a societal perspective, inclusive of productivity loss.

The data showed that onset of COVID-19 symptoms more than 3 months ago, having a positive COVID-19 test result and age between 31 and 55 years were associated with significantly higher societal costs.

This study identifies and quantifies factors associated with the economic costs incurred during the second wave of the COVID-19 pandemic in the UK.

The COVID-19 pandemic resulted in substantial disruptions to employment and work patterns, resulting in losses in income and reduced economic output (productivity) in the UK and worldwide. In the UK, the pandemic led to the loss of approximately 660,000 jobs in the hospitality sector in 2020 [7]. The number of people requesting either jobseeker's allowance or universal credit for unemployment grew from 1.4 million people at the start of the COVID-19 pandemic in March 2020 to 2.6 million in January 2021 [8]. The Coronavirus Job Retention Scheme, which started from 1 March 2020 and finished on 30 September 2021, provided financial support to employers so they could retain and continue to pay employees on furlough up to 80% of their wages during COVID-19 lockdowns [9]. This scheme resulted in expenditure of approximately £70 billion for 11.7 million employees on furlough [9], and 1.2 million employees still remained on furlough at the scheme's end on 30 September 2021 [10]. Another financial support scheme by the UK government is statutory sick pay. In 2021, employees were entitled to ask their employers for £94.25 statutory sick pay per week if they were unable to work owing to illness associated with COVID-19 [11]. The COVID-19 outbreak thus resulted in a serious financial as well as health burden on households and the public sector.

Furthermore, the COVID-19 pandemic reduced productivity within businesses in the UK. Bloom et al. [12] measured the impact of COVID-19 on productivity, using data from a firm-level monthly survey of businesses that asked how much COVID-19 had affected their inputs and outputs. They found that COVID-19 reduced productivity within businesses between 2020 Q2 and 2022 Q1; that is, hourly labour productivity fell by an average of 2.3%, with the biggest drop of 3.7% in 2021 Q4. They concluded that COVID-19 had lowered total factor productivity in the UK private sector by up to 5% during the pandemic. Also, the Bank of England reported that total factor productivity fell by up to 5% at firm level during 2020–2021 [12, 13].

There is a paucity of evidence on the health and social service costs and broader societal costs, encompassing those attributable to productivity losses and productivity changes during the COVID-19 pandemic, especially in the context of national healthcare systems such as the NHS. We conducted a scoping review of the literature on COVID-19 and economic costs in March 2023 through the PubMed repository using the keywords 'COVID-19', 'economic costs' and 'UK' and retrieved only eight studies [14–22] that explicitly valued economic costs in some capacity. These studies focussed on hospital inpatient costs [15], costs of hypothetical suppression policies [22], intensive care unit and general and acute hospital ward costs [19], lost productivity [17], and community rehabilitation provision for people with long COVID [16]. Additional hand searches identified one study that estimated equity in health care access on the basis of a survey in the UK [4]. Thus, the current study contributes to the existing literature by analysing costs from two perspectives: (a) total healthcare and social service costs, and (b) societal costs inclusive of economic values of productivity changes.

The objective of this study was to estimate the association between COVID-19 status for individuals who experienced anosmia in combination with either high fever, a new continuous cough, or shortness of breath, sociodemographic, socioeconomic and clinical factors and (a) health and social care costs and (b) societal costs, incurred during the early period of the pandemic, namely July to December 2020. The specific objective was to assess how these economic costs varied by symptomatic status, stage of illness, socioeconomic status, sociodemographic and clinical characteristics, and severity of social restriction policies.

2 Methods

2.1 Digital Symptoms Surveillance Survey

This study used patient-reported data from a digital symptoms surveillance survey conducted by the University of Oxford and the Royal College of General Practitioner's Research and Surveillance Centre in collaboration with EMIS Health, a major primary care computerised medical record system supplier in the UK [23]. A second edition of the survey, which ran between July and December 2020 in 10 regions across the UK, collected 11,534 responses amenable to a costing analysis and was used for this study. This was after the first COVID-19 wave, during an increase in cases and the second wave of the pandemic in Autumn

2020. Figure 1 provides contextual information on national COVID-19 cases by specimen date before, during and after the data collection period. Participants aged 16 years and above were recruited via the EMIS-run Patient Access website and app, a digital primary health care service tool used in the UK to obtain health-related information and to book general practice visits. The survey collected patient-level information on COVID-19 related status, health and social care resource use, employment status and productivity changes, sociodemographic data, and data on patient health conditions and comorbidities. The survey was piloted to ascertain its acceptability to patients and patient comprehension of its constituent modules [23].

2.2 COVID-19-Related Status

The survey included a series of questions aimed at ascertaining information on participants' COVID-19-related status. COVID-19-related self-reported status was delineated in terms of participants' current health state and past health state. Symptoms-based COVID-19 conditions were identified as the combined presence or otherwise of anosmia (loss of smell or taste) with either high fever, a new continuous cough, or breathlessness, following the literature and the classification used in previous studies, including our own [24–26]. Respondents who reported as having had no COVID-19-related or any other symptoms at the time of the survey or previous COVID-19-related illness episodes were defined as healthy. Symptoms-based information on the time between the most recent COVID-19 related illness episode and respondents' health status during the survey completion was used to refine the definition. COVID-19 symptom-based status was further categorised as 'onset of COVID-19 symptoms in the past 3 months' and 'onset of COVID-19 symptoms more than 3 months ago', to align with the recall period of 3 months adopted for the resource use and costing questions.

Additionally, we used another measure, based on self-reported COVID-19 test results within a 14-day window (accounting for the COVID-19 incubation period [34]), defined as a binary variable with a value equal to zero if respondents had a negative test result and no symptoms, and equal to one if respondents had a positive test result and high fever/new continuous cough/breathlessness. This definition excludes both asymptomatic individuals with positive test results and those with symptoms but negative test results. This definition is in line with that applied within sensitivity analyses in our previous research [26]. In this study, COVID-19 tests include the following: sputum test, nose/throat swab, traditional blood test, or a finger prick test.

2.3 Costing Methodology

2.3.1 Overview

This study employed a cost-of-illness methodology. A retrospective assessment of economic costs incurred during the 3-month period that preceded the completion of the survey was implemented in this study. The estimation of costs followed a standard micro costing approach [27]. This approach assigns a weight to each service used (resource use). This weight reflects the opportunity cost, or 'price', of the service (unit cost). In other words, we multiplied the number of times each service was used by its unit cost to calculate the total cost for each service.

The value of productivity loss was estimated as a product of lost working days and daily wage estimated from individual annual income, using survey data collected specifically for this study. Productivity losses related to presenteeism (i.e. working with reduced productivity due to illness or

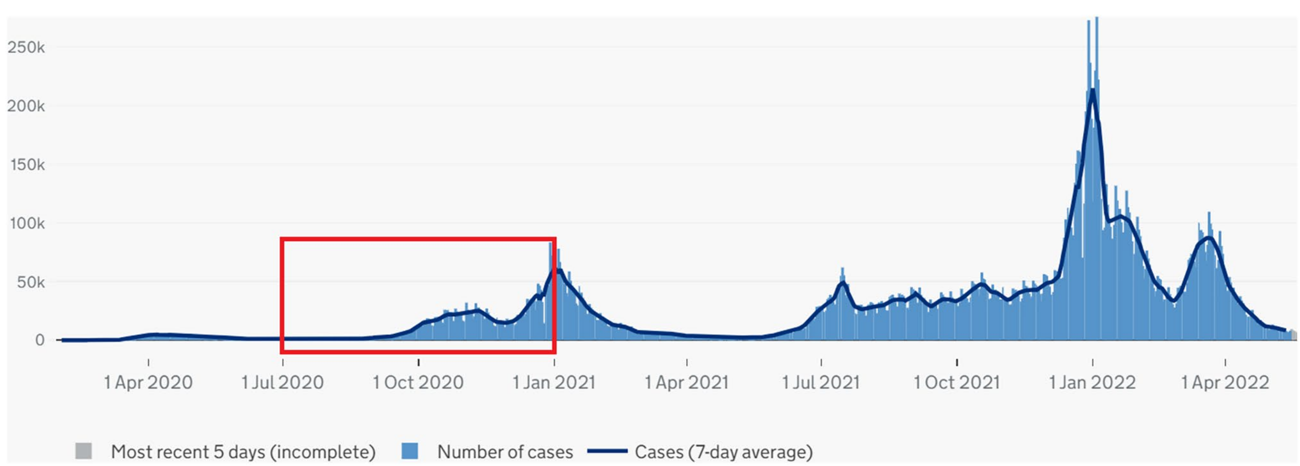

Fig. 1 COVID-19 cases by specimen date. (The red rectangle highlights the data collection period.). Source : GOV.UK [70]

another medical condition) were not considered in this study owing to measurement limitations. The steps for estimating economic costs, namely measurement and valuation of resource use, are described below.

2.3.2 Measurement of Resource Consequences

The survey data provided detailed information about the following health and social service use and other categories of resource use and expenses attributable to COVID-19 during the previous 3 months, as the purpose of this study was to estimate health and social care costs and, separately, societal costs over a retrospective 3-month period:

1. Use of hospital outpatient and accident and emergency services
2. Hospital inpatient stays
3. Use of primary care, community health services, and social services
4. Additional expenses incurred by participants
5. Duration and type of work absences; self-reported income losses

Data about participants' service use and expenses included information on the number of times they had used the following services during the previous 3 months: (i) hospital outpatient services, including contacts with accident and emergency departments, psychologists, psychiatrists, physiotherapists and other specialists; (ii) hospital inpatient stays by type and duration; and (iii) primary care services and community health and social services such as local pharmacists, ambulance services, NHS 111, social workers, community nurses, practice nurses, occupational therapists, physiotherapists, psychiatrists, psychologists, home carers, general practice services and health visitors. The survey also collected information about medication use, including both prescribed medicines and over-the-counter purchases of medicines. Further information included additional COVID-19-related expenses incurred by participants resulting from technical equipment for remote working, grocery delivery services, accommodation expenses for social isolation, protective gear, expenses incurred for caring for children and relatives, home-schooling, and duration of work absences (in days) by work type and self-reported income.

With respect to work and productivity, the survey collected information on employment status (worked fully from home, worked partly from home, partly on site, employer cut hours, lost job and not found another one, lost job and found another one, temporarily closed business or activity, permanently closed business or activity, using sick leave, been absent from work, laid-off temporarily or furloughed), lost working days, lost wage, occupation group (managers, directors and senior officials, professional occupations, associate professional and technical occupations, administrative and secretarial occupations, skilled trades occupations, caring, leisure and other service occupations, sales and customer service occupations, process, plant and machine operatives, elementary occupations) and levels of government support (e.g. universal credit, statutory sick pay, employment support allowance, job seeker allowance, payments for furloughed staff).

2.3.3 Valuation of Resource Consequences

Unit costs were mostly obtained from the Personal Social Services Research Unit's (PSSRU) Unit Costs of Health and Social Care compendium [28] and NHS reference costs [29]. Additional sources were searched for unit costs not covered by the PSSRU reports [30] and NHS reference cost schedules. Unit costs were converted to the reference year of 2022, the latest year for which price indices were available at the beginning of this study, using the NHS Hospital and Community Health Services (HCHS) Pay and Prices Index [31]. The value of technical equipment provided was annuitised to reflect depreciation and then adjusted to a 3-month time interval to align with the survey's 3-month data recall period. Table 1 presents the unit costs used to value resource inputs. Per diem intensive care had the highest unit cost (£874.8), while a food delivery service had the lowest unit cost (£3.50, per delivery, excluding food).

The value of lost productivity was estimated using the 'human capital approach', which values lost productivity in terms of reduced amount of working time due to illness [32]. The self-reported total number of lost working days was multiplied by the average daily salary for each participant, obtained from the survey [33]. It should be noted that the loss of income to employees was generally less than the value of their lost productivity owing to receiving government support including the furlough scheme.

2.3.4 Total Economic Costs

We estimated and analysed two categories of total economic cost outcomes: (i) NHS and personal social services (PSS) costs and (ii) societal costs. NHS and PSS costs included community health and social care costs, inpatient care costs, outpatient care and accident and emergency service costs, and medication costs. Societal costs encompassed all NHS and PSS costs and other relevant economic consequences, irrespective of the identity of the cost bearer [34]. These included NHS and PSS costs, costs directly borne by participants including technical equipment for remote working, grocery delivery services, accommodation expenses for social isolation and protective gear, and values of productivity losses. The value of social security benefits received was

Table 1 Unit costs of resource use items (£ sterling, 2022 prices)

Resource category	Unit cost	Unit of analysis	Sources of unit costs
Local pharmacist	21.3	Contact	PSSRU 2011/2012 [65]
NHS111	11.4	Contact	Turner et al. [30]
GP-telephone	8.7	Consultation	PSSRU2021/2022 [66]
GP-video	37.7	Consultation	PSSRU2021/2022 [66]
GP-surgery appointment	14.2	Consultation	PSSRU2021/2022 [66]
GP-home visit	45.6	Visit	PSSRU 2018 [67]
Ambulance	91.0	Patient journey	PSSRU2021/2022 [66]
Practise nurse	11.4	Contact	PSSRU 2011/2012 [65]
Community nurse	11.4	Contact	PSSRU 2011/2012 [65]
Physiotherapy	15.0	Contact	PSSRU 2011/2012 [65]
Counsellor[1]	59.6	Consultation	PSSRU 2011/2012 [65]
Psychiatrist	92.3	Consultation	PSSRU 2011/2012 [65]
Psychologist[2]	43.3	Consultation	PSSRU 2011/2012 [65]
Food delivery service	4.9	Use	Independent.co.uk [68]
Social worker	29.0	Contact	PSSRU 2011/2012 [65]
Home carer	17.0	Contact, weekday	PSSRU 2011/2012 [65]
Occupational therapy[3]	20.5	Contact	PSSRU 2005/2006 [69]
Outpatient	175.0	Day	NHS reference costs 19/20 [29]
Accident and emergency (A&E)	313.4	Attendance	NHS reference costs 19/20 [29]
Respiratory clinic	752.0	Day case	NHS reference costs 19/20 [29]
Intensive care	874.8	Day	NHS reference costs 19/20 [29]
General medical ward	325.0	Day	NHS reference costs 19/20 [29]
General surgical ward	325.0	Day	NHS reference costs 19/20 [29]
Cardiac care	620.0	Day case	NHS reference costs 19/20 [29]
Psychiatric ward	325.0	Day	NHS reference costs 19/20 [29]

[1]Band 7
[2]Band 7
[3]Band 5

excluded from estimates of societal costs to avoid double counting with the value of lost productivity.

2.4 Covariates

Covariates controlled for in the multivariate regressions were selected on the basis of published evidence [26]. The multivariate regressions included the following covariates: gender (male (referent), female), age (years) (16–30 (referent), 31–55, 56–65, above 65)**,** ethnicity (white (referent), non-white), employment status (not employed (referent), employed), comorbidity status (no comorbidity (referent), comorbidity), presence of risky condition (no risky condition (referent), risky condition), lockdown status at time of survey completion (no lockdown (referent), lockdown), education status (below undergraduate (referent), undergraduate, above undergraduate) region (Scotland, Northern Ireland, North East, North West, East Midlands, West Midlands, Wales, South West, South East, Greater London) and month of survey completion (January–December). Considering the UK state pension age of 66 years [35] and the minimum recruitment age into the survey of 16 years, we categorised the age groups into four categories: 16–30, 31–55, 56–65, above 65. Comorbidity status was categorised as presence or otherwise of any comorbid or chronic health condition. Comorbidities included the following diseases: lung disease such as asthma or chronic obstructive pulmonary disease (COPD), heart disease, chronic kidney disease, liver disease, nervous system conditions, diabetes, problems with spleen, a weakened immune system such as being on long-term steroid tablets or acquired immunodeficiency syndrome (AIDS), or seriously overweight (body mass index (BMI) ≥ 40). A risky pre-existing health condition (in the context of COVID-19) included organ transplant, pregnancy with heart disease, lung cancer with ongoing radiotherapy, blood or bone marrow cancer, cancer with ongoing chemo/immunotherapy, taking medication that weakens the immune system, sickle cell disease, cystic fibrosis or severe asthma/COPD, motor neuron disease, and patients asked to shield/self-isolate by the NHS. Lockdown status was defined by the periods of lockdown under the government-specified tier 3 (very high alert) and tier 4 (stay at home) restrictions (e.g. no mixing of households; hospitality closure; highly restricted travel), versus periods without such restrictions. Region and month variables were used as fixed-effect dummy variables in the regression analyses.

2.5 Econometric Analysis

This study used two multivariable regression modelling approaches to explore the association between COVID-19 illness status and individual characteristics and (1) total NHS and PSS costs and (2) total societal costs: generalised linear modelling (GLM) and two-part models. GLM regression is recommended for dealing with skewness in the distribution of outcome variables [36, 37], which is typically the case with cost data. Model specifications and goodness of fit were checked with a modified park test [36] and Akaike information criterion (AIC) statistics [38]. On the basis of these tests, a gamma distribution family and a log link were selected for this study. In addition, two-part regression is widely used for analysing economic costs in the presence of a significant proportion of zero-cost observations. Logit was used to specify the model for the first binary part, whilst GLM with a gamma family and logit link was used to specify the distributional family and link function for the second part [39]. Sampling weights were computed using sex and age population counts in the UK in 2020 and applied to the regression models to improve the representativeness of the study population. The values for age and gender that generated sampling weights were obtained from the Office of National Statistics (ONS) [40]. We also conducted a sensitivity analysis that included interaction terms for (1) age $\geq$ 66 years and symptoms in the last 3 months and (2) female gender and symptoms in the last 3 months, to examine the interaction between COVID status and its potential correlates. All analyses were conducted using STATA 17 (StataCorp, College Station, TX).

3 Results

The version of the survey that considered economic costs was completed by 11,534 participants. Among them, 317 reported their test-based COVID-19 status. Table 2 presents the descriptive statistics of the study population, which was categorised into two groups: (i) respondents with symptoms-based COVID-19 illness status information (N = 11,534) and (ii) respondents with test-based COVID-19 illness status information (N = 3117). In the symptoms-based sample, 54.5% of respondents were women (N = 6287), whilst 45.1% were men (N = 5207) (0.3% of gender data were missing). Of the respondents, 8.6% reported one or more risky health conditions (N = 996). The majority of respondents were aged $\geq$ 66 years (41.5%; N = 4790), followed by those aged 31–55 years (28.4%; N = 3280). The largest group of respondents were retired (43.1%, N = 4972), followed by those in full-time employment (25.7%; N = 2967). The mean NHS and PSS cost was £70.9 and £124.0 for the symptom-based and test-based cases, respectively. Similarly, the mean societal cost was £722.4 and £785.7 for the symptom-based and test-based cases, respectively.

Table 3 presents the results of regression analyses that categorised COVID-19 illness status using the symptom-based definition. For the model using NHS and PSS costs as the dependent variable, the onset of COVID-19 symptoms during the past 3 months was associated with higher costs than the reference group by £137.8 (p < 0.01) and £79.9 (p < 0.01) for the GLM and two-part models, respectively. For the same model, onset of COVID-19 symptoms more than 3 months ago was associated with higher costs than the reference group by £319.8 (p < 0.01), and £171.7 (p < 0.001) for the GLM and two-part models, respectively. In the same manner, for the model using total societal costs as the dependent variable, onset of COVID-19 symptoms more than 3 months ago was associated with higher costs than the reference group by £776.9 (p < 0.001) and £675.6 (p < 0.001) for the GLM and two-part models, respectively. Age between 31 and 55 years was associated with significantly higher NHS and PSS costs by £77.6 (p < 0.01) and £44.1 (p < 0.05) compared with the referent age group for GLM and two-part models, respectively. Age between 31 and 55 years was also associated with significantly higher societal costs by £447.7 (p < 0.01), and £376.9 (p < 0.01) compared with the referent age group for the GLM and two-part models, respectively. Age $\geq$ 66 years was associated with significantly lower societal costs by £563.7 (p < 0.001) and £536.8 (p < 0.001) compared with the referent age group for the GLM and two-part models, respectively. Employed status was associated with lower societal costs than the reference group by £244.9 (p < 0.01) and £200.9 (p < 0.01) in the GLM and two-part models, respectively. Undergraduate education status was associated with higher societal costs by £426.9 (p < 0.01) and £323.6 (p < 0.01) compared with the reference group (below undergraduate status) for the GLM and two-part models, respectively. Education status above undergraduate was associated with higher societal costs by £277.5 (p < 0.05) and £230.8 (p < 0.01) compared with the reference group for the GLM and two-part models, respectively. On the other hand, undergraduate education status was associated with lower NHS and PSS costs by £105.1 (p < 0.05) and £67.7 (p < 0.01) compared with the reference group for the GLM and two-part models, respectively.

Table 4 presents the results of regression analyses based on the test-based COVID-19 status variable, using either NHS and PSS costs or total societal costs as the dependent variable. A positive test result within the previous 14 days was associated with significantly higher societal

Table 2 Descriptive statistics of the study population

	N (%) Symptom based (*N* = 11,534)	*N* (%) Test based (*N* = 3117)
Gender		
Male	5207 (45.2)	1331 (42.7)
Female	6287 (54.5)	1779 (57.1)
Missing	40 (0.3)	7 (0.2)
Age (years)		
16–30	509 (4.4)	131 (4.2)
31–55	3280 (28.4)	1041 (33.4)
56–65	2955 (25.6)	847 (27.2)
≥ 66	4790 (41.5)	1098 (35.2)
Ethnicity		
Non-white	638 (5.5)	186 (6.0)
White	10,890 (94.4)	2931 (94.0)
Missing	6 (0.1)	0 (0)
Comorbidity		
Yes	1038 (9)	1897 (60.9)
No	10492 (91)	1159 (37.2)
Missing	4 (0)	61 (1.9)
Risky health condition		
Yes	996 (8.6)	257 (8.2)
No	9399 (81.5)	2549 (81.8)
Missing	1139 (9.9)	311 (10.0)
Social restrictions[1]		
Yes	791 (6.9)	299 (9.6)
No	10,739 (93.1)	2818 (90.4)
Missing	4 (0)	0 (0)
Employment status		
Not employed	7115.0 (228.3)	1596.0 (51.2)
Employed	4413.0 (141.6)	1521.0 (48.8)
Missing	6 (0.1)	0 (0)
Education status		
Below university degree level	7320 (63.5)	1960 (62.9)
Degree level	1872 (16.2)	488 (15.7)
Above degree level	2342 (20.3)	669 (21.5)
Region		
Scotland	659 (5.7)	173 (5.6)
Northern Ireland	1 (0)	0 (0)
North East	449 (3.9)	125 (4)
North West	1210 (10.5)	357 (11.5)
East Midlands	339 (2.9)	92 (3)
West Midlands	807 (7)	207 (6.6)
Wales	510 (4.4)	149 (4.8)
South West	496 (4.3)	122 (3.9)
South East	2223 (19.3)	615 (19.7)
Greater London	1004 (8.7)	296 (9.5)
Missing	3832 (33.2)	981 (31.5)
Month		
January	508 (4.4)	225 (7.2)
February	16 (0.1)	5 (0.2)
March	4 (0.03)	2 (0.1)

Table 2 (continued)

	N (%) Symptom based (N = 11,534)	N (%) Test based (N = 3117)
April	3 (0.03)	1 (0)
May	8 (0.1)	2 (0.1)
June	17 (0.2)	10 (0.3)
July	3 (0.03)	1 (0)
August	84 (0.7)	6 (0.2)
September	1069 (9.3)	244 (7.8)
October	8475 (73.5)	2103 (67.5)
November	756 (6.6)	281 (9)
December	585 (5.1)	237 (7.6)
Missing	6 (0.1)	0 (0)
Symptom-based	*N* (%)	*N* (%)
Never ill	6849 (59.4)	
Current illness (symptoms)	2278 (19.8)	
Past illness (symptoms)	2407 (20.9)	
Test-based		
COVID19 negative		2040 (65.4)
COVID19 positive		1077 (34.6)
NHS and PSS costs by COVID-19 status	**Mean (SE)**	**Mean (SE)**
Never ill	£33.5 (8.9)	
Current illness (symptoms)	£99.9 (21.0)	
Past illness (symptoms)	£156.7 (22.1)	
COVID19 negative		£75.5 (28.4)
COVID19 positive		£230.0 (39.4)
Total economic costs by COVID-19 status		
Never ill	£542.3 (32.4)	
Current illness (symptoms)	£766.4 (53.7)	
Past illness (symptoms)	£1193.5 (89.1)	
COVID19 negative		£609.6 (67.0)
COVID19 positive		£1117.4 (90.7)
NHS and PSS costs		
N	8994	2415
Mean (SE)	£70.9 (0.7)	£124.0 (2.5)
Missing	2540	702
Total economic costs[2]		
N	9841	2648
Mean (SE)	£722.4 (6.7)	£785.7 (14.1)
Missing	1693	469
Total	11534	3117

[1]Social restrictions are defined by the periods of lockdown or tier 3 (very high alert) and tier 4 (stay at home order) under the government-specified restrictions (e.g. no mixing of households; hospitality closure; highly restricted travel), versus the rest

[2]These included NHS and PSS costs, costs directly borne by participants including technical equipment for remote working, grocery delivery services, accommodation expenses for social isolation, protective gear and values of productivity losses

costs compared with the reference group by £470.7 ($p < 0.01$) and £439.2 ($p < 0.01$) for the GLM and two-part models, respectively. Age between 31 and 55 years was associated with significantly higher NHS and PSS costs by £160.7 ($p < 0.05$) and £126.4 ($p < 0.05$) compared with the referent age group for the GLM and two-part models, respectively. Likewise, age between 31 and 55 years was associated with significantly higher societal costs by

Table 3 Regression analyses: COVID-19 illness state (symptoms-based) and economic costs associated with COVID-19

	NHS and PSS costs		Societal costs	
	GLM	Two-part	GLM	Two-part
COVID symptoms (referent: no COVID symptoms)				
COVID symptoms in recent 3 months	137.8** (52.0)	79.9** (26.9)	145.1 (88.7)	129.8 (79.4)
COVID symptoms started more than 3 months ago	319.8** (104.0)	171.7*** (40.8)	776.9*** (172.7)	675.6*** (149.8)
Gender (referent: male)				
Female	−31.2 (36.7)	−26.9 (23.3)	−25.5 (90.8)	0.6 (68.5)
Age (years) (referent: 16–30)				
31–55	77.6** (26.4)	44.1* (19.6)	447.7** (153.9)	376.9** (136.9)
56–65	89.3* (40.2)	23.1 (18.9)	301.0 (160.8)	230.8 (142.4)
≥ 66	98.1* (49.5)	27.9 (26.5)	−563.7*** (127.7)	−536.8*** (123.6)
Other ethnic group (referent: white)				
Non-white	−24.6 (32.7)	−21.5 (25.1)	−143.9 (149.8)	−97.6 (127.2)
Comorbidity[1] (referent: no)				
Yes	60.4 (47.7)	31.6 (26.0)	169.4 (114.0)	112.0 (82.8)
Risky health condition[2] (referent: no)				
Yes	89.2 (66.1)	75.8 (47.3)	193.7 (165.0)	143.7 (119.0)
Lockdown (referent: no lockdown)				
Lockdown	34.2 (44.5)	−2.8 (21.1)	−21.8 (127.0)	−15.4 (98.3)
Employment status (referent: not employed)				
Employed	−49.3 (27.1)	−38.6* (17.8)	−244.9** (91.8)	−200.9** (68.6)
Education status (referent: below undergraduate)				
Undergraduate	−105.1* (42.8)	−67.7** (21.6)	426.9** (138.9)	323.6** (106.5)
Above undergraduate	−113.9** (43.3)	−60.9** (22.2)	277.5* (112.7)	230.8** (88.6)
Region				
Fixed effects	Yes	Yes	Yes	Yes
Month				
Fixed effects	Yes	Yes	Yes	Yes
N	7651	7651	8365	8365

[1]Comorbidities: lung disease such as asthma or COPD, heart disease, chronic kidney disease, liver disease such as hepatitis, nervous system conditions such as Parkinson's or MS, diabetes, problems with your spleen, a weakened immune system such as being on long term steroid tablets or having AIDS, seriously overweight (BMI ≥ 40)

[2]Risky conditions: having any highly risky pre-existing health conditions, such as: organ transplant, pregnancy with heart disease, lung cancer with ongoing radiotherapy, blood or bone marrow cancer, cancer with ongoing chemo/immunotherapy, taking medication that weakens immune system, sickle cell disease, cystic fibrosis or severe asthma/COPD and motor neuron disease.

Standard errors in parentheses

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

£541.6 ($p < 0.05$), and £473.4 ($p < 0.05$) compared with the referent age group for the GLM and two-part models, respectively. Appendix 1 shows the results of a sensitivity analysis that included interaction terms for (1) age ≥ 66 years and symptoms in the last 3 months and (2) female gender and symptoms in the last 3 months. The interaction terms were not statistically significant.

4 Discussion

This study estimates the association between COVID-19 illness experiences and economic outcomes, from both UK NHS and PSS, and UK societal perspectives. The study generated reliable estimates of economic costs and economic values by using patient-reported data from a COVID-19 Symptom Surveillance survey. To the best of our knowledge, this is the first study that explores the association between COVID-19 illness, sociodemographic and socioeconomic factors, and underlying health conditions,

Table 4 Regression analyses: COVID-19 illness state (test-based) and economic costs associated with COVID-19

	NHS and PSS costs		Societal costs	
	GLM	Two-part	GLM	Two-part
Test status (referent: negative test, no symptoms)				
Positive test result	537.6 (282.9)	389.1* (152.8)	470.7** (174.4)	439.2** (165.0)
Gender (referent: male)				
Female	−174.7 (113.6)	−240.7* (117.0)	−221.6 (190.2)	−156.9 (154.9)
Age (years) (referent: 16–30)				
31–55	160.7* (72.0)	126.4* (49.5)	541.6* (252.2)	473.4* (220.5)
56–65	464.6 (264.0)	199.5** (71.7)	328.0 (231.3)	340.4 (213.2)
≥ 66	213.2 (142.7)	102.4 (69.3)	−463.8* (191.1)	−417.3* (183.1)
Other ethnic group (referent: white)				
Non-white	−163.2* (76.7)	−124.9* (53.0)	−369.3* (150.8)	−314.9* (139.2)
Comorbidity[1] (referent: no)				
Yes	139.9 (127.3)	53.4 (69.6)	320.5 (225.3)	207.7 (169.6)
Risky health condition[2] (referent: no)				
Yes	110.4 (126.2)	131.9 (109.9)	502.6 (383.9)	360.4 (287.4)
Lockdown (referent: no lockdown)				
Lockdown	−78.8 (66.4)	−48.5 (64.5)	−10.7 (209.4)	26.8 (183.8)
Employment status (referent: no employed				
Employed	−15.3 (73.5)	−19.6 (58.4)	−138.9 (155.5)	−116.2 (130.9)
Education status (referent: below undergraduate)				
Undergraduate	−212.4 (126.6)	−178.0* (74.3)	187.9 (214.6)	155.4 (175.1)
Above undergraduate	−250.7 (131.2)	−176.6* (74.6)	53.2 (167.3)	67.7 (143.7)
Region				
Fixed effects	Yes	Yes	Yes	Yes
Month				
Fixed effects	Yes	Yes	Yes	Yes
N	2065	2065	2262	2262

[1]Comorbidities: lung disease such as asthma or COPD, heart disease, chronic kidney disease, liver disease such as hepatitis, nervous system conditions such as Parkinson's or MS, diabetes, problems with your spleen, a weakened immune system such as being on long-term steroid tablets or having AIDS, seriously overweight (BMI ≥ 40)

[2]Risky conditions: having any highly risky pre-existing health conditions, such as: organ transplant, pregnancy with heart disease, lung cancer with ongoing radiotherapy, blood or bone marrow cancer, cancer with ongoing chemo/immunotherapy, taking medication that weakens immune system, sickle cell disease, cystic fibrosis or severe asthma/COPD, and motor neuron disease.

Standard errors in parentheses

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

and broader societal costs, including values of productivity changes, in the UK.

The study found that the main factors associated with economic costs were presence of COVID-19 symptoms, positive COVID-19 test result, age, employment status and education. COVID symptoms that started more than 3 months earlier were associated with both higher NHS and PSS costs and higher societal costs; likewise, a positive COVID-19 test result was associated with higher societal costs. COVID-19 symptoms and a positive COVID-19 test result are likely to have affected productivity loss [41] through individuals having to take time off work or being unable to work from home. The experience of COVID-19 symptoms or a positive COVID-19 test result may have reduced working days through the implementation of social isolation or quarantine measures [42].

Age ≥66 years was negatively associated with societal costs. From a societal perspective, this finding suggests that the value of lost productivity was a key factor associated with societal costs during the pandemic as participants belonging to the oldest age group were largely economically inactive and did not experience as many lost working days as younger people did. In this study, the value of lost productivity increased as lost working days increased. In our data, in fact, the majority (83%) of people aged ≥ 66 years were retired. This association between age ≥ 66 years and decreased societal costs is in line with recent evidence [40]. The COVID-19 pandemic significantly impacted retirement plans, resulting in involuntary early retirements for older people who were made redundant and thus forced into self-employment after furlough [43]. If an individual was absent from the workforce owing to illness, this potentially represented a loss not only to the economy but also a loss to themselves in the form of lost income unless they were furloughed and continued to receive salaries/wages or benefited from government support for self-employed people [32]. The UK longitudinal analysis using the British Household Panel Survey revealed a significant decline in economic well-being following retirement [44].

On the other hand, age between 31 and 55 years in our study was positively associated with societal costs. Evidence for this age group is limited, as the existing COVID-19 literature primarily focusses on the two age extremes: younger and older populations; however, ample external evidence on the younger age group is available. Individuals aged 16–24 years accounted for a substantial portion (over 40%) of the total decrease in employment in 2020 [10]. It was found that younger workers with low incomes and the self-employed were more likely to have lost their jobs or experienced decreased income during the lockdowns [45]. As another example, it was reported that young people (18–25 years old) accounted for nearly half (46%) of the total employment decline during the COVID-19 pandemic, experiencing a cumulative job loss of 425,000 in Manchester, UK [46]. This tendency continues, and still fewer younger people were economically active as of March 2022 [10]. On the basis of this evidence, our findings suggest that productivity losses and societal costs generated by the COVID-19 pandemic for those aged 31–55 years were even higher than the younger group aged 16–30 years, despite productivity losses not being evenly distributed across age groups.

Our finding that higher education was associated with higher societal costs is consistent with evidence from a few UK studies. Recent reports published in the UK found a significant rise in economic inactivity during the pandemic as young people returned to full-time education [10, 47]. According to the Office for National Statistics (ONS), in the UK, the average unemployment rate for recent graduates was the highest across all graduate groups between Q1 2017 and Q3 2020, reaching its peak of 12.0% in Q3 of 2020 [48]. Blundell et al. [49] found that the number of unemployed workers per opportunity relative to pre-pandemic levels in June 2021 was more than double for those with undergraduate degrees compared with A-level qualifications, using data from the UK Labour Force Survey. However, our finding is not consistent with a number of studies conducted outside the UK [50–53]. In summary, this implies that our finding should be interpreted carefully and should not be generalised to countries outside the UK. This study found a negative association between NHS and PSS costs and education level. A Scottish study found that teachers and their household members, typically having higher education levels, experienced lower hospitalisation rates and a reduced risk of severe COVID-19 compared with the general population [54]. A recent study based on 12 UK population-based longitudinal studies found no clear association between education level and healthcare disruption. Outside the UK, a study conducted in Hong Kong revealed an association between highly educated women who experienced a significant negative mental health due to COVID-19 and their avoidance of healthcare services [55]. In short, this finding is inconclusive and should be interpreted carefully within the context of the study.

The value of our research lies in its estimation of the economic costs and factors associated with COVID-19 prior to the introduction of vaccines. This is particularly important because the widespread vaccination campaign in England throughout 2021 altered the pandemic's landscape, mitigating symptom severity and significantly reducing both morbidity and mortality rates [56]. Consequently, we can expect major differences in health and social service utilisation and productivity loss between the pre- and post-vaccination periods, making this study's findings more crucial for understanding the full economic burden of the pandemic. Vaccination decreased the occurrence and severity of long-term and short-term COVID-19 complications [57]. A growing body of evidence suggests that vaccination significantly reduced both the need for hospitalisation and the risk of mortality associated with COVID-19, regardless of whether hospitalisation occurs [56]. A study conducted in the USA using a decision analytic model concluded that vaccination reduced loss of workdays. The study found that loss of workdays due to hospitalisation or isolation measures was valued at \$1.87 billion with vaccination and \$4.22 billion without vaccination [58]. Given this evidence, our study can be used to compare the factors associated with economic costs incurred during the pre-vaccination and post-vaccination periods.

It cannot be definitively concluded that the estimated economic costs based on the GLM analyses are more precise estimates than those derived from the two-part estimator. Different statistical models have their own strengths and are best suited for analysing data within specific contexts. A GLM with a Gamma distributional family and a log link function is a common approach for modelling skewed cost data [36]. The log transformation helps to normalise the distribution of the cost variable, making the GLM framework suitable for analysis. A two-part model can be also considered for handling cost data where there are a large number of observations with zero values [59]. Given this, we attempted to estimate the results using alternative estimators.

This study has several strengths. Firstly, the findings of this study were based on a large survey sample of people from 10 regions across the UK. We had a large sample size, which allowed us to characterise associations with economic costs by health, sociodemographic, socioeconomic and clinical factors. Information on the timing of illness allowed us to compare economic costs among people at different stages of illness, while holding other factors constant. Our results were also consistent when we controlled for other factors that were associated with economic costs during the COVID-19 pandemic, such as comorbidities, physical health conditions and social restriction measures. This suggests that our associations between symptomatic COVID-19 illness and economic costs are robust and not simply due to other factors that affected the general population during the pandemic. The survey was conducted online, which allowed us to collect data across the whole of the UK. Secondly, by including lost working days and valuing those losses using self-reported income, this study provides evidence of factors associated not only with NHS and PSS costs during the pandemic but also with societal costs. Thirdly, this study provides precise cost results based on a micro costing strategy. It included various costing items for a wide range of resource categories, including hospital outpatient services, hospital inpatient stays, use of primary care, community health services and social services, and additional expenses incurred by participants. These resource use data were linked with unit costs for each item derived from reliable national cost compendia. As a result, compared with other studies [60, 61] that use simulation methods, this study provides more precise estimates of economic costs incurred during the pandemic.

There are limitations to our study that should be noted. Firstly, the respondents in this study voluntarily joined the survey, using a digital survey tool. Therefore, the sample is not fully representative of the UK population and may reflect a 'collider bias' [62], which is a distortion that modifies an association between an exposure and outcome. Likewise, owing to the study design, this research likely underrepresents people who were seriously ill or deceased from COVID-19. Prospective cohort studies may be better suited to capture data from these populations. Therefore, this study does not fully capture the total burden of COVID-19 across economic outcomes such as years or quality-adjusted life years lost. To reduce the bias, we applied sampling weights to the regression models. Because of this fact, the results of this study should be interpreted cautiously. Secondly, the survey was originally designed to collect information about the situation, symptoms, circumstances and resource use of people 'over the past 3 months'. Despite the fact that the survey only collected information about the past 3 months, it is still expected to provide a good overview of the economic activities and experiences of the participants. This is because the current symptoms of the survey participants are likely to have been related to the symptoms and resource use at previous time points. We attempted to overcome this limitation by controlling for the time when respondents' COVID-19 symptoms started. We classified the symptom variable by when they had the symptoms, generated a new variable, and included the variable in the regression analyses. Thirdly, this study does not consider productivity losses due to presenteeism. Presenteeism is the act of presenting to work despite being sick or injured, and includes reduced productivity; that is, employees who are sick or injured are often not able to work at their full productivity. Similarly, this study could not measure the impact on productivity of study participants working remotely whilst mildly sick. Unfortunately, the survey data did not collect information regarding presenteeism. Furthermore, there are no clear methodological guidelines as to whether productivity costs related to presenteeism need to be included in cost of illness studies [63], and hence we included only the economic value of work absences or work changes. Nevertheless, it should be noted that this is not a problem unique to this study. Many research studies have found that it is difficult to measure presenteeism [64]. A validated method to measure costs associated with presenteeism is still lacking [33]. It is a difficult task to determine how much productivity is lost when someone is not fully productive. Employees may be reluctant to admit that they have symptoms of illness, or they may not be aware of the impact that their symptoms are having on their productivity. Fourthly, the analysis does account for lost productivity from unpaid work such as unpaid care for older or disabled people or voluntary work, which have a direct effect on wellbeing and an indirect effect on the economy. Finally, it should be noted that our study results only apply to people experiencing the specific symptoms we included (i.e. reports of anosmia in combination with high fever/new continuous cough/or shortness of breath, and any other possible additional symptoms) and may not be generalisable to individuals with different symptomatic experiences. The inclusion of individuals with milder or no symptoms may have resulted in lower per-person costs compared with healthy individuals than the symptom profile adopted in this study.

In conclusion, this study identifies and quantifies factors associated with the economic costs incurred during the second wave of the COVID-19 pandemic in the UK. Furthermore, the results of our study can inform cross-country comparisons and other cost comparisons.

Appendix 1: A sensitivity analysis including interaction terms of female gender and symptoms in the last 3 months and age ≥ 66 years and symptoms in the last 3 months

	NHS and PSS costs	Societal costs
Gender (Referent: male)	0.1 (18.4)	66.3 (97.6)
Interaction: female × symptoms in recent 3 months	−3.4 (19.4)	−123.4 (117.0)
Age		
Age 31–55	47.4* (22.2)	432.2* (174.8)
Age 56–65	11.2 (20.8)	165.0 (171.1)
Age 66+	1.8 (24.7)	−731.9*** (149.7)
Interaction: age 66+ * symptoms in recent 3 months	12.3 (54.2)	257.6 (323.4)
Other ethnic group (referent: white)	−12.8 (20.7)	−144.1 (162.1)
Comorbidity[1] (referent: no)	39.5 (26.9)	179.3 (114.6)
Risky health condition[2] (referent: no)	52.6 (40.2)	151.9 (156.3)
Lockdown (referent: no lockdown)	−1.1 (19.8)	−53.9 (121.9)
Employed (referent: no employed	−22.1 (14.9)	−221.0* (92.6)
Education (referent: below undergraduate)	−41.3* (19.1)	460.7*** (137.3)
	−25.9 (24.6)	441.9** (158.4)
Month	−4.6 (4.2)	23.0 (19.0)
Region	−1.0 (2.7)	−29.6 (15.8)

***p<0.001; ** p<0.01; * p<0.05

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Declarations

Conflict of Interest None.

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Author Contributions S.W.K. carried out the bulk of the analyses, designed the economic study, drafted and revised the article, and approved the final article as submitted. S.P. designed the economic study, coordinated and supervised the analysis, critically reviewed the article, and approved the final version for publication. C.A. drafted and revised the article critically and approved the final version for publication. C.N. drafted and revised the article critically and approved the final version for publication. R.W. drafted and revised the article critically and approved the final version for publication. S.L. drafted and revised the article critically and approved the final version for publication. All authors read the final manuscript and approved the final version for publication.

Ethics Approval We obtained official confirmation from the University of Oxford Medical Sciences Interdivisional Research Ethics Committee (MS IDREC) (ref. R97572/RE001) that our study does not require ethics approval in the UK. EMIS Health's COVID-19 Symptom Surveillance tool covered the underpinning research infrastructure and governance, including approval and consent procedures for voluntary participation as articulated in EMIS Health's privacy policy. Processing of personal and sensitive data is conducted by EMIS Health under the legal basis of medical research or public interest. The data used for this study underwent previous full anonymization by EMIS Health. The research team had access to a dataset stripped of all personal identifiers.

Code Availability The Stata code used for this study is available upon request.

Consent to Participate EMIS Health obtained explicit consent from each survey participant (or their guardian, if aged 16–18 years) and provided de-identified data to the research team.

Consent for Publication from Patients/Participants Medical research to answer legitimate research questions in the public interest is justified under schedule 1, sections 2–4 of the Data Protection Act 2018 and in the presence of appropriate data subject safeguards. The legal basis for EMIS's processing of data is consent or approval for exemption under Section 251 of the NHS Act 2006.

Data Availability Statement These data were obtained from EMIS Health's COVID-19 Symptom Surveillance tool. Accessing these data requires permission from EMIS Health as it is not publicly available.

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