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Estimating the monetary value of the deaths prevented from the UK Covid-19 lockdown when it was decided upon – and the value of “flattening the curve”

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Summary

In tackling Covid-19, the UK made a very significant decision to move from a mitigation strategy to one of suppression in mid-March 2020. As with any decision, this brings benefits and creates costs. In this paper, we seek to provide an indicative value of the benefits from the policy shift. We calculate the expected monetary value of the deaths prevented using data available when the decision was made.

We first calculate the expected number of incremental deaths prevented from Covid-19 from this policy shift to be around 159,000. The UK Government has placed great weight on preventing indirect “overflow” deaths by avoiding overwhelming the intensive care units at hospitals. We calculate that around 44,000 of the 159,000 deaths prevented come from “flattening the curve”. Suppression policies also unintentionally serve to reduce mortality risks from other causes (such as influenza, air pollution and road traffic accidents), which will avert around another 19,000 deaths.

The UK Treasury currently uses £2m as the value of a prevented fatality (VPF) in economic appraisal (based on the death of an “average” aged person e.g. from a road traffic accident). If we assume that all lives are valued equally (i.e. we do not adjust the VPF for the fact that fewer life years are lost from Covid-19 deaths than from road accidents), then we calculate the monetary value of the switch to be £318 billion. This translates to around £5,000 per capita in 2018 prices, of which the monetary value of avoiding the “overflow deaths” is around £1,400 per capita (which amounts to about 4% of GDP). When we add in deaths averted from other causes, the total value of the fatalities prevented is about £355 billion, or about £5,600 per capita. This represents about 16% of GDP.

These results are of course sensitive to the assumptions we make about the number of deaths prevented, to the VPF used and about the remaining life expectancies of those whose deaths the suppression policy averts. Deaths from Covid-19 are highly concentrated in older people and those with underlying health problems, who have lower life expectancies than the average individual. If we assume an average remaining life expectancy of eight years to account for this, then the value of the switch is £100 billion, or just under £1,600 per capita. This would be about 5% of GDP.

This value can be set against the costs of the suppression policy. We do not seek to calculate these here, but the costs will include lives lost and blighted by the inability to access services, loneliness, lack of physical exercise, domestic violence, child development and nutrition, child abuse, unemployment, divorce, and suicide. A full-blown cost-benefit analysis would also need to consider the distributional consequences of the policy move, and especially the intergenerational transfers from younger to older people. In the meantime, the indicative figure of £5,600 per capita can be seen to represent a generous estimate of the benefits of moving from mitigation to suppression at the time the decision was made.

1. Introduction

Covid-19 first emerged in Wuhan, China in December 2019 and was officially declared a pandemic by the World Health Organization on 11 March 2020 (World Health Organization, 2020). The first official Covid-19 cases in the UK were identified in late January 2020 (Department of Health and Social Care, 2020). In a report presented to the UK government, two fundamental strategies in tackling Covid-19 were presented: mitigation and suppression (Ferguson et al., 2020). Ferguson et al. (2020) define mitigation as “slowing but not necessarily stopping epidemic spread – reducing peak healthcare demand while protecting those most at risk of severe disease from infections and suppression as aiming to “reverse epidemic growth, reducing case numbers to low levels and maintaining that situation indefinitely.” The UK appeared to have adopted a mitigation strategy, but then on 23 March 2020, in arguably the most significant policy decision since WWII, switched dramatically to a suppression policy by closing schools, shutting down non-essential shops, restaurants, gyms and bars and enforcing widespread social distancing.

As with any decision, the government’s decision involves an implicit weighting of the costs and benefits of action. The decision was motivated by a desire to reduce the number of direct and indirect deaths from Covid-19. It also comes with other benefits, such as a decrease in road traffic accidents due to limitations in the freedom of movement, as well as a myriad of costs, such as lives lost and blighted by the inability to access services, unemployment, divorce, and suicide. In this paper, we seek to provide an indicative monetary value for the incremental (direct and indirect) deaths prevented from the UK government’s policy shift. We also calculate a monetary value for the expected number of life years saved by the policy shift based on the remaining life expectancies of the people whose deaths were prevented. These figures can then be compared to the costs of the policy shift to establish whether it was worth it on the grounds of cost-benefit analysis (CBA) (HM Treasury, 2018).

The deaths prevented from the change to a suppression policy can be broken down into three types: 1) direct Covid-19 deaths; 2) intensive care unit (ICU) overflow deaths; and 3) indirect deaths prevented due to restrictions in movement. The policy debate has centred around (1) and (2). The switch to suppression was, in large part, motivated by a desire to “flatten the curve” and prevent overwhelming the ICUs in the hospitals. To the best of our knowledge, this is the first paper to calculate the ICU overflow deaths prevented in the UK. For the purposes of CBA, we must also value the unintended benefits from (3), which include fewer fatalities from road traffic accidents, air pollution and influenza. It is estimated that at least one half of the deaths from Covid-19 would have occurred by the end of the year (Knapton, 2020) and so we focus on the *incremental* number of deaths prevented by the end of the year following the decision.

It is also possible to look at the benefits from the policy shift in terms of life years rather than lives (Sunstein, 2004). The gains in expected life expectancy from preventing the death of an 80-year-old are considerably less than from preventing the death of a 40-year-old (nine years compared to 42). We may wish to reflect this in our assessment of the policy shift even if policymakers were emphasising the reduction in mortality risks rather than the age groups whose risks were being most impacted. There are many issues surrounding intergenerational equity to consider here (HM Treasury, 2018) but, in the very least for the purposes of sensitivity analysis in CBA, it is important to consider the difference between lives and life years in the case of Covid-19 because it is a virus that is known to have a much higher case fatality rate (CFR) in older people (Office for National Statistics, 2020; Zhou, et al., 2020).

We seek to estimate the mortality and life expectancy benefits implied by the government's decisions at the time it was made. We therefore base our calculations on data in the epidemiological model formulated by Imperial College London because this report appears to have been so influential in the government's thinking (Ferguson et al., 2020). We calculate the average number of life years saved by the move from mitigation to suppression on what the government would have known in mid-March about the CFR by age. More accurate data become available every day, but decisions can only ever be made on the best available evidence *at the time*.

Monetary values act as a common metric in CBA, allowing for a comparison between costs and benefits, and so we need to monetise the deaths prevented and life years saved from the policy shift. Government agencies traditionally rely on the value of a statistical life (Viscusi & Aldy, 2003), or the value of a prevented fatality (VPF) as it is currently known in the UK (HM Treasury, 2018). The VPF is based on an individuals' *internal valuation* of the marginal rate of substitution between wealth and mortality risk. It is usually determined using one of two methods: 1) stated preferences of individuals about their willingness-to-pay (WTP) or their willingness-to-accept (WTA) a change in their mortality risk (HM Treasury, 2018) 2) revealed preferences based on the market behaviours of individuals, such as the compensating differentials accepted for different levels of mortality risk in different jobs (Viscusi & Aldy, 2003). The current VPF used by the Department for Transport (DfT) in the UK is around £2m in 2018 prices and is based on a stated preference study conducted in the 1990s, which elicited individuals' WTP to reduce their risk of death and injury from road traffic accidents (Carthy et al., 1998).

In order to calculate the value of a life year (VOLY) from the VPF, early approaches simply divided the VPF by the average remaining life expectancy (Hirth et al., 2000). Alternatively, it is possible to treat the VPF as an annuity with a set discounting factor (Pearce, 2000). In this paper, we treat the VPF as an annuity with equal "payments" over the remaining years of life. We deconstruct the annuity (VPF) into yearly payments (i.e., a VOLY) by using the HM Treasury's discount rate of 1.5%. We take the average citizen's expected life expectancy to be 40 years since the mean age in the UK population is around 40 and the average 40-year-old male and the average 40-year-old female in the UK have life expectancies of 40.77 and 43.99 years respectively (ONS 2018; ONS 2019). This is in line with previous analyses, such as Jones-Lee et al. (2007).

It is much more commonplace to consider life years rather than lives in the economic appraisal of healthcare intervention, where, the UK led the way in the adoption of quality-adjusted life years (QALYs) (National Institute for Health and Care Excellence (NICE), 2018). QALYs seek to combine the value of changes in quality of life and length of life into a single number, with one year of life in full health being equivalent to one QALY. Based on the submissions made by medical device manufacturers and pharmaceutical companies about the cost-per-QALY of their therapies, and from the decisions made by NICE about which therapies to recommend for NHS funding, it is possible to estimate an *external valuation* (i.e. based on policy-maker preferences) of the marginal rate of substitution between wealth and QALYs (Devlin & Parkin, 2004; Towse, 2002). Currently, NICE recommends using a standard threshold of around £20-30K per QALY when appraising new health technologies and a higher value of around £50K per QALY when appraising end-of-life technologies (NICE 2014; NICE 2018; Paulden, 2017). We now have four ways of calculating the VPF and the VOLY – an internal value of the VPF scaled, which can be “scaled down” to a VOLY, and an external value of the VOLY (QALY) which, can be scaled up to a VPF. We calculate the monetary value of the policy shift using all four methods.

The paper is organised as follows. In section 2, we calculate the incremental deaths prevented from Covid-19 deaths, account for the ICU “overflow” deaths prevented, and add in the unintended deaths prevented from fewer road traffic accidents, lower air pollution and less influenza. We take Ferguson et al.’s estimations of direct deaths from Covid-19 under the mitigation and suppression scenarios as given and assume that half of the deaths would have occurred in the next year, which translates into 115,000 incremental direct deaths prevented by the policy switch. We model the ICU “overflow” deaths prevented by using Ferguson et al.’s estimations of required daily ICU bed capacity for Covid-19 patients and calculating the available bed capacity on each day by relying on previous bed occupancy data and Covid-19 and non-Covid-19 ICU mortality rates (Greenstone & Nigam, 2020; National Health Service (NHS), 2020). We calculate 44,000 ICU “overflow” deaths prevented. For the unintended deaths prevented, we use Myllyvirta & Thieriot (2020)’s report from The Centre for Research on Energy and Clean Air (CREA) and Shilling & Waetjen (2020)’s research on the impact of Covid-19 on air pollution and car accidents, and interpolate for influenza deaths, arriving at around 19,000 deaths prevented. We therefore calculate that the policy shift from mitigation to suppression, based on the best available evidence at the time, was estimated to prevent 177,000 fatalities.

In section 3, we calculate the life years saved by estimating the remaining life expectancies of the different types of deaths. Accounting for the fact that deaths from Covid-19 are concentrated in older people with underlying health problems, and assuming a life expectancy of 8 years for Covid-19 deaths means 0.9m life years saved from preventing direct Covid-19 deaths. Assuming 8 years saved per Covid-19 ICU patient and 19 years saved per non-Covid-19 ICU patient translates to around 0.4m life years saved from preventing overflow deaths. Accounting for 22, 8 and 38 years saved for air pollution, influenza and road traffic accident deaths respectively translates to 0.3m life years saved from unintentionally preventing these other types of deaths. The ratios of the three types of deaths to each other (direct Covid-19, ICU overflow and other) is roughly 6:2:1 from a lives-saved perspective and about 3:1:1 from a life-years saved perspective, meaning the lower number of lives saved from other deaths is offset by the higher life expectancies of these deaths.

In Section 4, we attach monetary values to the mortality and life expectancy benefits. When we take the standard economics viewpoint to monetising the mortality benefits and use the £2m VPF recommended by the UK Treasury, the monetary value of the policy shift is about £355 billion, or about £5,600 per capita (HM Treasury, 2018). When we take the health economics point of view and construct a VPF based on the QALY values recommended by NICE, the monetary value is around £163 billion, or around £2,600 per capita (NICE 2014; NICE, 2018; Paulden, 2017). We provide the first estimate of the ICU overflow deaths prevented by the policy decision and show that ICU overflow deaths prevented make up about one quarter of the total benefits (£88m out of £355m). Monetising the life years saved results in benefits of around £100 billion, or £1,600 per capita, from the standard economics viewpoint and of around £51 billion, or £800 per capita from the QALY viewpoint.

In section 5, we discuss the results in the context of CBA, consider some limitations (e.g. around the assumptions we have made, showing which parameters the results are most sensitive to), and provide some suggestions for future research. The economic appraisal of mortality risks currently lacks a consensus on how to value life, and whether we should instead focus on life years. We hope that the four methodologies we set out against each other open the field to more discussion on this topic.

2. Calculating the incremental deaths prevented

Recall that these fall into three groups: 1) direct deaths from Covid-19 prevented; 2) ICU overflow deaths prevented; and 3) unintended deaths prevented from “lockdown” measures. We deal with each in turn.

2.1. Reductions in direct Covid-19 mortality

The Imperial paper projects that the “optimal” mitigation scenario would have resulted in 250,000 direct Covid-19 deaths, and presents three different suppression policy options, with the associated deaths ranging from 5,600 to 120,000. Even though it does not choose one estimate over the others, Neil Ferguson, the lead author, stated that a strategy of suppression was likely to lead to fewer than 20,000 deaths, hence we use this number for the suppression policy.[1] This leads to a difference of 230,000 direct Covid-19 deaths between the two policies. Some of the deaths from Covid-19 would have occurred in the next 12 months in any case. Ferguson has suggested that this could be anywhere between one-half and two-thirds “because these are people at the end of their lives or have underlying conditions.”[2] We take the lower bound and assume that 50% of patients who would have died from the mitigation strategy would have been in the all-cause mortality figures in the UK in the next year. This means that suppression was expected to result in around 115,000 fewer direct deaths from Covid-19.

2.2. Reductions in “overflow” mortality

One of the main factors influencing government policy was the “overflow” deaths in a scenario of mitigation due to ICUs in hospitals being overwhelmed. This was the rationale behind “flattening the curve” of the peak in infection and death rates. In order to calculate the “overflow” deaths in the mitigation scenario, we calculate the number of new Covid-19 patients and non-Covid-19 patients in need of ICU beds every day and compare the total inflow with the available ICU bed capacity on that day. In line with the Imperial report, we assume that Covid-19 patients stay in the ICU for 10 days on average. Based on our review of the literature, we assume that non-Covid-19 patients stay in the ICU for 6.25 days on average.[3]

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[1] Covid-19 deaths in the UK have already exceeded this number at the time of writing. However, we still use 20,000 in our calculations in order to estimate the mortality benefit the government sought at the time of its decision.

[2] We do not have access to the calculations underlying these numbers; however, we take the numbers as given from Ferguson considering his membership at the time in the Scientific Advisory Group for Emergencies (SAGE) which advises the government on the course of action for Covid-19.

[3] Ridley & Morris (2007) have shown that a regular ICU patient stays in the ICU for an average of 5 days. We adjust this number up by 25% to account for the fact that the ICU patients who will be coming in during the Covid-19 outbreak will be more serious patients who will need an ICU bed as a result of non-elective circumstances since elective surgeries will be cancelled. There is evidence in the literature to show that patients needing an ICU bed due to non-elective circumstances stay in the ICU for longer. To the best of our knowledge, a direct comparison of the average length-of-stay (LOS) of these two types of patients does not exist. However, Weissman (1999) has shown that the average LOS at a hospital where most ICU patients were there due to non-elective circumstances was 25% higher compared to other hospitals, hence we take this to be our adjustment factor and arrive at 6.25 days.

For the number of new Covid-19 patients in need of ICU every day, we rely on the Imperial College estimates of ICU bed demand in the "optimal" mitigation scenario. We do not have access to Imperial's ICU bed demand projections, so reproduce it using the same method as Greenstone & Nigam (2020) who reproduced the data for the US. We assume that ICU bed demand over time follows a normal distribution and reproduce the Imperial College data by taking the centre of the peak as occurring on the 5th of June. We take the ICU demand per 100,000 people as being 94 at the peak and the standard deviation as 18 days. This allows us to plot a normal distribution curve for the five-month mitigation period and reproduce the underlying data. Combining this data with the average length-of-stay for the patients (10 days) allows us to calculate the Covid-19 patient inflow for each day.

Next, we calculate the non-Covid-19 ICU patient inflow by relying on past ICU occupancy numbers. In January 2020, NHS had an ICU bed capacity of 4,123, of which 3,423 were occupied. We assume that the number of patients needing an ICU bed due to non-Covid-19 reasons will be lower during the Covid-19 outbreak than before the outbreak due to cancelled surgeries and the limitations in the freedom of movement. Since the number of surgeries cancelled due to Covid-19 is not available for the UK, we use the US ratio of 3:1 unavoidable to avoidable ICU patient ratio that we calculate from Greenstone & Nigam (2020) to estimate the total number of unavoidable ICU patients. We conclude that once the previous occupancy of 3,423 is cleared, a cumulative total of 2,500 patients will need an ICU bed on any given day during the Covid-19 pandemic. Assuming an average length of stay of 6.25 days for these patients leads to 400 new non-Covid-19 patients needing an ICU bed every day.

In line with Ferguson et al, we assume that Covid-19 patients have a 50% survival rate in the ICU. We follow Greenstone & Nigam (2020) in assuming that the Covid-19 patients have a 10% chance of survival outside of the ICU, which gives a change in the survival rate of 40% when the patients are treated in the ICU. Based on a review of the literature and assuming that the non-Covid-19 patients coming into the ICU during the pandemic will be more serious patients than the average ICU patient before the outbreak due to elective surgeries being cancelled, we estimate that the incoming non-Covid-19 ICU patients have a 60% chance of survival with treatment and 30% without, which means a 30% change in the survival rate.

At the time the decision was made in mid-March 2020, there were no official guidelines for the allocation of ICU beds when capacity is exceeded, so we randomly assign ICU beds between Covid-19 patients and other patients in need of ICU beds when the number of incoming patients exceeds available capacity. We find that, under these circumstances, 210,000 Covid-19 patients and 15,000 non-Covid-19 patients in need of critical care are denied ICU beds.[4] Assuming that being given an ICU bed leads to an absolute increase of 40% in the survival rate for Covid-19 patients and 30% for non-Covid-19 patients means that a total of 88,000 patients die due to being denied ICU treatment. We calculate that the optimal mitigation policy has prevented 44,000 incremental deaths that would have resulted from ICUs being unable to meet demand.

2.3. Reductions in other types of mortality

The decision to "lockdown" the country means severe limitations on freedom to movement, which will result in the unintended benefit of reducing mortality risks from other causes, most

[4] In line with Ferguson et al, we assume a Covid-19 surge capacity of 5,000 and combine this with the capacity for non-Covid-19 patients because we ultimately allocate the total capacity between the two types of patients.

notably air pollution, influenza, and road traffic accidents. Every year around 40,000 people die from air pollution, 20,000 people die from influenza[5], and about 2,000 from road traffic accidents (Department for Transport (DfT), 2019; Public Health England (PHE), 2019; Royal College of Physicians (RCP) & Royal College of Paediatrics and Child Health (RCPCH), 2016). We first calculate the deaths prevented from air pollution as a result of the UK government policy. As part of a Europe-wide study, The Centre for Research on Energy and Clean Air (CREA) in Finland estimated that more than 1,700 air pollution deaths in the UK have already been prevented in the first month (April 2020) following the government decision (Myllyvirta & Thieriot, 2020). In the suppression scenarios leading to 20,000 total deaths, the Imperial report estimates that the suppression measures would need to stay in effect for 64% to 94% of the time until a vaccine is found (Ferguson et al., 2020). We take the average of the two estimates and assume that the suppression measures were expected to be in effect 79% of the time (starting from April). Combining the 79% and the 1,700 air pollution deaths prevented per month (when suppression policies are in place) gives us 12,000 deaths prevented from air pollution until the end of 2020.[6]

Next, we calculate the deaths prevented from influenza and road traffic accidents. Shilling & Waetjen (2020) estimated that traffic accidents have fallen by 50% in California since the start of the lockdown. In order to calculate an illustrative value for the benefits of the policy shift for road traffic accidents and influenza, we assume that the suppression policies were expected to be in effect around 79% of the time starting from April (as above) and that half as many people will die from suppression compared to mitigation, which is around 6,500 fewer[7] deaths. We acknowledge that this is far from being a precise estimate.[8] Overall, we estimate that around 18,500 (rounded up to 19,000 elsewhere in the text) fewer people will die due to air pollution, influenza and road traffic accidents until the end of 2020 in a scenario of suppression compared to one of mitigation.

2.4. Total reductions in mortality

Combining the reductions from direct Covid-19 mortality, ICU overflow mortality and other types of mortality means 177,000 incremental deaths prevented by switching from a strategy of mitigation to one of suppression. See Table 1 for a summary.

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[5] Public Health England (2019) estimates that 28,330 people died of influenza in the UK between 2014-15, 11,875 between 2015-16, 18,809 between 2016-17 and 26,408 between 2017-18 but notes that these are uncertain numbers with varying confidence intervals; hence we take their average to be around 20,000.

[6] We assume that the "on" time is distributed equally in the time until a vaccine is found.

[7] It is worth noting that there might be an overlap between those at most risk of dying from influenza and those that die from Covid-19 but we take this overlap to be negligible.

[8] We also acknowledge that many of the deaths prevented from air pollution will occur in the future and therefore should be subject to discounting. Given the uncertainty around the number itself, we have done this here, and can in this sense be seen to be giving the benefits from the suppression policy the "best shot".

Table 1: The incremental Covid-19 deaths and other deaths in the mitigation and suppression scenarios assuming a 50% overlap with all-cause mortality

	All deaths	Covid-19 deaths					Other impacted deaths
		Total Covid-19	Direct deaths	Overflow deaths			
				Total Overflow	Covid-19 patients	Non-Covid-19 patients	
Mitigation	230,815	168,815	125,000	43,815	41,403	2,412	62,000
Suppression	28,500	10,000	10,000	0	0	0	43,500
Difference	177,315	158,815	115,000	43,815	41,403	2,412	18,500

We calculate the expected number of incremental deaths prevented from Covid-19 by the policy shift to be around 159,000, of which 44,000 come from arguably the most salient part of the policy, avoiding overwhelming the intensive care units at hospitals. The suppression policy will also unintentionally reduce mortality risks from other causes (such as road traffic accidents), which we estimate will avert around another 19,000 deaths. This leads to a total of 177,000 incremental deaths averted as a result of the UK government's decision to switch from a strategy of mitigation to one of suppression.

3. Calculating incremental life years saved

There has been considerable debate about whether the benefits from reductions in mortality risks should be valued according the expected number of life years saved rather than lives *per se* (Sunstein, 2004; Zeckhauser & Shepard, 1976). In one of the earlier contributions to the debate, Zeckhauser & Shepard (1976) pointed out that appraising policies with the two approaches could result in differing conclusions about the policies. Sunstein (2004) argues that a VOLY approach produces greater welfare than a VPF approach as all changes to mortality risks extend lives instead of saving them indefinitely. So, if the goal is to extend lives by as much as possible, a regulation that saves more life years, all other things equal, is preferable. One prominent criticism of this approach is that it would discriminate against the elderly and result in a "senior death discount" (Seelye & Tierney, 2003). This argument caused the Environmental Protection Agency (EPA) to cease plans to use an age-adjusted analysis in decision-making in 2003. But as Sunstein (2004) points out, since elderly people were once young and so the VOLY does not discriminate against them in the longer-term. The only people disadvantaged from the switch from VPF to VOLY are those that are elderly when the switch is first made as they will already be past their youth.

The issue of lives per se versus life years matter a lot in the case of Covid-19 because it is a virus that has a much higher case fatality rate (CFR) in older people. So, whilst we cannot resolve the issue of whether to use the VPF or a VOLY, we can provide empirical evidence on just how different they are.

3.1. Incremental life years saved from preventing deaths from Covid-19

Using the CFRs provided by Ferguson et al. for different age groups in the population (which have been converted into mortality by age group by Greenstone & Nigam, 2020) and assuming that the average age of the group falls in the middle of the age band gives us an average age of 75 for Covid-19 deaths (Ferguson et al., 2020; Greenstone & Nigam, 2020). The life expectancy of 75-year-olds is 11.48 for males and 13.19 for females in the UK (ONS 2018; ONS 2019). When we account for the fact that around 60% of the deaths from Covid-19 in the UK have been that of males, we reach a life loss of around 12 years (ONS, 2020).

It has been shown that a large number of those who have died from Covid-19 had underlying health problems (ONS, 2020). For example, 90.4% of the Covid-19 deaths that occurred in England and Wales in March and April 2020 had at least one pre-existing condition while the mean number of pre-existing conditions was 2.3 in the same timeframe (ONS, 2020). Briggs (2020) has shown how the life expectancies of Covid-19 deaths changes in the presence of an underlying health problem by adjusting the standardised mortality ratio (SMR) – the ratio of the observed deaths within a study group to the expected deaths. Using Covid-19 mortality data available on 16 April 2020, Briggs (2020) calculates that the deaths had an average life expectancy of 11.04 years with an SMR=1 i.e. without adjustment for any underlying health conditions. The 11.04 life expectancy becomes 8 when SMR=2 and 6.5 when the SMR=3. We take the midpoint of these two figures (i.e. 2.5) and apply it to the 12 we calculated above, which results in a life expectancy of 8 years. Multiplying 8 years by the 115,000 lives saved directly from preventing deaths from Covid-19 results in around 0.9 m life years saved.

3.2. Incremental life years saved from preventing ICU overflow deaths

The first part of overflow deaths comprises Covid-19 patients requiring ICU beds who are denied one. Research has shown that a much higher share of elderly people infected with Covid-19 require hospitalisation than younger ones and a much higher share of elderly people hospitalised with Covid-19 require an ICU bed than younger ones (Ferguson et al. 2020; Verity et al. 2020). For example, according to Ferguson et al., while 24.3% of people aged between 70-79 and infected with Covid-19 are hospitalised with a further 43.2% of those needing an ICU bed, the same figures are 4.9% and 6.3% respectively for the 40-49 age group. However, in a scenario like ours where ICU beds are assigned randomly, even if those needing an ICU bed are relatively old on average, it is possible that those denied a bed would be the young ones in the group. It is therefore difficult to determine with certainty how the age distribution of the Covid-19 overflow deaths would differ from that of direct Covid-19 deaths. Hence, we take their life expectancies to be equal to direct Covid-19 deaths at 12.

The second part of overflow deaths comprises the non-Covid-19 patients requiring an ICU bed who are denied one. The median age of ICU patients was 66 in 2013 in the UK (Creagh-Brown & Green, 2014) but the age distribution of would-be ICU patients denied an ICU bed during the overflow is likely to be different than other times both because elective surgeries will be cancelled and because some of those needing non-elective surgeries could need them due to different reasons than before (e.g. there could be a lower share of road traffic accidents and a higher share of suicide attempts, which could entail people with different life expectancies). It is therefore difficult to determine with certainty how the mean age of would-be ICU patients would differ from 66. Hence, we take it to be 66. An average 66-year-old male in the UK has a life expectancy of 17.98 years while an average 66-year-old-female has a life expectancy of 20.30 years (ONS 2019). We take the average of the two and assume that non-Covid-19 patients requiring an ICU bed who are denied one in an overflow would have had a 19-year life expectancy on average. Multiplying the 41,403 lives saved through preventing Covid-19 overflow deaths by 8 years and multiplying 2,412 lives saved through preventing non-Covid-19 deaths by 19 results in around 0.4 m life years saved.

3.3. Incremental life years saved from preventing deaths from other causes

We explore the life years associated with deaths prevented from the three other causes: Air pollution, influenza, and road traffic accidents. WHO (2018) attributes some of the deaths from five causes (acute lower respiratory infection (ALRI), lung cancer, ischaemic heart disease (IHD), stroke and chronic obstructive pulmonary disease (CPD)) in the UK in 2016 to air pollution.[9] We use the air pollution attributable deaths from these causes by age group from WHO (2018) and assume that the average age of the age group falls in the middle of the band to calculate that the average age of deaths from air pollution is 63. The life expectancy of 63-year-olds is 20.34 for males and 22.83 for females in the UK (ONS 2019). We take the average of these figures (and round up) to reach an average life expectancy of 22 for air pollution deaths.

Deaths from influenza are highly concentrated in the elderly (Public Health England, 2019). Between 2017-18, about 60% of influenza deaths in the UK were of people aged 65 and above, about 39% were of people aged 15-64 and the remaining 1% were of people younger than 15 (Public Health England, 2019). To the best of our knowledge, a further breakdown by age is not available. Hence, we take the life expectancies of influenza deaths prevented to be equal to the life expectancies of direct Covid-19 deaths at 12. Multiplying 12 by the 5,900 lives saved results in 0.07m life years saved.

Fatalities from road traffic accidents in 2018 in the UK had an average age of 48 (Department for Transport, 2020). An average 48-year-old male in the UK has an average life expectancy of 37.03 years while an average 48-year-old female in the UK has an average life expectancy of 40.15 years (ONS, 2019). When we account for the fact that 74% of the fatalities from road traffic accidents in 2018 were male, the average life expectancy is around 38 years. Multiplying 38 years by the 600 lives saved results in around 0.02m life years saved. In total, 1.6m life years were saved by preventing deaths from other causes.

3.4. Total number of life years saved

Combining the life-years saved from direct Covid-19 deaths, overflow deaths and other types of deaths means 1.6m life years saved by switching from a strategy of mitigation to one of suppression. Please see Table 2 for a summary.

Table 2: Incremental life-years lost by type of death in mitigation and suppression scenarios

All deaths	Covid-19 deaths					Other impacted deaths			
	Total Covid-19	Direct deaths	Overflow deaths						
			Total Overflow	Covid-19 patients	Non-Covid-19 patients	All other deaths	Air pollution deaths	Influenza deaths	Road traffic accidents

[9] The 40,000 air pollution deaths figure we use in the paper from RCP & RCPCH (2016) cover a wider range of diseases and hence is higher than the 9,502 air pollution attributable deaths in 2016 from WHO (2018). However, since the age breakdown is not available for RCP & RCPCH (2016) or elsewhere (to the best of our knowledge), we interpolate from WHO (2018).

Mitigation	2,493,052	1,377,052	1,000,000	377,052	331,224	45,828	1,116,000	880,000	160,000	76,000
Suppression	862,000	80,000	80,000	-	-	-	782,000	616,000	112,800	53,200
Difference (Life-years saved)	1,631,052	1,297,052	920,000	377,052	331,224	45,828	334,000	264,000	47,200	22,800

4. Monetising the benefits

As with any appraisal, it is vital to provide a monetary value for the benefits in order to compare them to the costs. In this section, we compare the standard economics approach of using the value of a prevented fatality (VPF) and teasing out the VOLY from this (Mason, Jones-Lee & Donaldson, 2008) with the health economics approach of using QALYs for the VOLY. Whilst we have not seen this done before, we also aggregate up the QALY-based value into a VPF**.** In standard economics, the value of a prevented fatality (VPF) is used in order to arrive at a monetary value for scenarios involving changes in the probability of death. The VPF is based on the internal valuations of individuals, i.e. how much an individual is willing to pay for a reduction in the probability of death.[10] The UK Treasury currently uses £2m as the value of a single prevented fatality (VPF) in economic appraisal (HM Treasury 2018). This figure is used by the Department for Transport (DfT) among other government bodies and is based on research conducted on behalf of DfT on the internal willingness-to-pay valuations of individuals to avoid mortality risk (Carthy et al., 1998; Department for Transport, 2019; HM Treasury, 2018)

The health economics approach is based on external valuations, i.e. the shadow price of health. In this approach, the monetary value of a life year, more specifically of a quality-adjusted life year (QALY), is used when appraising proposals with a potential to improve health outcomes (NICE, 2018; Paulden, 2017). Currently, UK's National Institute for Health and Care Excellence (NICE) recommends a standard threshold of around £20-£30K per QALY gained in appraising new health technologies (NICE, 2018) and a higher QALY value of around £50Kwhen appraising end-of-life technologies (NICE, 2014; Paulden, 2017).

We compare the standard and health economics methods of monetisation through two analyses. In section 3.1, we treat all the deaths prevented through the policy shift as equal by assuming an average life expectancy of 40 years for all of them and then apply the two methods of monetisation (by directly taking the HM Treasury (2018) VPF for the standard economics method but aggregating a VPF from the NICE (2018) and NICE (2014) QALYs for the health economics method). In section 3.2, we use the life expectancies calculated in section 2.2. for the different types of deaths and then apply the two methods of monetisation.

4.1. Valuing lives vs life-years

Taking all the deaths to be those of an average-aged citizen allows us to directly use the standard VPF of £2m as this figure is based on the life expectancy of an average individual (i.e. around 40 years)**.** For the health economics approach, we need to construct a 40-year VPF using the yearly NICE QALY values (NICE, 2014; NICE, 2018). To allow for the policy shift from mitigation to suppression to be seen in a more favourable light, we assume a QALY of £30k for the first 38 "standard" years of remaining life and a QALY of £50k for the last two "end-of-life" years of life (NICE, 2014; NICE, 2018). Discounting at the Treasury's rate of 1.5%, we end up with a 40-year VPF of £0.92m (HM Treasury, 2018).

[10] For example, if an individual is willing to pay £1,000 to avoid a 0.1% chance of dying, then the value of a prevented fatality is calculated by dividing the £1,000 by 0.001, which in this case leads to a VPF of £1,000,000.

It is worth noting that NICE does not present a definite timeframe for what constitutes end-of-life. In its 2019 end-of-life guide, it states that "end of life care is defined by NHS England as care that is provided in the 'last year of life'; although for some conditions, end of life care may be provided for months or years" (NICE, 2019). Its guidance for "appraising life-extending, end of life treatments" states that for a treatment to be qualified as an end-of-life treatment it needs to be "indicated for patients with a short life expectancy, normally less than 24 months" (NICE, 2009). Hence, we take the last two years as being the end-of-life. Using the standard economics approach and multiplying the current UK VPF of £2m with the lives saved by switching from mitigation to suppression means that the total value of the fatalities prevented is about £355 billion, or about £5,600 per capita. This represents about 16% of GDP. Using the health economics approach and multiplying the QALY-based VPF of £0.92m with the lives saved means the total value of the fatalities prevented is about £163 billion, or about £2,600 per capita. This represents about 7% of GDP.

We calculate the monetary value of the deaths prevented using the baseline data for the number of deaths prevented, and assuming an eight-year loss for direct Covid-19 deaths and Covid-19 overflow deaths (as calculated in section 2). We assume a 19-year loss for other overflow deaths, eight-year loss for deaths from influenza, 22-year loss for air pollution deaths and a 38-year loss for deaths prevented from road traffic accidents.

Relying on the standard economics approach and using a VPF of £2m, the monetary value of the deaths prevented would then be £100 billion, or around £1,600 per capita. This would be about 5% GDP. On the other hand, relying on the healthcare approach results in a monetary value of £42 billion, or around £700 per capita. This would be about 2% GDP.

			All deaths
Monetary valuation based on lives-saved	**VPF-based (2018 GBP)**	Total (m)	354.6
		Per capita	5,567
	QALY-based (2018 GBP)	Total (m)	163.1
		Per capita	2,560
Monetary valuation based on life-years saved	**VPF-based (2018 GBP)**	Total (m)	100.0
		Per capita	1,569
	QALY-based (2018 GBP)	Total (m)	51.1
		Per capita	802

See table 3 for a summary.

Table 3: The monetary valuation of the incremental Covid-19 deaths and other deaths in the mitigation and suppression scenarios

5. Discussion

In this paper, we calculate the expected number of deaths prevented and life years saved when the UK government, in response the threat posed by Covid-19, made the decision to switch from a strategy of mitigation to one of suppression in mid-March 2020. We base our calculations on the report from Imperial College (Ferguson et al, 2020), which was the evidence available at the time which most influenced the government's shift in policy. The evidence base is constantly evolving, of course, but decisions can only ever be made on what is expected at the time. Accounting for direct deaths prevented and life years saved from Covid-19, "overflow" prevented by the NHS not being overwhelmed and unintended benefits from reductions in air pollution, influenza and road traffic accidents, we estimate that a suppression policy would prevent 177,000 deaths and save 1.6 million life years until the end of 2020.

Cost-benefit analysis, which is also conducted from an ex ante perspective, requires that we attach monetary values to these benefits. The total value of the fatalities prevented is £355 billion, or about £5,600 per capita using the "internal valuation" from the standard economics approach to the VPF, or about £163 billion or £2,600 per capita when using the "external valuation" from scaling up a QALY value into a VPF. When we take the life expectancies into account and calculate the life-years saved, the value of the fatalities saved is £100 billion, or about £1,600 per capita using the "internal valuation" from the standard economics approach to the VPF, or about £51 billion or £800 per capita when using the "external valuation" from scaling up a QALY value into a VPF. These values can then be compared to the costs of the policy shift to determine which, if any, of these values makes the policy worth it from a welfare economic perspective.

Our overall results are, of course, sensitive to the assumptions that we make about the parameters. We have examined the sensitivity of our overflow deaths model by considering alternative assumptions for the four main parameters: the ICU lengths-of-stay (LOS) for Covid-19 and non-Covid-19 patients and the ICU mortality for Covid-19 and non-Covid-19 patients. This analysis shows that the deaths avoided only show a high sensitivity to the Covid-19 ICU mortality parameter, with the total overflow deaths ranging from around 16,000 to 72,000 when this parameter is changed by 50%.

We have also examined the sensitivity of our age-adjusted results to the life expectancy assumptions. Our results are not very sensitive to the different SMR values from Briggs (2020). When SMR=2, the total VPF-based value becomes about £90 billion and the total QALY-based value becomes about £47 billion. When SMR=3, the total VPF-based value becomes about £109 billion and the total QALY-based value becomes about £55 billion. Overall, our age-adjusted results are only moderately sensitive to the 8-year life expectancy assumption out of all the life expectancy assumptions, with the overall VPF-based value changing from £61 billion to £137 billion and the QALY-based value changing from £34 billion to £67 billion when the life expectancy of 8 is changed to 4 and 12 respectively. This is foreseeable as the three prevented deaths (direct Covid-19 deaths, Covid-19 ICU mortality deaths and influenza deaths), for which the life expectancy of 8 is used, make up more than 90% of all prevented deaths. As a contrast, the second most influential life expectancy assumption is the 22 years for air pollution, with the results only changing from £98 billion to £102 billion for the VPF-based approach and from £50 billion to £52 billion for the QALY-based approach when the 22 is adjusted downwards and upwards by the same absolute amount (4 years).

An alternative methodology to VPF, called a j-value, has been suggested for the UK (Thomas, Stupples & Alghaffar, 2006). It puts the average value of life at £9m (in 2018 GBP)[11] (Thomas, 2018). J-value proponents argue that the Carthy et al. (1998) study the current UK VPF figure is based on is outdated, based on too small a sample and invalid (Thomas & Vaughan, 2015; Thomas 2018). The higher figure is also closer to the VPF

[11] Based on the £8.6m in 2015 prices from Thomas (2018) which we convert to 2018 prices.

figures used in other countries, such as the US, where the Environmental Protection Agency, for example, uses a VPF figure of $7.4m (in 2006 USD), which is around £7m (in 2018 GBP) (Environmental Protection Agency, 2020).
We also test the sensitivity of our results to the higher value of £9m. When we take a lives-saved approach, the monetary value of the policy shift is about £1,600 billion, or about £25,600 per capita. When we deconstruct the £9m into the VOLY by treating is at as an annuity with equal yearly payments over the remaining 40 years and applying the HM Treasury's discount rate of 1.5%, the monetary value is around £460 billion, or around £7,200 per capita.

Using the VPF or VOLY for evaluating policy, especially in the context of Covid-19, has come under criticism (Adler, 2020). Adler (2020) argues that applying the VPF or VOLY figures to certain social distancing policies in the US brings about CBA results in favour of the policies (compared to the status quo) even when these policies are not Kaldor-Hicks efficient (which is used to define situations where those who are made better off compensate those who are made worse off, leading to Pareto efficiency, which, in turn, is a situation where nobody can be made better off without making somebody worse off). Adler (2020) recommends that social distancing policy be set "with reference to a utilitiarian or prioritarian social welfare function" instead of VPF-based methodologies. A utilitarian social welfare function posits that a policy is better than an alternative if the sum of total individual wellbeing under it is better than under an alternative (Adler, 2017). While the prioritarian welfare function follows the same idea, it assigns a greater weight to the wellbeing gains of those that are worse-off (Adler, 2017). We encourage researchers to explore these considerations further.

It is also worth noting that neither the internal nor external VPF and VOLY take proper account of the context of the mortality risks. It is well-established that people have different levels of dread surrounding different types of deaths (Slovic, Fischhoff, & Lichtenstein, 1981). It has been suggested that people are willing to pay a premium to avoid "bad deaths" such as cancer (Sunstein, 1997). The "dread" factor might even be more pronounced in the case of Covid-19 as it not only includes fear about the individual risk but also the collective risk (e.g. worries about relatives catching Covid-19). Hence, it can be argued that the monetary values used in this paper provide lower bounds of the value of the shift from mitigation to suppression. On the other hand, it is also possible that the shift stoked up greater feelings of dread about the type of death. A full CBA would also monetise the net effect on fear and other emotional reactions (Adler, 2004)

Indeed, there is increasing interest in monetising the subjective wellbeing (SWB) impacts of policies (Fujiwara & Campbell, 2011). In the context of Covid-19, some researchers have already begun to look into SWB-based valuations. A survey by Fujiwara et al. (2020) has shown that wellbeing levels in the UK during the "lockdown" were the lowest they have been since records began. They estimate that the cost of COVID-19 itself and the social distancing measures on mental health and wellbeing are about £2.25 billion per day. Assuming each month has 30 days, this translates to around £610 billion for the nine-month Covid-19 period (from April 2020 until the end of 2020) covered in this paper. In future, it might be possible to calculate a VPF or VOLY from SWB data, such as a global assessment of their life, but the state of the art is still relatively underdeveloped (Dolan, 2008; Dolan et al., 2008).

Currently, a limited number of other studies have also looked at the monetary valuation of different Covid-19 strategies, but these mostly focus on the US. Thunström et al have estimated that physical distancing in the US generates a benefit of $5 trillion, which translates to about £12,000 per capita in the UK or £3,400 in age-adjusted terms, while Greenstone and Nigam have found that physical distancing in the US leads to a benefit of $8 trillion, which translates to about £20,000 per capita. The differences between their numbers and ours are explained by: a) the VPF used in the US is higher (generally above £8m); b) these studies take "uncontrolled" outbreaks as their alternatives whilst we use an "optimal" mitigation scenario; and c) they do not account for an overlap between all-cause mortality and Covid-19.

One exception is the CBA conducted by Rowthorn & Maciejowski (in press), which calculates the economic costs under various scenarios in the UK. In contrast to our paper, which uses the infection projections available to the government at the time of the lockdown to calculate the expected benefits when the decision was made, Rowthorn & Maciejowski (in press) seek to show how the mortality benefits and the economic costs of Covid-19 are affected by policy choices and timings. Rowthorn & Maciejowski (in press) note the importance of avoiding overwhelming the NHS and so they put a cap on "the permitted level of infection to avoid overload of the health system". In contrast, our calculations lay out what the overflow deaths would have been in the policy alternative presented to the government.

Covid-19 is a pandemic in progress, of course, and the true extent of its impact will only be revealed in the long-term. What our analysis does show, however, is the monetary value of the expected benefits from mortality risk reduction when the UK moved from "optimal" mitigation to "optimal" suppression, and the fraction of this accounted for by the benefits from not overwhelming the NHS. About one-quarter of the expected benefits dcome from "flattening the curve".

The benefit figures should ultimately be compared to the costs of the suppression policy. The Office for Budge Responsibility (OBR) recently forecast that, as a result of Covid-19, real UK GDP could fall by 35% in the second quarter of 2020 and unemployment could increase by more than 2 million. We do not seek to calculate the full costs here, but they will include lives lost and blighted by the inability to access services, loneliness, lack of physical exercise, domestic violence, child abuse, unemployment, divorce, and suicide. A full-blown cost-benefit analysis would also need to consider the distributional consequences of the policy move, and especially the intergenerational transfers from younger to older people.[12]

In the meantime, the indicative VPF-based figure of £5,600 per capita and the indicative QALY-based figure of £2,600 from a lives saved approach and the indicative VPF-based figure of £1,600 per capita and the indicative QALY-based figure of £800 from a life-years saved approach can be seen to represent relatively generous estimates of the benefits of moving from mitigation to suppression at the time the decision was made.

[12] The Green Book recommends that additional sensitivity analysis be conducted "where the possible effects of an intervention being examined as part of an appraisal are long term and involve very substantial or irreversible wealth transfers between generations."

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