Cost-effectiveness of providing additional intensive care bed capacity for the treatment of COVID-19 patients in Germany

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Abstract

Introduction: In preparation for a possible second COVID-19 pandemic wave, expanding intensive care unit (ICU) bed capacity plays an important consideration. The purpose of this study was to determine the costs and benefits of this strategy in Germany.

Methods: This study compared the provision of additional capacity to no intervention from a societal perspective. A decision model was developed using, e.g., information on age-specific fatality rates, ICU costs and outcomes, and the herd protection threshold. The net monetary benefit (NMB) was calculated based upon the willingness to pay for new medicines for the treatment of cancer, a condition with similar disease burden in the near term.

Results: The marginal cost-effectiveness ratio (MCER) of supplying one additional ICU bed is €25,735 per life year gained and increases with the number of additional beds. The NMB is positive over an increment of 10,000 beds or 73% of the currently available capacity. Expanding ICU bed capacity by 10,000 beds results in societal costs of €40 billion and reduces ICU mortality by 18% compared to no intervention. In a sensitivity analysis, the variables with the highest impact on the MCER were mortality rates in the ICU and after discharge.

Conclusions: In Germany, the provision of additional ICU bed capacity appears to be cost-effective over a large increment of beds. Extending the existing capacity by more than 50% results in only a small fraction of the ongoing expenses for COVID-19 containment measures.

Introduction

Following the first SARS-CoV-2 pandemic wave in Germany, the German federal government and the federal states currently pursue a strategy of COVID-19 containment. This strategy includes a bundle of measures such as a partial shutdown of businesses, social distancing, tracking, testing, public mask wearing, and quarantine orders. The primary goal of this strategy is to avoid an overproportional increase in the number of new infections by keeping the reproduction number below one. If successful, this strategy avoids a spread of the virus in the population until the point of herd immunity. In addition, this strategy could suppress a second wave of COVID-19 outbreaks or postpone it ('flatten the curve') and thus avoid overstretching intensive care unit (ICU) capacity at the time of peak demand. Based on confirmed COVID-19 cases in Germany, the probability of a COVID-19 patient to have an indication for ICU admission is approximately 6% (Robert Koch Institut 2020).

In general, COVID-19 response measures can be categorized based on the three levels of prevention: primary, secondary, and tertiary prevention (Fletcher 2013). Primary prevention aims at reducing the incidence of COVID-19. Secondary prevention screens asymptomatic and symptomatic patients (with infection) for COVID-19. And tertiary prevention aims at preventing sequelae of COVID-19. Hence, while the COVID-19 containment strategy currently pursued by the German government emphasizes primary and secondary prevention, adding ICU bed capacity is an example of tertiary prevention. The German government has pursued the latter strategy until recently (with nearly 9000 beds added as of May 26,2020 (Bundesamt für Soziale Sicherung 2020)) but now intends to redeploy part of the available hospital capacity for treating non-COVID-19 patients (Bundesgesundheitsministerium 2020). An alternative tertiary prevention strategy that is still under investigation is medical treatment of COVID-19. Currently, there is great hope in future COVID-19 treatments that are obtained from repurposing drugs already approved for other diseases and demonstrating acceptable safety profiles (cf. Kupferschmidt 2020).

The current COVID-19 containment strategy in Germany may turn out to be insufficient in suppressing a possible second SARS-CoV-2 pandemic wave, however. It may also become unsustainable in terms of affordability, psychological burden, or violation of civil rights. Given the re-risk of an exponential growth of COVID-19 cases, expansion of ICU bed capacity becomes an important consideration again. The purpose of this study was to determine the costs and benefits of this strategy in preparation for a potential second pandemic wave. The objective agrees with a recent recommendation by the German National Academy of Sciences Leopoldina (2020) with regard to the COVID-19 pandemic stating that "time gained by the shutdown must be used to evaluate the actions taken using empirical data, and the costs and benefits of these actions must be evaluated prior to readjustment". Results of this study also allow comparing the health benefits and cost-effectiveness of extending ICU bed capacity with those of a future COVID-19 treatment.

Methods

General

I conducted a cost-effectiveness analysis using life-years gained as a measure of health benefits. The analysis was conducted over the remaining lifetime of COVID-19 patients who have an indication for ICU care. By comparing the costs and health benefits of different levels of ICU bed capacity, I calculated marginal cost-effectiveness ratios (MCERs). In addition, I performed net benefit and return on investment (ROI) calculations.

Calculation of health benefits

A decision model was constructed using a previously developed and validated model as a basis (Gandjour 2020). The later model determines the loss of life years of a successful shutdown and no intervention, i.e., no ICU bed capacity left to treat COVID-19 patients, each compared to the situation before the pandemic. This paper extends the previous model relying on the following conceptual idea: The clinical value of an additional ICU bed is equivalent to the marginal loss of life years in the absence of an additional ICU bed, i.e., when demand for ICU beds exceeds the available capacity by one ICU bed. Following this principle, I calculated a weighted-average loss of life years when demand exceeds available ICU bed capacity by one bed, with weights reflecting portions of patients admitted to the ICU and refused admittance. These weights were multiplied with the average per-capita loss of life years in the German population (compared to non-crisis mortality rates) when all patients with ICU indication are admitted to the ICU and refused admittance. The difference of this weighted average compared to the loss of life years with sufficient ICU bed capacity presents the value of an additional ICU bed. Sequentially adding an *n* number of beds relies on the same marginal calculation. Given that this calculation relates the addition of beds to the existing national capacity, it is conducted at the population level. For this reason, I multiplied the clinical value of an additional ICU bed with the population size. By dividing the value of an ICU bed by the average length of stay (LOS), I obtained the value of an additional ICU bed at the level of a single COVID-19 patient. A longer LOS, ceteris paribus, translates into less value of an ICU bed on a per-patient basis. I conservatively assumed that the benefits of ICU bed capacity would only last for 12 months, the earliest expected arrival date for a vaccine that protects against COVID-19 (WSJ 2020).

Presuming a harvesting effect in a sensitivity analysis, I assumed for age groups with excess mortality associated with COVID-19 (the difference between observed and noncrisis mortality rates) that except for COVID-19, there are no other causes of death in the forthcoming 12 months (Gandjour 2020).

In addition to the above calculation, which yields the clinical value of an ICU bed in terms of life years gained, I also determined the value in terms of reduction of ICU mortality. To this end, I followed, in principle, the same methodological approach but applied, as weights, mortality of patients admitted to the ICU and refused admittance.

Cost analysis

For the cost analysis, I used a societal perspective. In terms of medical costs, I considered costs of the initial ICU stay, costs of re-hospitalizations occurring in the first year after discharge from the ICU, hospital copayments, and future consumption and unrelated medical costs incurred during added life years. To determine the hospital costs of treating COVID-19 patients, I considered both operating and infrastructure costs. To calculate operating costs, I assumed an average patient trajectory. I applied the corresponding Diagnosis-related group (DRG) codes plus additional tariffs on top of the DRG payments ("Zusatzentgelt"). Moreover, I considered extra payments by the German government for personal protective equipment and nursing care in treating COVID-19 patients.

To identify appropriate DRG codes for COVID-19 cases admitted to the ICU, I followed guidance by the German Interdisciplinary Association for Intensive Care and Emergency Medicine (DIVI 2020). Specifically, I applied DRG codes that reflect the average LOS with and without mechanical ventilation. I purposely used conservative cost estimates, thus biasing against the value of an additional ICU bed. To arrive at the final cost estimate of treating a COVID-19 patient in the ICU, costs of patients with and without mechanical ventilation were weighted by their respective shares.

To arrive at the costs of infrastructure, I accounted for the opportunity costs of capital. To calculate the latter, I considered the weighted average cost of capital (WACC). Strictly speaking, WACC only applies to private hospitals, which account for 36% of all German hospitals, based on 2016 data (BDPK 2020). But in the corona crisis government funds cover a portion of the capital costs resulting from the expansion of ICU capacity (€50,000 per additional ICU bed) (Bundesregierung 2020). Hence, WACC needs to be adjusted for this portion (cf. Zapp 2010). In contrast, when public hospitals expand their capacities, they receive interest-free loans from the federal states without any obligation to pay them back. Nevertheless, only half of the infrastructure investments are currently covered by the federal states (GKV-Spitzenverband 2018). The overall opportunity cost of capital was thus calculated as a weighted average of WACC and a zero cost of capital, with weights representing shares of private and public funding, respectively.

To determine future unrelated medical costs incurred during added life years, 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) using the life table embedded in the previously published decision model (Gandjour 2020). I multiplied the cumulative probability of surviving until age j with health expenditures at age j, took the sum over all ages j, and thus obtained the remaining health expenditures of an individual at age i. By determining the difference between changes in ICU bed capacity, I obtained life extension costs. To account for the age distribution of the population, I weighted age-specific life-extension costs by age-specific population sizes. I performed all calculations for men and women separately and then aggregated results.

Moreover, a societal perspective requires considering expenses for primary needs such as food, shelter, and clothing as their satisfaction contributes to the extension of life (Gandjour 2006). That is, as the denominator of the MCER captures the benefits of the resources used to satisfy primary needs, the costs of these resources also need to be included for consistency reasons (Gandjour 2006). To determine these types of consumption costs during added life years, I followed the same principle as for health expenditures outlined in the above paragraph.

Net benefit and ROI calculation

The monetary value of an additional life year was borrowed from new, innovative oncological drugs as cancer reflects a condition with a similar morbidity and mortality burden in the general population in the short-term (Gandjour 2020). To calculate the net monetary benefit (NMB) of an additional bed, I subtracted the cost of an additional bed from the monetary value created. By dividing the monetary value of an additional bed by its additional cost, I also determined the ROI.

Discounting

In the base-case analysis, I did not discount costs and health benefits as the reported survival benefits from cancer treatment (Storm 2017), which were used to determine the economic value of a life year, were undiscounted as well. In a sensitivity analysis, I discounted both costs and effects.

Sensitivity Analysis

In one-way deterministic analyses, I assessed parameter uncertainty by varying the input parameters that are subject to variation one at a time. In addition, I conducted threshold sensitivity analyses that determined the break-even points for additional ICU bed capacity, government subsidies for ICU bed provision, and ICU bed utilization.

Data

The model input data are listed in Table 1. For COVID-19 patients receiving mechanical ventilation, LOS in the ICU has been estimated to be between 11 and 20 days (KSTA 2020, Stang 2020, SWR 2020). Among the DRGs that are applicable in this range, I made conservative choices, i.e., selected higher-cost DRGs in the presence of several coding options. Of note, in the German DRG system, age-specific DRG codes are usually limited to children and thus played no role in assigning DRG codes. Specifically, for ICU patients with mechanical ventilation, I chose DRG code A13F (InEK 2020), which has a case-mix index of 3.395 and allows for an additional payment of €18.21 (code ZE162). For ICU patients without mechanical ventilation, I conservatively assumed the same LOS range and applied DRG code E77B, which entails a case-mix index of 2.090, and allows for an additional payment of €34.48 (code ZE163). Each case-mix index was multiplied by the national base price (GKV-Spitzenverband 2020). Of note, the DRG codes I applied cover all hospital expenditures including nursing costs.

In terms of infrastructure costs of ICU beds, estimates range between €85,000 and €100.000 (DIVI 2020, DKG 2020, ZEIT 2020). In the base case, I applied an estimate provided by the German Hospital Federation, which is €85,000 (DKG 2020). This estimate includes costs of supplies (e.g., protective clothing) and equipment (e.g., ventilators) associated with ICU bed provision (DIVI 2020).

To estimate the costs of re-hospitalizations occurring in the first year after discharge from the ICU, I used the results of a published cohort study on 396 ICU survivors with acute respiratory distress syndrome. The study was conducted between September 2014 and April 2016 in 61 German hospitals (Brandstetter 2019). It reported a median number of re-hospitalizations of 2 (interquartile range 1-3). LOS was 16 days on average (interquartile range 10-25). Of note, re-hospitalizations included stays in rehabilitation facilities as well as admissions for medical conditions unrelated to acute respiratory distress syndrome. The data did not differentiate between different types of re-hospitalizations as well as admissions to ICUs and normal wards. Given the latter, I applied the costs of the initial ICU stay, thus conservatively assuming that all rehospitalized patients would be admitted to the ICU.

As outlined in the Methods section, for ICU survivors I determined both future (unrelated) medical and consumption costs during added life years. To account for the former, I used healthcare expenditures in the general population, which were available for four age categories (Statistisches Bundesamt 2015) and explicitly referred to national (societal) costs and not to social health insurance costs. Data on private consumption costs were from the year 2017 (Statistisches Bundesamt 2019). Categories of private consumption costs were available for adults and children but not according to age. To narrow down consumption costs to those for primary needs, I considered per-capita private consumption costs on food and non-alcoholic beverages, clothing and shoes, housing (including maintenance), energy, and health.

Capital costs were based on the whole healthcare and pharmaceutical industry (PwC 2020). All costs were inflated to year 2020 euros based on the general German Consumer Price Index.

Given the lack of official guidance on discount rates for costs and health benefits from a societal perspective in Germany, I applied a 3% discount rate for costs, which is based on the social rate of time preference derived from the Ramsey equation (1928). For health benefits, I applied a 1% lower discount rate reflecting the expected growth rate of the consumption value of health in Germany (cf. John 2019).

Results

Expanding existing ICU bed capacity by exactly one bed yields a MCER of €25,735 per life year gained and an ROI of 3.9 in the base case. Cost-effectiveness and ROI diminish with additional ICU bed capacity (Figure 1). This holds because when demand for ICU beds exceeds the available capacity, the marginal loss of life years in the absence of an additional bed diminishes. The reason is that an increase in excess demand leaves a growing share of the patient population without ICU admittance and hence the non-provision of ICU bed capacity matters relatively less. Hence, the value of an additional ICU bed decreases with the available number of ICU beds because it prevents relatively less excess demand. That is, for a given demand level, adding one bed to 1000 beds at baseline is more valuable than adding one bed to 10,000 beds.

Based on the harvesting assumption, cost-effectiveness of supplying an additional ICU bed improves because COVID-19 patients being saved from death in the presence of an additional bed are assumed to represent a healthier subgroup of ICU patients than the lives that are unavoidably lost.

As shown in the sensitivity analysis (see Figure 2), the variables with the highest impact on the NMB were mortality rates in the ICU and after discharge. Ceteris paribus, higher mortality rates reduce the NMB of an additional ICU bed.

Expanding ICU bed capacity by another 10,000 beds or 73% of the currently available capacity would increase societal costs by €40.2 billion. The resulting decrease in ICU mortality is 18% compared to no intervention (Figure 3). While ROI diminishes with an expansion of capacity, it remains above 2.98 for the ten thousandth bed added. Even a bed utilization of just 1.5% still allows for a positive ROI due to the low share of infrastructure costs.

A threshold sensitivity analysis shows that negative returns do not appear even with a 18-fold increase in ICU bed capacity. Pointing in the same direction, even a government subsidy of €5 million per ICU bed yields a positive NMB for the ten thousandth bed added.

Discussion

In preparation for a possible second SARS-CoV-2 pandemic wave, the German government has adopted a COVID-19 containment strategy. The current strategy may turn out to be insufficient in preventing an overstretch of ICU capacity at the time of peak demand, however. Therefore, the expansion of ICU bed capacity presents an important consideration. As shown in this analysis, building ICU bed capacity provides a high ROI even over a large increment.

Extending the existing ICU bed capacity seems acceptable based on the MCER but also from a budgetary perspective. That is, extending capacity by more than 50% results in a one-time increase in healthcare expenditure (Statistisches Bundesamt 2020a) of 10%. This amounts to 1.2% of the gross domestic product in Germany (Statistisches Bundesamt 2020b). In light of these findings and in particular the threshold sensitivity analysis, the current government subsidy for additional ICU bed provision, which is €50,000 per bed, seems inadequate.

Whether the ROI of ICU bed expansion is larger than that of a shutdown still needs to be investigated. As a complicating factor, calculating the latter needs to account for a potential underfunding of the health care system as a result of the comparatively larger reduction in the gross domestic product. In case the ROI of ICU bed expansion turns out to be higher, a switch from the current strategy of primary and secondary prevention of COVID-19 to a strategy focusing on secondary and tertiary prevention would seem warranted.

As a word of caution, the above conclusions are based on the presumption that there is a positive probability of utilizing the additional ICU bed capacity. If, however, the additional beds remain entirely vacant, the value of investment becomes negative due to the presence of fixed costs. It is re-assuring though that even a vacancy rate of 98% stills allow for a positive return due to the low share of infrastructure costs. This is equivalent to a just 2% probability of having a full utilization. How does this finding fit to the virus containment strategy currently pursued by the German government, which aims at keeping the reproduction number below one until a vaccine is available? A strategy of supplying additional ICU beds becomes cost-effective once there is a 2% probability that the virus containment strategy is not successful or abandoned because it is too expensive or burdensome for society. Hence, there needs to be a positive probability of a viral spread in the population, thus leading to herd immunity by natural infection, whether actively sought by the government or not. Still, treating additional COVID-19 patients in the ICU may require cancelling or postponing unrelated treatments. Hence, considering the latter would increase the minimum acceptable bed utilization rate. Therefore, a strategy of supplying additional ICU beds still requires careful planning.

Of note, there are different ways of providing the additional ICU capacity. These not only include the construction of new buildings but also freeing up existing capacity, e.g., deferring elective procedures, moving non-COVID-19 patients to alternative sites, and using step down care more aggressively. In addition, ICU units and beds may be converted from existing capacity such as operating, recovery, procedure and treatment rooms; ambulatory surgery centers; unstaffed floors; physical therapy space; outpatient facilities; and non-healthcare facilities (Government of Alberta 2020, Singhal 2020). In the short term, freeing up existing capacity may, in fact, be the only feasible approach. In order to meet a potential rise in future demand for ICU beds, construction of new buildings and converting existing capacity may be unavoidable, however.

Preparing for an increased demand of ICU care also requires recruiting additional personnel (e.g., ICU nurses) as well as purchasing additional materials, supplies (e.g., protective clothing), and equipment (e.g., ventilators). Strategies to address a shortage of labor include accelerated training for ICU nurses; contacting former nurses with ICU experience and other recently retired staff; as well as redeploying anesthesiologists, other physicians, other nurses, respiratory therapists, other allied health professionals and other staff with appropriate skills to work in a critical care environment (Government of Alberta 2020).

In contrast to future survival-prolonging treatments of COVID-19, which have not been approved yet at the time of writing this manuscript, expanding ICU bed capacity can be considered an already feasible approach of managing severely sick COVID-19 patients and reducing their mortality. Expanding ICU bed capacity and future treatments of COVID-19 become complementary interventions if a future treatment has a label for ICU patients. In that case, ICU bed expansion becomes an enabling strategy for a future treatment. Both interventions then would form a combination therapy. This is also confirmed in the sensitivity analysis of this paper, yielding that the effect of a future treatment in terms of ICU mortality reduction improves the cost-effectiveness of ICU bed expansion. Of note, it was recently estimated that "even a highly successful trial is likely to reduce the mortality outcome by only a 5% to 10% absolute difference" (Bauchner 2020). In my analysis, a comparable mortality decrease is already achieved by an ICU capacity expansion of 4500 beds, thus emphasizing the clinical significance of an ICU bed expansion.

If expanding ICU bed capacity and future treatments of COVID-19 are complementary but ICU bed capacity is a limiting factor, a future treatment may not be applicable unless it is provided off-label before ICU admission. In that case, the future treatment can be regarded as a substitute for expanding ICU bed capacity. Similarly, if future treatments have a label for hospitalized patients without mechanical ventilation and are able to reduce ICU admissions, they become a substitute for expanding ICU bed capacity.

Limitations of this study need to be acknowledged. First, there are reasons why the base-case analysis overestimates the NMB, i.e., underestimates the MCER. Some of these reasons were already described in the sensitivity analysis and include a high mortality in the ICU and post discharge. Furthermore, this study did not include direct non-medical costs such as time and transportation costs, which are mandated by the societal perspective adopted in this paper. As a minor point, costs of an increased use of personal protective equipment for non-COVID-19 patients were not included.

On the other hand, there are reasons to believe that the base case underestimates the NMB, i.e., overestimates the MCER. First, by including future medical costs along with costs of hospitalizations in the first year after ICU discharge, some double counting of hospitalization costs may result. Furthermore, DRG rates may not reflect true hospital costs and may yield a positive profit margin for ventilated patients (Welt 2020). Moreover, productivity gains resulting from a reduction in mortality were not included due to the age distribution of averted deaths (the median age is 82 years) and the difficulty of disentangling deaths in relevant age groups (e.g., in the age group 50-69 years). Some of the biases mentioned in this and the previous paragraph may cancel each other out, however.

In terms of transferability of results and conclusions of this study to other countries the usual caveats apply. Reasons for caution include between-country differences in clinical and epidemiological data, costs, and the willingness to pay for health benefits.

For data collection in the forthcoming months of the crisis, policymakers should pay particular attention to mortality data, as MCERs and ROIs 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
Epidemiological and clinical data		
Probability of death by age and gender in Germany	see reference	Statistisches Bundesamt 2019
Population size by age	see reference	Statistisches Bundesamt 2020
CFR in Germany		Robert Koch Institut 2020
Total population	0.021 (0.0037 – 0.021)	
0-4 years	0.001	
5-14 years	0.001	
15-34 years	0.001	
35-59 years	0.001	
60-79 years	0.035	
80+ years	0.148	
Probability of ICU indication	0.039 (0.02 – 0.06)	Robert Koch Institut 2020
CFR in the ICU	0.30 (0.21 – 0.52)	Robert Koch Institut 2020
CFR for ICU non-admission	1.0	Assumption
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 beds available for COVID-19	13,749	Robert Koch Institut 2020
Weighted average cost of capital	0.06	PwC 2020
Proportion of ICU patients with mechanical ventilation	0.74	Robert Koch Institut 2020
ICU length of stay	14 (11 – 20)	KSTA 2020, Stang 2020, SWR 2020
Cost data		
Healthcare expenditure by age	see reference	Statistisches Bundesamt 2015
Consumption costs per year, primary needs (€)		Statistisches Bundesamt 2019

Adult	11,580	
Child	3984	
ICU bed, infrastructural cost (€)	85,000 (85,000 – 100,000)	
ICU costs per admission (with mechanical ventilation) (€)	12,551	GKV-Spitzenverband 2020, InEK 2020
ICU costs per admission (without mechanical ventilation) (€)	7725	GKV-Spitzenverband 2020, InEK 2020
Hospital copayment per day (€)	10	Bundesministerium für Gesundheit 2018
Extra payment for nursing care per day (€)	147	Bundesregierung 2020
Personal protective equipment per patient (€)	50	Bundesregierung 2020

ICU = intensive care unit, CFR = case fatality rate

Figure 1. Marginal costs per life year gained of adding intensive care unit (ICU) bed capacity.

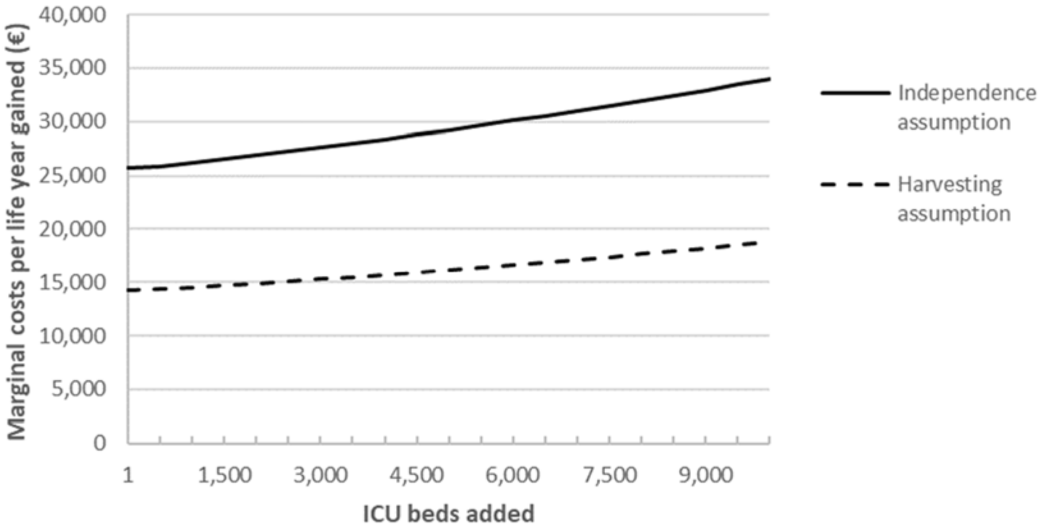
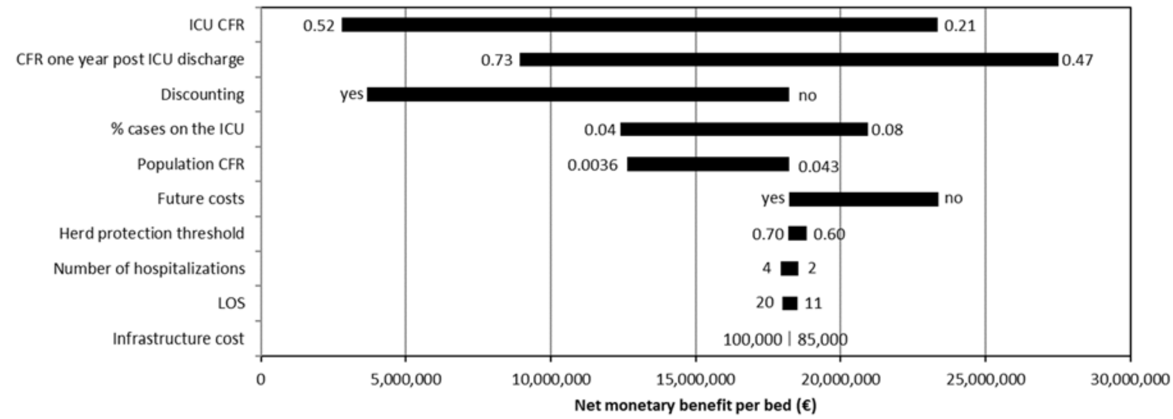


Figure 2. Tornado diagram demonstrating the results of the one-way sensitivity analysis. Variables are ordered by impact on the net monetary of the provision of additional ICU bed capacity versus no intervention. Numbers indicate upper and lower bounds.



ICU = intensive care unit, CFR = case fatality rate, LOS = length of stay

Figure 3. Mortality reduction in the intensive care unit (ICU) compared to non-admittance by increasing bed capacity.