Willingness to pay for a fully effective shutdown during the SARS-CoV-2 epidemic in Germany

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Abstract

Background and aim: Given the anticipated surge of COVID-19 cases in Germany, the federal government and the federal states have ordered a shutdown. The main purpose of the shutdown is to avoid overstretching intensive-care unit (ICU) capacity ('flattening the curve'), while allowing for a controlled spread of SARS-CoV-2 in the population. The purpose of this study was to determine the societal willingness to pay (WTP) to minimize the number of life years lost due to the SARS-CoV-2 epidemic in Germany.

Methods: In the base case, the study compared a fully effective shutdown to a worst-case scenario with no ICU capacity left to treat COVID-19 patients. To this end, a life-table model was developed using, e.g., information on age-specific fatality rates, intensive care unit outcomes, and herd protection threshold. The WTP for an additional life year was borrowed from new, innovative oncological drugs as cancer may reflect a condition with similar ethical priority and associated anxiety.

Results: A fully effective shutdown is projected to yield an average gain between 0.02 and 0.08 life years (0.3 to 0.9 months) per capita in the German population. The corresponding WTP ranges between €2462 and €7921 per capita or, extrapolated to the total population, 6% to 19% of the gross domestic product in 2019. Nevertheless, even a fully effective shutdown is expected to yield a loss of 0.21 life years per capita at the time of herd immunity compared to the situation before the epidemic.

Conclusion: A fully effective shutdown is forecasted to yield a considerable gain in life years in the German population. Still, questions around affordability and underfunding of other parts of the healthcare system emerge.

Introduction

Coronavirus disease 2019 (COVID-19) is an infectious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). A SARS-CoV-2 outbreak was identified first in Wuhan, Hubei, China, in December 2019. The SARS-CoV-2 epidemic was recognized as a pandemic (a worldwide spread of a new disease (WHO 2010)) by the World Health Organization (WHO) on March 11, 2020. It was confirmed to have been transmitted to Germany on January 27, 2020. In terms of the number of reported COVID-19 cases, Germany currently ranks 4th in the world, while its current case fatality rate (CFR), which is 1.3%, is still below the average (as of April 3, 2020; Centre for Evidence-Based Medicine 2020). The later may present an underestimate due to a time window between the beginning of an infection and death. On the other hand, it may present an overestimate due to undiagnosed cases in the population. The median age of death was 82 years on April 4, 2020 (Robert Koch Institut 2020).

The German federal government and the federal states have responded with travel restrictions, closures of schools, universities, restaurants, cafes, bars, and other public and private entities. This resulting situation has been described as a shutdown (Dorn 2020), which is "an occasion when a business or large piece of equipment stops operating, usually for a temporary period" (Cambridge Dictionary). In Germany, the main purpose of the shutdown is to postpone the epidemic wave ('flattening the curve') in order to avoid overstretching intensive care capacity at the time of peak demand. Hence, intensive care capacity presents a critical bottleneck in responding to the epidemic. 'Flattening the curve' may thus buy time to expand health care and intensive-care capacities as well as to develop and test new vaccines and treatments. The process of developing a vaccine and obtaining market approval has been estimated to take about 12 to 18 months (WSJ 2020). At the same time there is a "race" to find COVID-19 treatments by repurposing drugs that are already approved for other diseases and have acceptable safety profiles (Kupferschmidt 2020). Given the necessary time lag, 'flattening the curve' may only be able to halt the epidemic by achieving herd immunity.

As a result of the drastic restrictions on everyday life imposed by the German authorities, domestic demand is being hit by a combined supply and demand shock (van Harn 2020).

The German ifo Institute estimates that prolonging the German shutdown for one additional week results in costs of 25 to 57 billion euros and causes a reduction of the gross domestic product (GDP) by 0.7 to 1.6 percentage points (Dorn 2020).

Trade-offs between protecting lives and resurging the economy thus seem inevitable. Therefore, the purpose of this study was to determine the societal willingness to pay (WTP) to minimize the number of life years lost due to the SARS-CoV-2 epidemic in Germany. The study takes an ex-ante viewpoint, i.e., before the surge of COVID-19 cases will potentially overstretch ICU capacity. It assumes that new vaccines or treatments will not be available before herd immunity is achieved. As the study does not analyze specific subgroups of the population but the population in aggregate, minimizing the number of life years lost effectively translates into minimizing lives lost by minimizing the CFR (if a vaccine were available, it would be possible to minimize life years or lives lost by reducing the incidence of SARS-CoV-2 infections). At the same time the WTP to minimize the number of life years lost corresponds to the maximum WTP for a shutdown that is 100% effective at preventing an overstretch of ICU capacity (because a fully effective shutdown leads to a minimization of lives lost and life years lost). Hence, under the scenario that a spread of the virus in the population is unavoidable, a fully effective shutdown presents the best-case scenario.

As a comparator of a fully effective shutdown I considered a scenario with no ICU capacity left to treat COVID-19 patients. While this scenario presents an extreme (worst) case, it is appropriate in order to determine the maximum health benefit of an effective shutdown and calculate the maximum WTP for the shutdown. This allows to make a comparison with actual and expected spending on the SARS-CoV-2 epidemic in Germany. In addition, the study considers alternative scenarios with ICU capacity being exceeded by varying amounts. These scenarios help to assess the maximum WTP for freeing up or adding ICU capacity as well as ‘flattening the curve’.

An alternative strategy to ‘flattening the curve’, which has also received some attention in the preceding weeks, is stopping or ‘squashing’ the curve. This strategy aims at controlling the epidemic until an effective vaccine or treatment becomes available. Obviously, it requires an even more rigid government intervention than 'flattening the curve'. I also determine the WTP for this scenario.

Methods

Life-table model

As a basis for the calculation of life years saved by a fully effective shutdown and alternative scenarios, I used a lifetable. In order to account for an increase in mortality due to COVID-19, I used two methodological approaches. In the first, I multiplied probabilities of survival from COVID-19 with probabilities of survival from competing causes of death. This calculation relies on an independence assumption, implying that individuals not dying from COVID 19 have the same probability of death as all individuals before the rise of the epidemic. Given that patients dying from COVID 19 have more comorbidities (Wu 2020), I assumed a harvesting effect in the second approach. The latter presumes that those who die from COVID-19 are sicker and "would have died anyway" (cf. Financial Times 2020). In this scenario, I assumed for age groups with death rates from COVID-19 higher than for competing diseases that beyond COVID-19 there are no other causes of death. This is compatible with the notion that COVID-19 may be "the cause of all fatalities" (Centre for Evidence-Based Medicine). This scenario assumes that those who do not die from COVID-19 despite being infected represent a healthier population that does not die from other causes within the next 12 months either. In either approach the population not being infected (which is one minus the proportion of the population recovered from COVID-19 to provide herd immunity) is assumed to remain at risk for competing causes of death.

Assuming that deaths occur, on average, halfway at each age, I applied the so-called life-table method (Barendregt 2009) to life years. In order to calculate life-expectancy gains of a fully effective shutdown and alternative scenarios, I determined the cumulative probability of an individual at age i of surviving until age j (i.e., the product of age-specific survival probabilities up to age j) as obtained from the life table. I took the sum over all ages j, thus obtaining the remaining life expectancy of an individual at age i. The remaining life expectancy is a hypothetical measure that summarizes the age-specific death rates in a population exposed to SARS-CoV-2. We determined the difference between fully effective shutdown (and alternative scenarios) and no intervention, thus obtaining the incremental number of life years gained. In order to account for the age distribution of the population, I weighted age-specific life-expectancy gains by age-specific population sizes. I performed all calculations for men and women separately and then aggregated results.

As updating the probabilities of survival in the life table and calculating the remaining life expectancy yields the remaining life expectancy (and associated loss) with lifelong exposure to SARS-CoV-2 (as opposed to a one-time exposure), it was adjusted assuming that the SARS-CoV-2 epidemic reflects a one-time event and not a recurrent one. Hence, I distributed the loss in life expectancy over the average remaining life time before the epidemic by dividing the two variables. I did not discount health benefits as the reported survival benefits from cancer treatment (see below), which are used to determine the WTP for a life year, were undiscounted as well.

Scenario analysis

In the scenarios with insufficient ICU capacity, all patients barred from admission to the ICU were assumed to die (Barry 2004). Yet, even with sufficient ICU capacity patients face a probability of death both in the ICU and post discharge. The resulting mortality is considered to be unavoidable (with currently available treatments) and hence cancels out in the estimate of life years of a shutdown fully effective at 'flattening the curve' versus no intervention. More specifically, I assumed that fatality in the ICU is already reflected in the CFR reported for Germany before the occurrence of the epidemic peak. Hence, I only added fatality one year after discharge (multiplied with the portion of the population admitted to the ICU) to the currently reported population CFR.

In addition, I considered 4 scenarios with varying degrees of insufficient ICU capacity. To determine the corresponding CFRs, I calculated a weighted-average CFR for each of these scenarios, with weights reflecting portions of patients admitted to the ICU and refused to be admitted, respectively. These weights were multiplied with the CFR of patients admitted and refused to be admitted, respectively. Of note, excess demand for ICU beds refers to average demand and not peak demand at the height of the SARS-CoV-2 epidemic.

Finally, I analyzed a scenario based on the idea of 'squashing the curve'. To this end, I applied mortality data before the epidemic and calculated the difference in life years gained compared to no intervention. The calculation is equivalent to adding the absolute loss of life years of a shutdown fully effective at 'flattening the curve' to the gain in life years of the latter compared to no intervention.

Sensitivity Analysis

In one-way deterministic analyses, I assessed parameter uncertainty by varying input parameters that are subject to variation one at a time.

Valuation of life years

Given the absence of an official cost-effectiveness threshold in Germany and the lack of data on health care trajectories of COVID-19 patients, which could allow deriving the WTP for an effective shutdown (cf. Gandjour 2020), I borrowed the WTP from the cost-effectiveness ratio of new, innovative cancer drugs in Germany. The fundamental idea is to establish consistency in decision making, a hallmark of ethical decision-making. To explain, cancer seems to have a similar ethical priority for treatment. That is, like COVID-19 cancer is a life-threatening disease that causes great anxiety both in affected and unaffected individuals and demonstrates a steep age gradient. Moreover, both diseases display similar urgency in terms of how soon the harm will be suffered if individuals are left untreated. While the threat of dying from COVID-19 is more immediate due to the short course of the disease, the majority of individuals is not yet infected and hence face a prospect of being infected. Furthermore, as prices of new cancer drugs have come under intense scrutiny in the public and are also driven by the costs of research and development, they provide an upper anchor for the WTP.

Given that the WTP would not only cover direct medical costs to treat COVID-19 patients but also indirect costs secondary to productivity loss, the perspective of the analysis is inherently societal. Given the societal perspective, I made the simplifying assumption that cancer drug costs from the SHI perspective are equal to drug costs from a societal perspective. Strictly speaking, this does not hold particularly if the manufacturer resides inside Germany. In the latter case, drug expenditures need to be adjusted for producer surplus as it presents a gain in societal welfare (Garrison 2010).

Data

Health benefits

Input data are listed in Table 1. I used the most recent mortality table of the German Federal Office of Statistics (2019), incorporating mortality data between 2016 and 2018 by age and gender up to the age of 100 years. In addition, I used data from the German Federal Office of Statistics on population size by age and gender up to the age of 100 years.

Data on overall case fatality in the German population and in 6 age groups as well as data on ICU fatality were obtained from the Robert Koch Institut (2020). Data on 270 cases could not be classified by age. Based on data from the Robert Koch Institut (2020) as well, the current admission rate to the ICU is 2.9%. A 6% estimate was presented in the media (Deutschlandfunk 2020), which I apply in a sensitivity analysis.

In Germany, the fatality rate on the ICU for all COVID-19 patients is 29% (Robert Koch Institut 2020). Eighty percent of patients admitted to the ICU due to COVID-19 are treated with mechanical ventilation (Robert Koch Institut 2020). Given that ICU survivors face an increased probability of death after discharge, I added the difference between ICU fatality rate and post-discharge fatality rate to the ICU fatality rate. Data were obtained from a meta-analysis of international studies on critically ill patients treated with prolonged mechanical ventilation (Damuth 2015). In this study pooled mortality at hospital discharge was 29% and thus is close to the rate reported for COVID-19 ICU patients. One-year mortality increased to 59%. Nevertheless, the meta-analysis may be criticized because data are relatively old (studies were published before November 2013) and heterogeneous in terms of outcomes. For example, the United States (U.S.) showed a significantly higher mortality compared to the rest of the world. Still, the fact that mortality at hospital discharge matches exactly the current data for COVID-19 patients seems to be a convincing argument in favor of incorporation of data from this meta-analysis. In a sensitivity analysis, I incorporated the one-year CFRs reported for the U.S. and non-U.S. countries (73% and 47%, respectively).

A considerable increase in mortality after hospital discharge has been confirmed in a recently published study on 21 COVID-19 patients admitted to the ICU at a single center in Washington State (Arentz 2020). In this study CFR at hospital discharge was 52% and increased 12 days after admission to 67%. In a sensitivity analysis I incorporated the CFR on the ICU from this study as an upper bound as it presents real-world evidence on COVID-19 patients. As the lower bound, I used data from an analysis of the European Surveillance System (TESSy) database including 13,368 patients admitted to the ICU with laboratory confirmed influenza virus infection between 2009 and 2017 (Adlhoch 2019). In this sample, 83% of patients were ventilated, comparable to current rate in Germany (80%). CFR was 21%, based on a median age of 59 years of admitted patients. Hence, the median age was lower than the median age of death (82 years) currently reported for Germany (Robert Koch Institut 2020). Nevertheless, it needs to be considered that in the SARS-CoV-2 epidemic a portion of the elderly patient population is less likely to be admitted to the ICU and dies, e.g., in nursing homes.

Willingness to pay

In Germany, annual treatment costs for new cancer drugs launched between 2011 and 2015 and granted an additional benefit by the German Federal Joint Committee are €65,854 on average (Hammerschmidt 2017). Average annual costs of comparators are €26,102 (Hammerschmidt 2017), resulting in incremental costs of €39,751.

Information on the average incremental survival benefit was taken from an analysis of all anticancer drugs launched in Germany between 2011 and 2016 and granted an additional benefit by the German Federal Joint Committee until June 2016. The analysis shows a median incremental survival benefit of 4.7 months or 0.39 years (Storm 2017). This result is similar to what was found in an analysis of 58 anticancer drugs approved in the U.S. between 1995 and 2013, showing an average incremental survival benefit of 0.46 years (Howard 2015). Yet, in both analyses incremental survival benefits are underestimated because they are restricted to the trial period, i.e., are not extrapolated beyond the trial period (strictly speaking, this is the case only for 47 out of 58 drugs in the study by Howard et al.; see also the Discussion).

Dividing incremental costs by the incremental survival benefit yields €101,493 per life year gained (€39,751/0.39 life years).

Results

Health benefits

Based on the independence assumption of mortality rates, a shutdown fully effective at 'flattening the curve' is projected to result in 605,000 lives being saved and 3.1 million life years being gained at the time of herd immunity (versus no intervention). The average number of life years per avoided death is 5.1, which is lower than the average remaining life expectancy before the epidemic (38.8 years), reflected the age gradient in COVID-19 deaths. Of note, the number of life years per avoided death is equivalent to the change in life years gained by a 1% change in CFR. Based on the harvesting assumption, the number of lives saved in COVID-19 is set to be the same. However, for competing diseases additional lives are forecasted to be saved (192,000 lives) because mortality from competing diseases is assumed to be lower.

On a per-capita basis, a fully effective shutdown is projected to yield an average gain of 0.053 life years (0.6 months) in the German population. This estimate is subject to non-negligible uncertainty, however. As shown in the sensitivity analysis (see Figure 1), a higher CFR in the population, ICU, or post discharge reduces the health benefit by one to two thirds. Health benefits of a shutdown also diminish when ICU capacity is exceeded. As shown in Table 2, if shutdown measures do not turn out to be successful, exceeding ICU capacity by 100% could more than halve the gain in life years.

Nevertheless, at the time of herd immunity, even a shutdown fully effective at 'flattening the curve' is expected to yield a loss of 0.21 life years per capita compared to the situation before the epidemic. For a newborn the loss in life expectancy amounts to 0.120 and 0.145 for males and females, respectively. The gain in life years of 'squashing the curve' amounts to 0.26 (0.053 + 0.26) life years per capita.

Willingness to pay

The WTP for a shutdown fully effective at 'flattening the curve', based on a per-capita gain of 0.053 life years, is approximately €5418 per capita (see Table 2) or, extrapolated to the total population, 13% of Germany's GDP in 2019. Using lower estimates based on the sensitivity analysis, the WTP decreases to 6% of the GDP. The WTP for 'squashing the curve' even amounts to 62% of the GDP.

Checks on internal validity

The product of the probabilities of ICU admission and death cannot exceed the CFR in the general population. In fact, given that a portion of deaths occur outside the ICU even with sufficient ICU capacity (e.g., in nursing homes), the product needs to be smaller. This was confirmed (1.0% < 1.3%).

Furthermore, the product of population CFR, herd protection threshold, and number of life years per avoided death divided by the average remaining life time before the epidemic yields a number very close to the loss of life years per capita compared to the situation before the epidemic (0.2037 versus 0.2052). The fact that the number is a little smaller is attributed to SARS-CoV-2 cases and associated deaths that could not be categorized by age by the Robert Koch Institut.

Moreover, I performed a back-of-the-envelope calculation to verify the health benefits of a shutdown fully effective at 'flattening the curve' versus no intervention. Multiplying the average remaining life expectancy in Germany at age 82 (the median age of death) with the increase in CFR under no intervention and the herd protection threshold yields a number very close to that calculated by the model (0.055 life years versus 0.053 life years).

Discussion

This study uses a lifetable model to estimate the impact of a shutdown on lives saved and life years gained in Germany. Despite the fact that the SARS-CoV-2 epidemic is presumed to be a one-time event, the loss of life years with insufficient ICU capacity is tremendous, resulting in a commensurate health gain by a shutdown that is fully effective at 'flattening the curve'.

The loss of life years expressed in terms of the life expectancy of a newborn approximates the annual gain in life expectancy in Germany over the past decade (Federal Office of Statistics 2019). In other words, at the time of herd immunity, the current epidemic will have canceled out the gain in life expectancy obtained from health-care and public-health interventions in the 12 months preceding the epidemic.

In addition to the comparison between a fully effective shutdown and no intervention, which forms the base case for the calculation of the maximum WTP, I also analyzed different scenarios with ICU capacity being exceeded to varying degrees. The likelihood of these scenarios depends on the spread of SARS-CoV-2 if shutdown measures do not turn out to be 100% effective. In favor of a sufficient ICU capacity in Germany are data (from 2010/11) suggesting that Germany has the highest number of intensive-care plus immediate-care unit beds on a per-capita basis in Europe (Rhodes 2012). Germany's leading position in terms of the number of ICU beds was recently confirmed in a report by the Organisation for Economic Co-operation and Development (OECD 2020). The currently available number of ICU beds is approximately 40,000, with 15,000 to 20,000 being unused (Rheinische Post 2020). Based on a conservative estimate of the length of stay of 7 days for COVID-19 patients (Ärztezeitung 2020), ICU capacity will be exceeded, however, when daily incidence of SARS-CoV-2 cases surpasses approximately 70,000 (unless capacity is further expanded).

As a word of caution, given time constraints as well as the ongoing inflow of new information on the SARS-CoV-2 epidemic whileconducting the study and writing this manuscript, making it pertinent to continuously update the projections, this modeling study has several caveats as discussed in the following. Given the clear direction of its results, however, it may still provide some important guidance for policymakers, which is outlined further below.

First, there are reasons why the base case overestimates the projected health benefits of a shutdown and the corresponding WTP. Some of these reasons were already described in the sensitivity analysis and include an underestimate of CFR (in total and in the ICU) due to a possible time lag in the occurrence of deaths. Furthermore, the study does not consider deaths and loss of health-related quality of life secondary to the shutdown, e.g., due to depressive disorders, anxiety, suicides, domestic violence, etc. In addition, ICU survivors may also suffer from a loss of quality of life (Needham 2013). Furthermore, non-diseased individuals experience a loss of personal freedom (Abele-Brehm 2020) and autonomy.

On the other hand, there are reasons to believe that WTP may be underestimated. Decreased economic activity can save lives partly because it reduces traffic accidents and air pollution (Science Magazine 2020). Furthermore, reducing the number of deaths prevents grief among caregivers. Moreover, a shutdown may provide a feeling of security and trust in the government. Finally, 'squashing the curve' might prevent direct and indirect costs associated with nonfatal COVID-19 cases. Some of the biases listed in this and the previous paragraph may cancel out.

Additional limitations apply to the estimate of the WTP for a life year borrowed from new, innovative cancer drugs. On the one hand, the estimate is too low because costs of drug-related adverse events and drug-related services are ignored and costs of cancer treatment are limited to a period of one year. That is, I do not account for the fact that some cancers have a chronic course, thus mandating treatment for more than one year. On the other hand, the estimate is too high because the survival benefit is underestimated as it is confined to the trial period, which typically may not be longer than a year. Again, some of the biases may cancel out.

Furthermore, it may be argued that treatments for conditions more related to COVID-19 would provide a more accurate estimate for the WTP. This may include treatments for other viral diseases such as SARS-CoV-1, influenza, or ebola. Even greater similarity could be obtained by restricting conditions to those that have a similar route of transmission (airborne droplets), CFR, and basic reproduction number (the average number of secondary infections due to a single primary infected person; it may reflect a sense a urgency). Nevertheless, the search for a better match may not turn out to be successful. It may also be hampered by the fact that an ideal WTP for flattening or squashing the curve would reflect recently set prices and not prices of drugs that were launched, say, more than a decade ago. Using prices of new, innovative cancer medications as a benchmark also provides an opportunity to check the appropriateness of current cancer prices themselves. If the WTP for flattening or squashing the curve as determined in this study were considered to be low, then, to be consistent, prices of new cancer drugs would equally deserve a price premium. This implication, however, is contradictory to the present situation as the pressure to save on health care costs will increase as a consequence of the corona crisis.

The definition of the objective of this study, which is the number of life years, may be criticized on ethical grounds. For example, Emanuel et al. (2020) suggest with regard to the SARS-Cov-2 epidemic "to give priority to maximizing the number of patients that survive treatment with a reasonable life expectancy and to regard maximizing improvements in length of life as a subordinate aim". This premise of their conclusion, i.e., a survival with a reasonable life expectancy, may be valid on average as shown in this study but does not hold for those age groups for which a harvesting effect is forecasted.

Given an unprecedented WTP as a share of GDP estimated in this study, the corona crisis also leads to new challenges for economic evaluations in health care and public health. The perhaps closest dilemma has risen around one-off treatments (cures) for genetic disorders. One-off payments for these therapies similarly raise affordability issues even in view of acceptable cost-effectiveness ratios (Towse 2019). Still, the magnitude of payments required for the COVID-19 shutdown is unparalleled. Hence, while the debate around one-off treatments appears structurally similar, it has only anticipated a little of what we are facing.

Even with an acceptable cost-effectiveness ratio of aggregated shutdown measures, one-time expenditures (as derived from the WTP) would lead to a considerable drop in GDP.

In fact, without government intervention this dip could have major ramifications for financing health care. Considering the maximum WTP for 'flattening the curve', a 13% drop in GDP would result in a 15% increase in the portion of total income spent on health care in order to finance the same type of health care basket (this increase explicitly does not refer to the increase in the contribution rate for social health insurance, which may be lower than 15%). As the basket does not cover COVID-19, the rise in spending must be viewed independently of the SARS-Cov-2 epidemic and not as an indirect way of supporting the shutdown. If the rise were not acceptable, underfunding of the health care system would result in order to keep spending within an acceptable range. Obviously, this problem is dramatically increased in the case of 'squashing the curve'.

Hence, there seems to be a tipping point where a drop in income necessitates to save on health expenditures. Defining this tipping point may be starting point for a discussion about the level of GDP decrease that may result in underfunding of the health care system without compensatory measures. As a consequence of underfunding, there would be a commensurate loss of lives in other diseases, thus leading to a zero-sum game. Such opportunity costs are already conceivable at the hospital level where excess admission for COVID-19 cases strains the health care system and possibly increases mortality from other serious diseases where hospital care is clearly effective (Ioannidis 2020).

Acknowledging this negative feedback loop on the health care system, the way to think about the problem at hand may be in terms of a constrained resource allocation problem, with minimization of life years lost as the objective function and cost-effectiveness ratio, contribution rate, and ICU capacity as three constraints. Ethical values were already incorporated in the WTP but reappear as an additional constraint when comparing the different exist strategies for lifting social isolation measures. In fact, if agreement on the maximum WTP were reached, the next step would involve assessing the cost-effectiveness of different exit strategies. For the purpose of minimizing the number of life years lost this would require calculating the degree of excess demand for ICU capacity and the resulting death toll in the absence of intensive care for each exit strategy.

For data collection in the forthcoming months of the crisis, policymakers should pay particular attention to mortality data, as health benefits and WTP forecasted in this study were shown to be particularly sensitive to these data.

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Table 1. Input data used in the base case and the sensitivity analysis.

Input	Mean (range)	Reference
Probability of death by age and gender in Germany	see reference	Federal Office of Statistics 2019
Population size by age	see reference	Federal Office of Statistics 2020
CFR in Germany (%)		Robert Koch Institut 2020
Total population	0.009 (0.005 – 0.020)	
0-4 years	0.001	
5-14 years	0.001	
15-34 years	0.001	
35-59 years	0.001	
60-79 years	0.020	
80+ years	0.123	
Proportion of cases in the ICU (%)	0.029 (0.02 – 0.06)	Robert Koch Institut 2020
CFR in the ICU (%)	0.34 (0.21 – 0.52)	Robert Koch Institut 2020
CFR for ICU non-admission (%)	1.0	Barry 2004
CFR one year post ICU discharge (%)	0.59 (0.47 – 0.73)	Damuth 2015
Herd protection threshold (%)	0.70 (0.60 – 0.70)	Kwok 2020

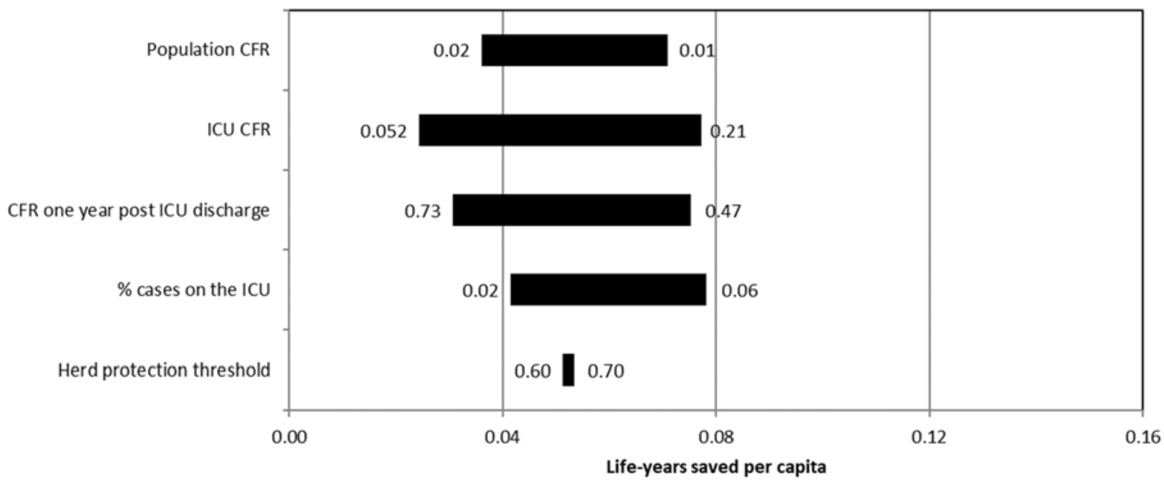
ICU = intensive care unit, CFR = case fatality rate

Table 2. Life years and their monetarized value under different methodological assumptions and strategies.

	Independence assumption			Harvesting assumption		
Intervention	Per-capita loss of LYs vs. no epidemic	Incremental gain in LYs vs. no inter-vention	Value of LYs gained (€)	Per-capita loss of LYs vs. no epidemic	Incremental gain in LYs vs. no inter-vention	Value of LYs gained (€)
'Flattening the curve'						
Fully effective shut-down	0.205	0.053	5418	0.146	0.062	6343
ICU capacity ex-ceeded by 50%	0.225	0.034	3433	0.167	0.042	4218
ICU capacity ex-ceeded by 100%	0.242	0.016	1637	0.188	0.020	2040
ICU capacity ex-ceeded by 200%	0.253	0.005	530	0.201	0.007	712
ICU capacity ex-ceeded by 300%	0.257	0.001	131	0.206	0.002	181
No intervention	0.259	0	0	0.208	0	0
'Squashing the curve'						
Fully effective shut-down	0	0.259	26,242	0.208	0.208	21,122

LY = life year, ICU = intensive care unit

Figure 1. Tornado diagram demonstrating the results of the one-way sensitivity analysis. Variables are ordered by impact on the number of life years gained per capita of a shut-down fully effective at 'flattening the curve' versus no intervention. Numbers indicate upper and lower bounds.



ICU = intensive care unit, CFR = case fatality rate