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Themed Section: COVID-19

Costing the COVID-19 Pandemic: An Exploratory Economic Evaluation of Hypothetical Suppression Policy in the United Kingdom

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ABSTRACT

Objective: This study aims to cost and calculate the relative cost-effectiveness of the hypothetical suppression policies found in the Imperial College COVID-19 Response Team model.

Methods: Key population-level disease projections in deaths, intensive care unit bed days, and non–intensive care unit bed days were taken from the Imperial College COVID-19 Response Team report of March 2020, which influenced the decision to introduce suppression policies in the United Kingdom. National income loss estimates were from a study that estimated the impact of a hypothetical pandemic on the UK economy, with sensitivity analyses based on projections that are more recent. Individual quality-adjusted life-year (QALY) loss and costed resource use inputs were taken from published sources.

Results: Imperial model projected suppression polices compared to an unmitigated pandemic, even with the most pessimistic national income loss scenarios under suppression (10%), give incremental cost-effectiveness ratios below £50 000 per QALY. Assuming a maximum reduction in national income of 7.75%, incremental cost-effectiveness ratios for Imperial model projected suppression versus mitigation are below 60 000 per QALY.

Conclusions: Results are uncertain and conditional on the accuracy of the Imperial model projections; they are also sensitive to estimates of national income loss. Nevertheless, it would be difficult to claim that the hypothetical Imperial model–projected suppression policies are obviously cost-ineffective relative to the alternatives available. Despite evolving differences between government policy and Imperial model–projected suppression policy, it is hoped this article will provide some early insight into the trade-offs that are involved.

Keywords: COVID-19, coronavirus, suppression, mitigation, economic evaluation, cost-effectiveness, United Kingdom.

VALUE HEALTH. 2020; 23(11):1432–1437

Introduction

Since the emergence of coronavirus disease 2019 (COVID-19) in December, the viral pandemic has spread from the Wuhan province in China across the globe, placing extraordinary demands on individuals, households, health systems, and every aspect of social and economic life.[1] Global confirmed cases have now surpassed a million and confirmed deaths are over 180 000.[2] In the United Kingdom there have been >130 000 confirmed cases with deaths (in and outside of hospitals) around 40 000 as of early June 2020.[3]

Most COVID-19 patients report mild symptoms and recover, with more serious infections skewed toward the elderly population and/or those with underlying conditions.[1] These vulnerable patients are more susceptible to acute respiratory distress and the development of pneumonia within 3 to 6 weeks of infection.[4,5] There is no known cure or vaccine for COVID-19, and although there may be some potentially effective pharmacological interventions, they have yet to be clinically validated. Governments have therefore introduced public health strategies that comprise a variety of nonpharmaceutical interventions (NPIs).[6]

Following the detection of the first case of COVID-19 in the United Kingdom in January 2020, UK government policy focused on containment with early detection and case isolation (eg, screening of arrivals from Wuhan province). In February 2020, the UK government introduced voluntary mitigation restrictions such as self-isolation for those with symptoms and social distancing advice for those most at risk.[7] By the fourth week of March, official UK government policy could be described as a strategy of enforced suppression, defined as case isolation and home quarantine, general social distancing (including a social venue ban), and school and university closure.

The Imperial College COVID-19 Response Team report (Ferguson et al, 2020)[8] and its projections published on March 16 are widely believed to have influenced the introduction of

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1098-3015/$36.00 - see front matter

suppression policies by the UK government. This study is an early economic evaluation of these hypothetical Imperial model–projected suppression policies and melds the rich outputs of the Imperial report with a model that estimated the impact of a hypothetical pandemic on the UK macroeconomy.[9] It constitutes an exploratory or early economic evaluation for the following reasons: it is not informed by a de novo cost-utility model but is an analysis of the results of disparate models; and government policy may have been influenced by, but not fully reflect, Imperial model–projected suppression policy.

Methods

Hypothetical Imperial Model–Projected Suppression Policies

This analysis compares 2 versions of hypothetical but plausible suppression strategies to a mitigation policy and an unmitigated pandemic presented in Ferguson et al (2020).[8] An unmitigated pandemic assumes no government control measures. The peak in deaths and intensive care unit (ICU) demand is predicted to occur by June 2020, with the latter being 30 times greater than the estimated surge capacity of 5000 ICU beds.[8]

The aim of mitigation, which was official government policy until the third week of March, is to reduce the impact of the pandemic by flattening the curve to reduce peak ICU demand and overall deaths. This analysis is in line with Ferguson et al (2020) and assumes a policy involving the following 3 NPIs: individual case isolation, home quarantine (ie, quarantine of a household with a suspected case), and social distancing advice for people over 70 years of age. Further, that these policies are implemented for 3 months without pause (April to July 2020) and are predicted to reduce deaths by half and ICU peak by two-thirds relative to an unmitigated pandemic.[8]

In suppression policy, the aim is to further flatten the curve and reduce ICU bed demand below surge capacity, by lowering the reproduction number (R) to 1 or below (ie, on average each new case generates 1 or fewer cases). Suppression involves the addition of more extensive controls to those implemented under mitigation, namely general social distancing and closure of schools and universities. The hypothetical suppression policies in this article assume alignment with Ferguson et al,[8] and the 3 mitigation NPIs are expected to remain in place until late 2021 but social distancing and school/university closures are triggered conditional on ICU bed demand. Two suppression strategies are considered: (1) suppression 1, triggered “on” when there are 100 ICU cases in a week and “off” when weekly cases halve to 50 cases; (2) suppression 2, triggered “on” when there are 400 ICU cases in a week and “off” when weekly cases halve to 200 cases. Ferguson et al[8] presented results for on triggers ranging from 60 to 400 ICU cases, and so the current analysis reflects the breadth of these plausible trigger scenarios. Current declared government suppression policy differs from these trigger scenarios, and the differences are discussed later.

Population-Level Disease Parameters

Ferguson et al[8] used an individual-based simulation model[10] to predict number infected, total deaths, cases that require critical care (ie, need admission to ICU), and cases that do not require critical care but require hospitalization (ie, non-ICU hospitalizations). Suitable quality-adjusted life-year (QALY) and costed resource use inputs were then applied to these projections. It was assumed that the infection was seeded in early January 2020 with a base-case reproduction number of $R_0 = 2.4$ (ie, on average each new case generates 2.4 more cases under unmitigated pandemic conditions). The proportion requiring hospitalization and critical care and the infection fatality ratio (IFR) varied by age based on early data.[11] It was assumed that those hospitalized would need 8 (non-ICU) bed days; 30% of those hospitalized would require critical care constituting 10 ICU bed days and 6 (non-ICU) bed days (16 days total). Fifty percent of those in critical care die, and age-variant IFRs determine other deaths; these assumptions resulted in a UK-level IFR of 0.9% and hospitalization rate of 4.4%.[8]

All population-level disease inputs (Table 1) for each of the strategies being evaluated are taken from the results of Ferguson et al[8] for those corresponding to $R_0 = 2.4$. Total deaths are taken as directly reported in text and tables. Excess ICU bed days for the unmitigated and mitigated pandemic are calculated by digitizing the relevant curves and using area under the curve methods. For suppression 1, there is only a relevant curve for $R_0 = 2.2$ and so the area under the curve was calculated and adjusted to reflect $R_0 = 2.4$ using the ratio of peak ICU figures reported for both R_0 values. Excess hospitalization (non-ICU) bed days could then be calculated using assumptions about hospitalization reported in Ferguson et al.[8]

Macroeconomic Parameters

Keogh-Brown et al (2010)[9] used a macroeconomic model of the UK to quantify the impact of a hypothetical influenza pandemic on macroeconomic variables including gross domestic product (GDP). The modeled routes by which a pandemic could influence GDP were through a reduction in labor supply owing to death, illness (ie, direct absenteeism), school closures, and prophylactic absenteeism; consumption shocks owing to illness and precautionary avoidance; and modest investment deferment.

Keogh-Brown et al[9] presented GDP loss scenarios for different pandemic severities and population behaviors. This article uses loss scenarios, for all interventions, consistent with a more severe disease: 50% of the population becoming infected, a working population mortality of 1.25%, and a 7-day average of direct absenteeism for those infected. The unmitigated pandemic assumes GDP loss consistent with 1 week of prophylactic absenteeism (PA) and no school closures (Table 1); the mitigation strategy, 4 weeks of PA and no school closures. Both suppression strategies assume GDP loss consistent with 4 weeks of PA, 13 weeks of school closures, and a more conservative precautionary consumption shock that raises 1-year GDP loss from 4.45% to 6.05%. Length of PA is varied, but under all scenarios it applies to 34% of the workforce (based on a survey and previous pandemic experience).[9] These base-case national income loss inputs do not align perfectly with the current pandemic (and suppression policy) and so extensive income loss scenarios were conducted.

The UK national income was calculated to be £2.3 trillion as converted from current US dollars.[12] For the scenario with QALY loss owing to unemployment, the workforce was assumed to be 32.6 million (Office for National Statistics).[13] In this scenario, weeks of unemployment for the suppression strategies is based on the proportion of time social distancing and school/university closures are triggered.[8]

Patient-Level QALY Loss and Costed Resource Use Parameters

All QALY sources used the EuroQol 5-dimension instrument, a descriptive system for quality of life comprising 5 dimensions (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression). Age-adjusted QALY loss associated with the average COVID-19 death was calculated by using age-varying QALYs[14] (based on age group's midpoints[8]) and the most recent England and Wales lifetables,[15] with weighting based on the IFR reported

Table 1. Summary of input parameters.

	Unmitigated	Mitigated	Suppression 1	Suppression 2
Population-level disease parameters (Ferguson et al[8])				
Total deaths[*]	510, 000	255, 000	15, 000	46, 000
ICU bed days[†]	7, 130, 158	3, 561, 617	141, 548	385, 326
Hospital (non-ICU) bed days[‡]	17, 587, 724	8, 785, 321	349, 152	950, 470
Macroeconomic parameters (Keogh-Brown et al[9])				
1-year national income loss (%)	1.84%	2.75%	6.05%	6.05%
Workforce unemployed (%)[§]	34%			
Weeks of unemployment[§,‖]	1	4	62	57
Patient-level QALY loss and costed resource use parameters				
Average QALY loss due to COVID-19 death	8.79882			
Average QALY loss for ICU bed day	0.00110			
Average QALY loss for hospital (non-ICU) bed day	0.00002			
Average QALY loss due to unemployment (per week)[§]	0.00161			
Average cost for ICU bed day	£1,152			
Average cost for hospital (non-ICU) bed day	£933			
Average (to death) healthcare saving due to COVID-19 death	£25, 544			
Average cost for end-of-life care[§]	£232			

AUC indicates area under the curve; COVID-19, coronavirus disease 2019; ICU, intensive care unit; QALY, quality-adjusted life-years.

[*] For unmitigated and mitigated total deaths as reported in text. For both suppression strategies taken from Table 5.

[†] For unmitigated and mitigated calculated using AUCs in Figure 2. For suppression 1 AUC in Figure 4 gives deaths for $R_0 = 2.2$ and so converted to $R_0 = 2.4$ using peak ICU bed numbers in Table 4 and assuming proportionality between total ICU bed days and ICU peaks.

[‡] Calculated using Ferguson assumptions: 30% of those hospitalized need critical care (CC); CC patients have 10 ICU + 6 non-ICU bed days; other patients hospitalized have 8 non-ICU bed days.

[§] For scenario analyses only.

[‖] 1 and 4 weeks are taken from Keogh-Brown et al[9] but 62 and 57 weeks based on % of time with social distancing in place reported in Table 4 of Ferguson et al.[8]

by age in Ferguson et al.[8] Average QALY loss per ICU bed day[16] and non-ICU bed day[16,17] were applied in a way consistent with an economic evaluation of pneumonia in the United Kingdom.[18] QALY loss owing to unemployment, based on a large Swedish quality-of-life study,[19] was applied as a decrement of 9.6%, taking account of the age-adjusted average utility of the UK population.[14]

Average cost for an ICU bed day and a non-ICU bed day were taken from National Health Service (NHS) reference costs (XC06Z and XC07Z).[20] End-of-life service costs corresponding to an inpatient emergency were taken from the Personal Social Services Research Unit[21] and adjusted to 16 days. An Institute for Fiscal Studies analysis[22] provided estimates of all inpatient healthcare costs (average per year) to death for different starting ages; using lifetables and weighting by Institute for Fiscal Studies, an average NHS healthcare savings could be calculated for each COVID-19 death. This accounts for 52% of total NHS hospital spending to death, and so this was adjusted upward to account for the remaining 48%.[22,23]

Results

A full list of assumptions is provided in Appendix A for the purposes of model transparency (see Appendix A in Supplemental Materials found at https://doi.org/10.1016/j.jval.2020.07.001).[24] The full breakdown of QALY loss by strategy, owing to COVID-19 deaths, ICU bed days for critical care patients, and (non-ICU) bed days are shown in Appendix B (see Appendix B in Supplemental Materials found at https://doi.org/10.1016/j.jval.2020.07.001). For all strategies, overwhelmingly most QALY loss is accounted for by deaths (≈ 99%), which is to be expected given the substantial average life-year loss per COVID-19 death. Total QALY loss is halved by mitigation (compared with an unmitigated pandemic) and then further reduced by 94% for suppression 1 and 82% for suppression 2. The scenario analysis including QALY loss owing to unemployment has a substantial impact on the Imperial model–projected suppression strategies—a 9-fold (4-fold) increase in QALY loss for suppression 1 (suppression 2)—attributable to the duration of unemployment spells.

For all strategies, most of the total cost is accounted for by national income loss, but the proportion it accounts for increases with more aggressive NPIs (and as hospitalization costs drop): 79% (unmitigated), 92% (mitigated), and almost 100% for both Imperial model–projected suppression strategies. Absolute national income loss increases 50% under mitigation and then is further doubled by suppression policies. Hospitalization (non-ICU) bed day costs are consistently double ICU bed day costs; healthcare savings from COVID-19 deaths are comparable to non-ICU bed day costs for all strategies.

Incremental total costs, QALY loss prevented, and incremental cost-effectiveness ratios (ICERs) do not vary greatly based on the

Table 2. Results for base-case settings and scenario and sensitivity analyses (R = 2.4).

	Suppression 1 vs unmitigated	Suppression 1 vs mitigated	Suppression 2 vs unmitigated	Suppression 2 vs mitigated
Base-case				
Incremental QALYs (ie, loss prevented)	4, 363, 464	2, 115, 656	4, 090, 420	1, 842, 611
Incremental costs	£85, 756, 622, 748	£70, 547, 645, 072	£85, 806, 769, 566	£70, 597, 791, 890
Cost per additional QALY	£19, 653	£33, 346	£20, 977	£38, 314
No death-related healthcare cost saving				
Incremental QALYs (ie, loss prevented)	£4, 363, 464	£2, 115, 656	£4, 090, 420	£1, 842, 611
Incremental costs	£73, 112, 468, 530	£64, 417, 146, 057	£73, 954, 471, 471	£65, 259, 148, 998
Cost per additional QALY	£16, 756	£30, 448	£18, 080	£35, 417
Unemployment QALY loss included				
Incremental QALYs (ie, loss prevented)	3, 279, 950	1, 085, 781	3, 092, 729	898, 560
Incremental costs	£85, 756, 622, 748	£70, 547, 645, 072	£85, 806, 769, 566	£70, 597, 791, 890
Cost per additional QALY	£26, 146	£64, 974	£27, 745	£78, 568
End-of-life cost included				
Incremental QALYs (ie, loss prevented)	4, 363, 464	2, 115, 656	4, 090, 420	1, 842, 611
Incremental costs	£85, 641, 720, 407	£70, 491, 934, 846	£85, 699, 063, 129	£70, 549, 277, 568
Cost per additional QALY	£19, 627	£33, 319	£20, 951	£38, 288
Net national income loss 50% less				
Incremental QALYs (ie, loss prevented)	4, 363, 464	2, 115, 656	4, 090, 420	1, 842, 611
Incremental costs	£37, 131, 122, 748	£32, 432, 645, 072	£37, 181, 269, 566	£32, 482, 791, 890
Cost per additional QALY	£85, 10	£15, 330	£9,090	£17, 629
Net national income loss 50% more				
Incremental QALYs (ie, loss prevented)	4, 363, 464	2, 115, 656	4, 090, 420	1, 842, 611
Incremental costs	£121, 737, 968, 530	£102, 532, 146, 057	£122, 579, 971, 471	£103, 374, 148, 998
Cost per additional QALY	£27, 899	£48, 464	£29, 968	£56, 102

QALY indicates quality-adjusted life-years.

Imperial model–projected suppression policy being compared to the unmitigated or mitigated pandemic (Table 2). The addition of an end-of-life cost has virtually no impact.

The ICERs are roughly proportional to changes in national income loss. For example, if income loss has been underestimated by 50% for all strategies, ICERs are expected to increase by around 50%. Consistent with Ferguson et al,[8] incremental results are relatively robust to changes in reproduction number (see Appendix C in Supplemental Materials found at https://doi.org/10.1016/j.jval.2020.07.001). Nevertheless, the results for R_0 = 2.2 suggest that the cost-effectiveness of suppression strategy increases as the transmission potential of COVID-19 increases.

Discussion

This study aims to cost and calculate the relative cost-effectiveness of the hypothetical suppression policies found in the Imperial College COVID-19 Response Team model.

For an economic evaluation to be meaningful, it must attempt to account for all the additional costs and health benefits associated with an intervention. For example, if the analysis had assumed an NHS perspective, the incremental analysis would show suppression strategy to be dominant (lower QALY loss and costs); but this would ignore the significant burden of costs that fall outside of the NHS budget that are required to achieve a reduction in deaths and hospitalizations (ie, national income loss).

The main strength of this evaluation is the use of population-level disease burden projections that are taken from a source that influenced the introduction of suppression policy by the UK government.[8] Nevertheless, it is important to note that these are highly uncertain projections of hypothetical strategies[25]; the various educated assumptions and inputs (eg, rates of compliance with NPI measures) must hold for the results of this economic evaluation to be valid. Reported COVID-19 deaths in the United Kingdom are already over the level projected under suppression 1 (15 000) and closer to those projected under suppression 2 (46

000). Deaths are predicted to have a large early peak and then level off with smaller peaks[8]; and these are deterministic point estimates and do not reflect parameter uncertainty.

This analysis would have the most predictive power if the evolution of suppression policy were to resemble the ICU trigger scenarios in Ferguson et al. Declared government policy is now based on regional R estimates, and so the timing and geographical distribution of suppression policies will likely differ from those modeled. Proportion of time under suppression (up to late 2021) may be the key determinant of how much of a divergence in projected deaths and hospitalizations the policy differences generate. If sustained containment of local outbreaks under "test and trace" is possible and successful, national income loss estimates may be relatively small and the ICERs estimated here could be considered a sort of effective upper bound.

Estimated NHS hospital savings owing to COVID-19 deaths do not include the costs of primary healthcare or social care services. The ICERs are relatively stable with changes in this variable: quadrupling the saving to £100 000 increases ICERs from around £35 000 (£20 000) per QALY to £45 000 (£30 000) versus mitigation (unmitigated) for both suppression strategies. Nevertheless, there is a case to be made that these costs are unrelated to treating COVID-19 and so should not be included in the analysis, which would reduce ICERs by around 10%. The addition of QALY loss owing to unemployment has a substantial impact on incremental QALYs and ICERs. Nevertheless, such a scenario can be considered extreme considering the furlough scheme introduced by the government (most of the QALY drop is owing to depression/anxiety about the future).[19]

No probabilistic sensitivity analysis is included because there are no uncertainty parameters reported in the main publications.[8,9] Discounting or debt interest is not considered for simplicity and because there is uncertainty about how national income loss accrues over time. A variety of intangible QALY losses and costs have not been modeled, including direct QALY effects of social distancing; QALY losses due to delays or displacement of other treatments, and wider social effects (eg, changes in criminal behavior). Excess bed days due to COVID-19 under unmitigated and mitigated pandemics are projected to be substantial and exceed NHS ICU bed capacity (Table 1); in contrast, it can be argued that under suppression, total occupancy due to COVID-19 will be similar to before the pandemic. Nevertheless, setting total excess bed days under the suppression policies to 0 lowers relative costs and ICERs only very slightly, as expected.

Results are sensitive to national income loss estimates, and these were taken from a source that is unlikely to reflect all the features of the COVID-19 pandemic.[9] The severe disease scenario from Keogh-Brown et al[9] assumed an IFR of 2.5% corresponding to a working population mortality of 1.25% and so is likely to overestimate COVID-19 severity. Nevertheless, income loss estimates for suppression policy (6.05%) reflect 4 weeks of prophylactic absenteeism and 13 weeks of school closures. This underestimates income loss relative to the hypothetical suppression polices modeled in Ferguson et al,[8] which suggest around 60 weeks of social distancing and school closures. Nevertheless, very recent forecasts suggest a sharp quarter fall in GDP (by up to 35%) but a long run fall of around 4% to 10% if suppression measures persist periodically into 2021, which is expected by Ferguson et al.[26-30] In this light, the base-case estimate of 6.05% income loss associated with Imperial-projected suppression policies is not unrealistic. Even a 10% loss under suppression translates to an incremental loss of 7.3% points (8.2% points) of national income versus mitigation (unmitigated) with ICERs below £90 000 (£45 000) (see Appendix D in Supplemental Materials found at https://doi.org/10.1016/j.jval.2020.07.001).

The government fiscal package, estimated to cost around 3% of GDP (net of liabilities),[31] is not intended to stimulate economic growth but has been described as a social insurance scheme. Therefore, it is assumed not to be an additional cost but to merely redistribute national income losses onto current and future taxpayers. It follows that there has been no adjustment for fiscal multiplier effects and the possible distortionary impacts of future changes in the tax system or monetary policy.

Cost-effectiveness invariably depends on views about the appropriate willingness-to-pay (WTP) threshold per QALY. A £20 000 to £30 000 per QALY threshold is used by NICE (£50 000 for end-of-life treatments)[32]; but this would assume national income loss only displaces other QALY-generating treatments funded from the NHS budget. More general estimates of the social value of a QALY suggest WTP thresholds of £10 000 to £70 000,[33] and this is consistent with the threshold used by the Treasury and Department of Health (£60 000 per QALY).[34,35] There will undoubtedly be substantial debate about what the relevant WTP threshold should be and even whether the pandemic constitutes a special case in which considerations of cost-effectiveness are less relevant (eg, Rule of Rescue).[36]

Results are uncertain and conditional on the accuracy of the Imperial model projections, especially under the hypothetical suppression policies being evaluated. They are also sensitive to estimates of national income loss. This analysis suggests that even assuming more conservative national income loss scenarios (10% under suppression), ICERs for the Imperial model–projected suppression policy versus an unmitigated pandemic are below £50 000 per QALY. Assuming a maximum reduction in national income of 7.75% (ie, an incremental loss of 5% points), ICERs for Imperial model–projected suppression versus mitigation are below £60 000 per QALY. In conclusion, based on this preliminary analysis it would be difficult to claim that the hypothetical Imperial model–projected suppression policies are obviously cost-ineffective relative to the alternatives available. Despite evolving differences between government policy and Imperial model–projected suppression policy, it is hoped this article will provide some early insight into the trade-offs required in planning the eventual end to suppression policies in the United Kingdom, in particular the impact of individual cost and QALY components on relative cost-effectiveness.

Supplemental Material

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.jval.2020.07.001.

Article and Author Information

Accepted for Publication: July 1, 2020

doi: https://doi.org/10.1016/j.jval.2020.07.001

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Acquisition of data: Zala, Mosweu, Critchlow
Analysis and interpretation of data: Zala, Critchlow, McCrone

Drafting of the manuscript: Zala, Mosweu, Critchlow
Critical revision of the paper for important intellectual content: Zala, Critchlow, Romeo, McCrone
Statistical analysis: Zala
Administrative, technical, or logistic support: Zala
Supervision: Zala, Romeo, McCrone

Conflict of Interest Disclosures: The authors reported no conflicts of interest.

Funding/Support: The authors received no financial support for this research.

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