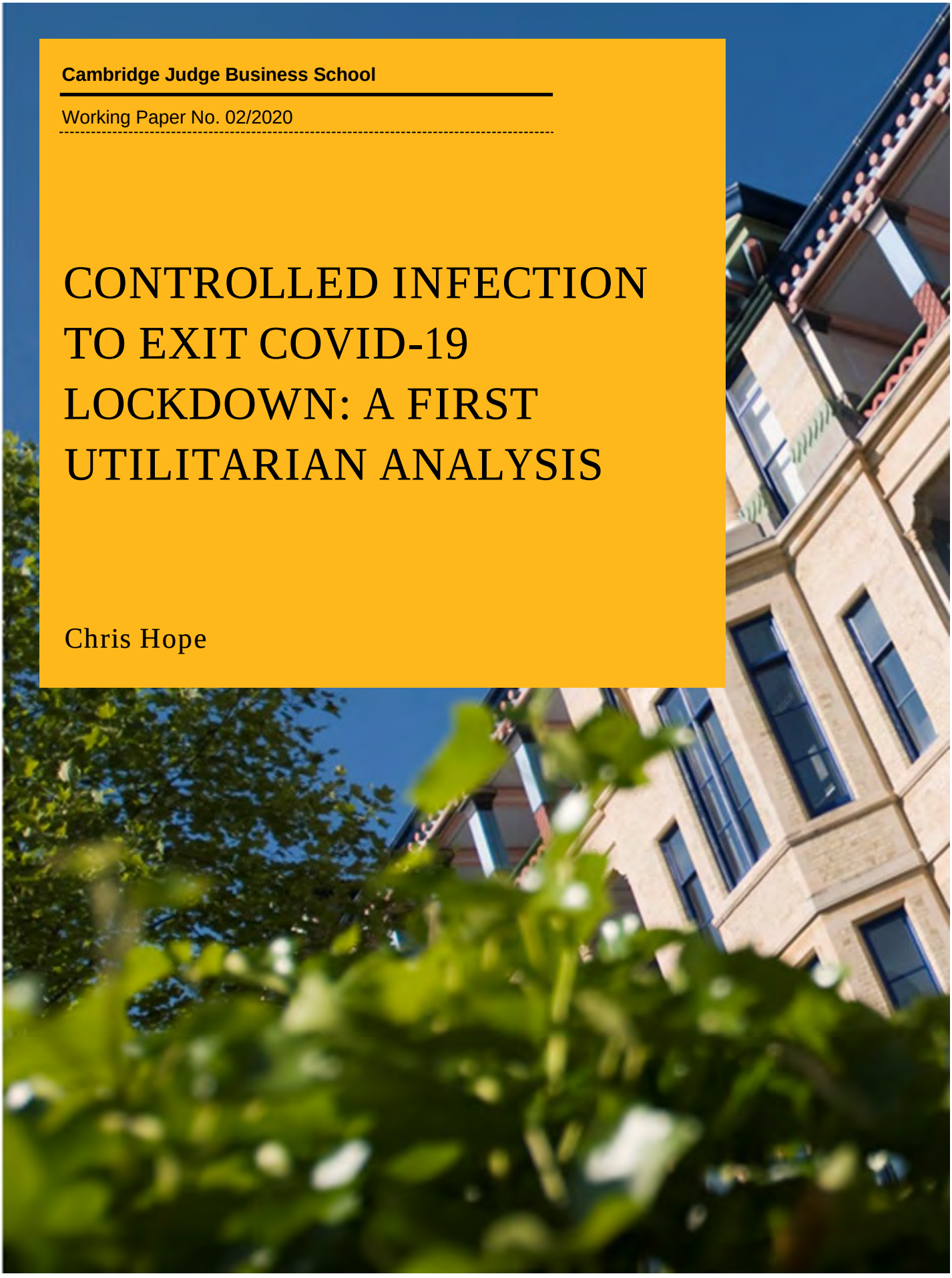

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CONTROLLED INFECTION TO EXIT COVID-19 LOCKDOWN: A FIRST UTILITARIAN ANALYSIS

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Cambridge Judge Business School Working Papers

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Controlled infection to exit COVID-19 lockdown – A first utilitarian analysis

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16 April 2020

Abstract

The UK-wide lockdown to cope with the COVID-19 pandemic is unprecedented. The government could offer the opportunity for healthy people to choose to be immediately infected with COVID-19 in a controlled way and then confined to their homes until they are no longer infectious. They would then be able to resume something closer to normal life, once sufficient numbers were immune and the government allowed it. We show here that this option could be attractive to many, with an overall net benefit for a representative young, healthy person of 0.34 to 0.71 Quality Adjusted Life Years (QALY). The parameters with the greatest influence on this net benefit are identified.

Introduction

The UK-wide lockdown to cope with the COVID-19 pandemic is unprecedented. It limits all except essential workers to their homes except for brief periods, leading to a drop in their quality of life, and an economic cost as they lose part or all of their income, possibly for an extended period (Knapton, 2020).

The hope is that this measure will lead to a flattening of the curve of infections, allowing the health service to cope with cases as they occur without becoming overwhelmed. But it also means that people do not know if they are infected until their symptoms show, and allows them to pass on the infection to people they encounter in shops, or on the street, while infectious (He et al, 2020).

There is another way. The government could offer the opportunity for healthy people to choose to be immediately infected with COVID-19 in a controlled way and then confined to their homes until they are no longer infectious. They would then be able to resume something closer to normal life, once sufficient numbers were immune and the government allowed it. Those at high risk or with pre-existing conditions would not be offered this, or presumably would not take up the offer if they were offered it.

So assume a healthy individual has a choice.

A. Social distance (SD) until the emergency is over, or they are infected anyway

or

B. Choose controlled infected (CI) now, with testing, isolation and then immunity. CI will nearly always be effective in causing infection, as the illness appears to be transmitted easily. As the infection occurs in controlled manner, there is no extra risk to those outside the household.

Social distancing leads to a quality of life drop, loss of earnings, later infection or no infection. Later infection might have a worse outcome if no intensive care unit (ICU) bed is available (Campbell et al, 2020). Infection is not immediately detected, so contacts outside the household are at risk of getting infected, which might concern you if you are socially responsible (He et al, 2020).

Controlled infection leads to immediate illness, probably for the whole household, if it is effective, then an ability to lead close to a normal life once govt relaxes restrictions for those who have had the disease. Walport, 2020, discusses the closeness of this type of antibody test.

There is an obvious extension to see whether the govt should compel some people to choose controlled infected for the greater good. I am not modelling this, as it takes us uncomfortably close to an extreme authoritarian state.

Which is better if I'm given a choice, CI or SD? The basic tradeoff is that CI allows me to obtain an earlier return to near-normal life, and a certainty that I'm not infecting others outside my household in exchange for increasing the small chance that I will suffer major symptoms, possibly death, since under SD I may not get infected at all.

I assume that the timescale is short enough that no discounting needs to be applied, except to express remaining lifetime as a reduced value to allow for discounting and the natural drop below normal quality by end of life.

There is an issue combining the health and loss of quality of life effects, which can be expressed as QALYs, and the economic effects, which are measured in financial units, such as pounds sterling. I've made the choice to express everything as expected QALY lost by converting loss of earnings and medical costs to QALY lost by using a standard value of a full quality life year (NICE, 2013).

The better choice of CI and SD is the one that leads to the lower value for total concern by the individual over QALYs lost by the individual, their household and those outside the household.

Parameters in the model

Time until emergency over T years

At some point the government will declare the COVID-19 emergency over and allow everyone to resume a normal life. Probably once a vaccine is available (Spinney, 2020). Of the order of six months to a year (Ferguson, 2020).

Length of infection F years

The length of time that an infection lasts. Of the order of two weeks (WHO, 2020a), or longer in severe cases.

Date of infection if it occurs under SD D years

Probably near the middle of the infection, which is likely to be the order of three months away (Yale, 2020).

Time until those who have had COVID can resume better life B years

This will happen when people can prove that they are immune using an antibody test. Of the order of a month or two away (Walport, 2020).

Remaining lifetime L years

Expected remaining lifetime if not killed by COVID-19, discounted for time and loss of quality towards the end of life. Will vary by person, up to about 50 years for a healthy young adult.

Prob of infection under CI Pci

As the virus seems to transmit easily, assume this is close to 100% (Pulse, 2020)

Prob of infection under SD Psd

There have been different views about this, ranging from 80% in some early work with no social distancing (Johnson, 2020). Possibly around 30% now (Lanese, 2020).

Prob of needing ICU if infected Pv

For healthy people, over 90% of infections result in no or mild symptoms (Michelen et al, 2020). Assume this is the order of 5% (WHO, 2020b). 'ICU' is shorthand in this paper for all appropriate intensive medical care.

Prob of obtaining ICU if needed under SD Pvsd

If the health service does become overwhelmed, not all patients who need ICUs will get one. Some early work suggested only one in eight might get them (Davies, 2020), but the information on this is changing rapidly, so maybe now the proportion could be 70% or more.

Prob of obtaining ICU if needed under CI Pvci

As the infection occurs early in the pandemic, I assume the health service will not be overstretched, so assume this to be close to 1

Prob of death if need ICU and obtain it Pdv

Of the order of 10%, giving a death rate of about 0.5% for previously healthy people (Le Page, 2020).

Prob of death if need ICU and do not obtain it Pdnv

Assume this is much higher, maybe close to 50%, but there appears to be very little data on this.

Value of full quality life year Eqaly £/year

Government uses a value of about £30,000 for this (Timmins, 2017).

Loss of earnings under SD Esd £/year

Will depend on the individual. Government support has reduced this loss by up to 80% for many people (HMRC, 2020). Maybe of the order of 10,000 to 30,000.

Normal quality of life Qn

Full quality life is rated as 1 in the QALY system. This will vary by person, but for many will be close to or at 1.

Quality of life under SD Qsd

Will vary by person. Some might feel badly affected, some are quite able to withstand it. Probably 0.5 to 0.95

Quality of life if infected Qi

Will involve mild symptoms and quarantine. Less than Qsd. Maybe around 0.5

Quality of life while needing ICU Qv

The major symptoms of pneumonia are very unpleasant. Probably close to 0.

Quality of life close to normal Qcn

Not everything will be back to normal. There will be other people still socially distancing, and other disruptions still continuing. Above Qsd but not back to Qn.

Number of people in household H

Assume all these people will be infected if you are. The model assumes their QALY loss from illness is the same as yours, but they have no economic losses. Obviously an oversimplification,

but may not be too bad as older people probably lose more and children less. Maybe count a child as half an adult for the purposes of the model, as they seem to be less affected by the illness than adults.

Number of people outside household infected under SD Nisd

These are people you encounter while infectious but before you know it. Will be lower the more effective social distancing is, but will not be zero. Maybe around 2 (He et al, 2020). Their health losses are assumed to be the same as yours if you were infected, which is an obvious oversimplification.

Concern for those outside household Cnh

People differ in their social responsibility. For some who only think of themselves this will be close to zero. For others with a strong social conscience it will be higher, but almost certainly less than 1, maybe around 0.5. The model assumes this applies only to their health losses, as you infecting them does not consistently change their economic losses.

Concern for those inside household Ch

For people in a happy family or social unit this will be close to 1, or even above 1. For others it could be significantly lower.

Medical costs if hospitalised Cm £

Under the NHS this will be zero or close to zero. It's included in the model so that it can be used in other countries without healthcare that is free at point of use.

Illustrative calculations

In this section the model is applied to a representative healthy young adult, who is normally very socially active, socially responsible, losing a lot of income under lockdown. The model uses very crudely estimated values for the parameters, initially as a deterministic calculation, so that the workings of the model can be understood, and then as a probabilistic one. Illustrative deterministic calculations for two other individuals, a middle-aged person with a family, and a retired person with a partner are included as appendix A. The main intention is to demonstrate the workings of the model and that it produces plausible results. In reality, there are a large number of different categories of people, each of whom could use the model tailored to their own circumstances.

Deterministic calculation

Parameters applied to all 3 people:

Time until emergency over	0.75	T	years
Date of infection if it occurs under SD	0.25	D	years
Time until those who have had COVID can resume better life	0.12	B	years
Prob of infection under CI	0.95	Pci	
Prob of infection under SD	0.3	Psd	
Prob of obtaining ICU if needed under SD	0.7	Pvsd	
Prob of obtaining ICU if needed under CI	0.9	Pvci	
Prob of death if need ICU and obtain it	0.1	Pdv	
Prob of death if need ICU and do not obtain it	0.4	Pdnv	
Value of full quality life year	30000	Eqaly	£/year
Medical costs if hospitalised	100	Cm	£

These are all obviously rough estimates, and should be kept under review. One year is an optimistic estimate for having a vaccine available, but the govt might choose to declare the emergency over in six months or so on the basis of herd immunity or public pressure. Assume infection occurs after 3 months under SD on the basis of flattening the curve below what has been seen in Italy. An antibody test could be available within 6 weeks and there will be great pressure from those who are immune to be allowed to resume normal activities. Controlled infection is assumed to be almost completely effective. The risk of infection under SD is very hard to estimate, so the 30% value is subject to change. Assume there is a 30% chance that the NHS will be overwhelmed under SD, but only a 10% chance if controlled infection is chosen early. The death rates for major symptoms are educated guesses. The QALY value is from govt guidelines, and under the NHS the medical costs would be minimal, maybe £100 for some prescriptions.

Person A, a healthy young adult, who is normally very socially active, socially responsible, losing a lot of income under lockdown:

Length of infection	0.04	F	years
Remaining lifetime	40	L	years
Prob of needing ICU if infected	0.05	Pv	
Loss of earnings under SD	25000	Esd	£/year
Normal quality of life	0.98	Qn	
Quality of life under SD	0.7	Qsd	
Quality of life if infected	0.6	Qi	
Quality of life while needing ICU	0.1	Qv	
Quality of life close to normal	0.9	Qcn	
Number of people in household	1	H	
Number of people outside household infected under SD	2	Nisd	
Concern for those outside household	0.4	Cnh	
Concern for those inside household	0.9	Ch	

She is fit and healthy so the illness would run its course in 2 weeks. Her remaining lifetime is 60 years, but discounted down to 40 years for time and loss of quality in old age. She has no existing conditions so would only have a 10% chance of needing an ICU. She is self-employed with limited government help available, so would lose 25,000 per year while under SD. Her normal quality of life is very good, but she is sociable and this drops to 0.7 under lockdown, and 0.6 if infected and quarantined. Her life would be of very poor quality, 0.1, if under intensive care, but back to 0.9 once immune and allowed to resume activity. She is the only one in her household, but has contact with quite a lot of people even under lockdown, from shopping etc. She is socially responsible, and cares almost half as much for those outside her household as she does for herself.

The health outcomes for person A are shown below.

	CI	**SD**
Prob of no infection	**0.050**	**0.7**
Prob of infection	0.950	0.3
Prob of minor infection	**0.903**	**0.285**
Prob of needing and obtaining ICU	0.043	0.0105
Prob of needing and obtaining ICU and recovering	**0.038**	**0.00945**

Prob of needing and obtaining ICU and dying	0.004	0.00105
Prob of needing and not obtaining ICU	0.005	0.005
Prob of needing and not obtaining ICU and recovering	**0.003**	**0.003**
Prob of needing and not obtaining ICU and dying	0.002	0.002
Prob of dying	**0.006**	**0.003**

She has a 70% chance of no infection under SD, and a 90% chance of a minor infection under CI. Her chances of dying are higher under CI, at 0.6% rather than 0.3% under SD.

Expected QALY loss	**CI**	**SD**	
No infection	0.011	0.147	
Minor infection	0.079	0.035	
Needing ICU and recovering	0.004	0.002	
Needing ICU and dying	0.242	0.111	
total	0.336	0.295	
concern about rest of household total	0.000	0.000	
concern about outside household total	0.000	0.158	
total concern	**0.336**	**0.453**	
Economic losses			
loss of earnings if not infected	18750	18750	£
loss of earnings if infected	3000	7250	£
Expected economic loss			
Expected loss of earnings	3788	15300	£
Expected medical costs	5	2	£
Total	**3792**	**15302**	**£**
QALY equivalent	**0.126**	**0.510**	
total concern over health and economic losses	**0.463**	**0.963**	
Net benefit of Controlled Infection	**0.500**		

Her major QALY loss under CI is the 0.242 QALYs from needing an ICU and dying. There is only a 0.6% chance of this happening, but she loses a lot of years of good health if it does. Her major QALY losses under SD are from the loss of quality of life during the lockdown (0.147), from dying (0.111) and, particularly, from concern about those outside the household she would infect while infectious (0.158). Although the QALY loss while needing an ICU is large, it only occurs for a short time if she recovers, so does not contribute greatly to her expected QALY loss under either choice. Her expected economic losses of £15302 under SD are much higher than the £3792 under CI, as she can get back to normal life much faster under CI. Adding in the QALY equivalent of her economic losses takes her total QALY losses to 0.463 under CI and 0.963 under SD. For her, CI is clearly the better option, giving a net benefit of 0.5 QALY.

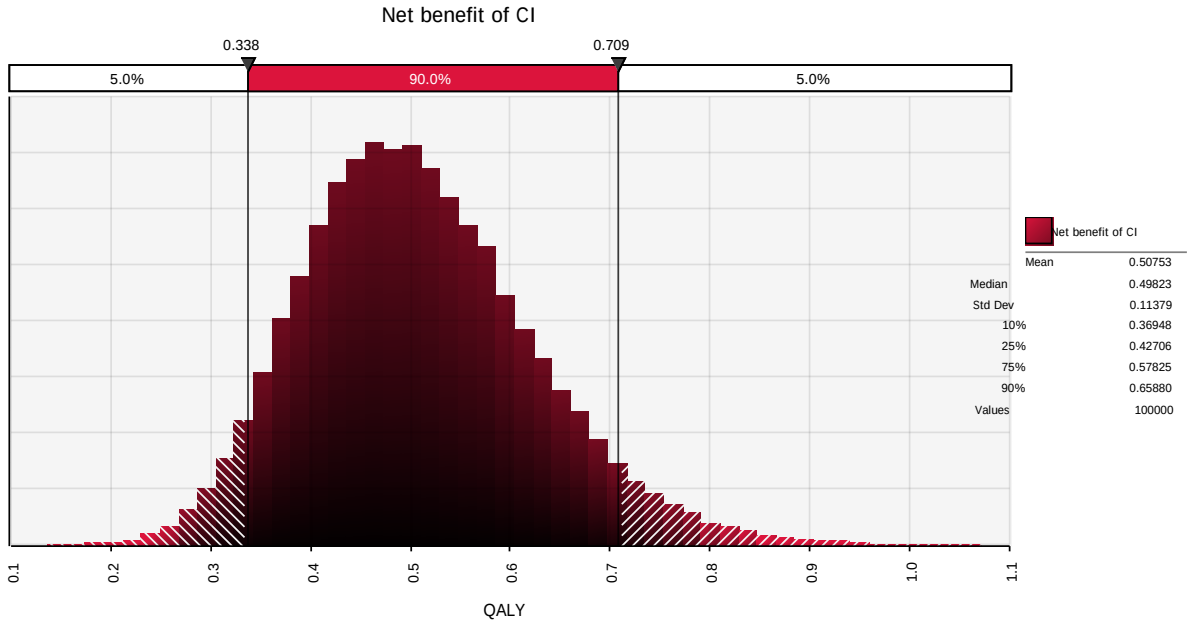
Probabilistic calculation

Nearly all the parameters in the model are in reality highly uncertain. In this section they are represented by symmetrical triangular probability distributions, with modal (and therefore mean)

values as in the deterministic calculation, and minimum and maximum values as shown in the table below.

	min	max	
Time until emergency over	0.5	1.0	years
Length of infection	0.02	0.06	years
Date of infection if it occurs under SD	0.13	0.37	years
Time until those who have had COVID can resume better life	0.06	0.18	years
Remaining lifetime	30	50	years
Prob of infection under CI	0.9	1.0	
Prob of infection under SD	0.1	0.5	
Prob of needing ICU if infected	0.02	0.08	
Prob of obtaining ICU if needed under SD	0.6	0.8	
Prob of obtaining ICU if needed under CI	0.8	1	
Prob of death if need ICU and obtain it	0.05	0.15	
Prob of death if need ICU and do not obtain it	0.3	0.5	
Value of full quality life year	20000	40000	£/year
Loss of earnings under SD	20000	30000	£/year
Normal quality of life	0.96	1	
Quality of life under SD	0.6	0.8	
Quality of life if infected	0.5	0.7	
Quality of life while needing ICU	0	0.2	
Quality of life close to normal	0.85	0.95	
Number of people in household	1	1	
Number of people outside household infected under SD	1	3	
Concern for those outside household	0.3	0.5	
Concern for those inside household	0.8	1	
Medical costs if hospitalised	0	200	£

Running the model 100,000 times, using Latin Hypercube Sampling to sample the parameters randomly from these ranges, gives the result shown in the figure below for the net benefit from choosing CI rather than SD.

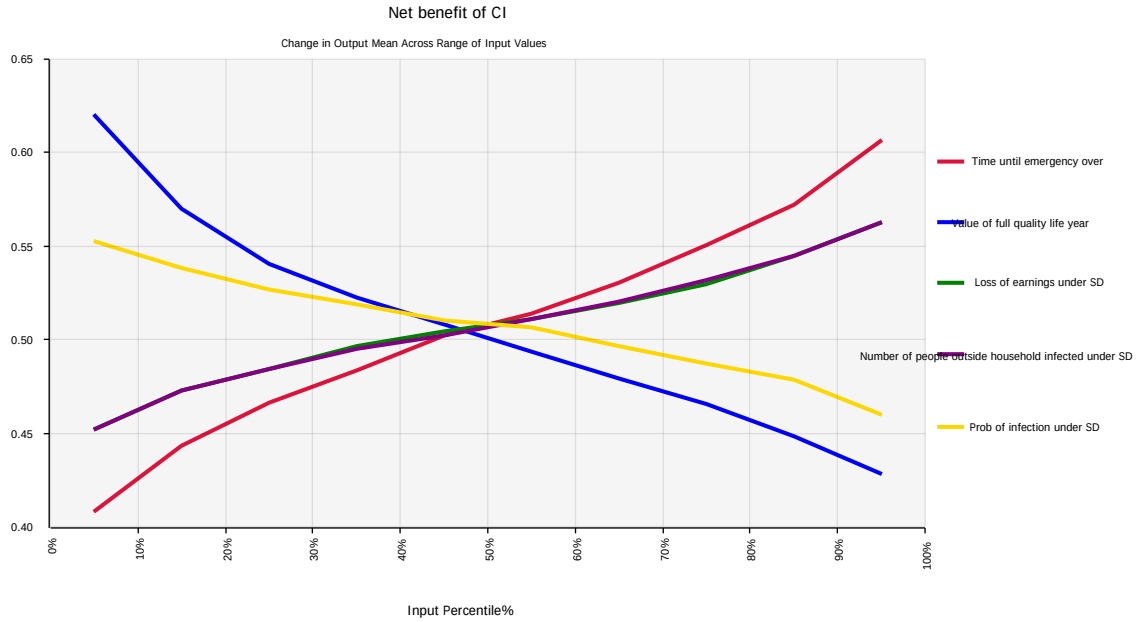


The mean benefit is very close to the 0.5 QALY net benefit in the deterministic calculation. The 90% confidence interval for the net benefit is 0.338 to 0.709 QALY. All 10,000 runs show CI to be better than SD for a person like this.

The figure below shows the influence of the five most influential parameters in the model on this result. The most influential parameter is T, the time until the emergency is declared over. If this is in the bottom 10% of its range, just over 6 months, and all other parameters continue to vary over their full range, the mean net benefit from CI is just over 0.4 QALY. If it is in the top 10% of its range, just below one year, the mean net benefit from CI is just over 0.6 QALY.

The second most influential parameter is Eqaly, the value of a full quality life year, whose influence is in the opposite direction. If it is in the bottom 10% of its range, just above £20,000, the mean net benefit of CI is about 0.62 QALY. If it is in the top 10% of its range, just below £40,000, the mean net benefit of CI is about 0.43 QALY. The influence is in this direction because a smaller value of Eqaly gives a higher QALY equivalent from the smaller economic losses under CI, and vice versa.

The other influences are interpreted in a similar way.



Discussion

Even with the referenced sources and a probabilistic calculation, we shouldn't take too much notice of the exact numerical results from the model, but they give at least a suggestion that there may well be many people who could benefit from and choose controlled infection. The result (in appendix A) that person C, a retired person with a partner, is clearly better under SD gives some confidence that the model is not systematically biased towards controlled infection. The government would clearly need to develop, validate and possibly extend the model before deciding whether to offer CI to healthy people.

Some might worry about the morality of letting people choose an action with a roughly 0.5% chance of death. But people often do this – mountain climbing and motorcycling are obvious examples (DfT, 2015). The worry would be valid if governments were to compel some people to become infected, but this is not what is being modelled here.

A final thought. As the lockdown wears on, many people are capable of making an informal calculation like the one modelled here. If the government does not offer the option for CI, some of those people may well be tempted to take matters into their own hands and become infected via friends or contacts. But this would be much less controlled than an official scheme, and in particular would not reliably avoid the contact with others while infectious, which is one of the main benefits of CI. So please do comply with government guidelines and not take matters into your own hands unless an officially sanctioned scheme is put in place.

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Appendix A Deterministic calculations for two other individuals

Person B: Middle aged with family, not very socially active, not too concerned about the wider world, losing some income but helped by government measures.

Person C: Retired with partner, not losing income or too badly affected by social distancing, moderately socially responsible.

Person B:

Length of infection	0.04	F	years
Remaining lifetime	30	L	years
Prob of needing ICU if infected	0.05	Pv	
Loss of earnings under SD	10000	Esd	£/year
Normal quality of life	0.98	Qn	
Quality of life under SD	0.8	Qsd	
Quality of life if infected	0.7	Qi	
Quality of life while needing ICU	0.1	Qv	
Quality of life close to normal	0.95	Qcn	
Number of people in household	3	H	
Number of people outside household infected under SD	1.5	Nisd	
Concern for those outside household	0.2	Cnh	
Concern for those inside household	1	Ch	

He is still fit and healthy so the illness would run its course in 2 weeks. His remaining lifetime is 45 years, but discounted down to 30 years for time and loss of quality in old age. He has no existing conditions so would only have a 10% chance of needing a ICU. He is employed and qualifies for government help, so would lose 10,000 per year while under SD. His normal quality of life is very good, he is moderately sociable and his quality of life drops to 0.8 under lockdown, and 0.7 if infected and quarantined. His life would be of very poor quality, 0.1, if under intensive care, but back to 0.95 once immune and allowed to resume activity. He has a partner and two children in his household (counted as 1 as they seem to be less affected by the virus), and has contact with a few people even under lockdown, from shopping etc. He is not so socially responsible, and cares only a fifth as much for those outside his household as he does for himself, or those inside his household.

The health outcomes for person B are shown below:

	CI	**SD**
Prob of no infection	**0.050**	**0.7**
Prob of infection	0.950	0.3
Prob of minor infection	**0.903**	**0.285**
Prob of needing and obtaining ICU	0.043	0.0105
Prob of needing and obtaining ICU and recovering	**0.038**	**0.00945**
Prob of needing and obtaining ICU and dying	0.004	0.00105
Prob of needing and not obtaining ICU	0.005	0.005
Prob of needing and not obtaining ICU and recovering	**0.003**	**0.003**
Prob of needing and not obtaining ICU and dying	0.002	0.002
Prob of dying	**0.006**	**0.003**

They are identical to person A.

Expected QALY loss	**CI**	**SD**	
No infection	0.007	0.095	
Minor infection	0.040	0.020	
Needing ICU and recovering	0.003	0.001	
Needing ICU and dying	0.182	0.083	
total	0.231	0.199	
concern about rest of household total	0.463	0.398	
concern about outside household total	0.000	0.045	
total concern	**0.694**	**0.641**	
Economic losses			
loss of earnings if not infected	7500	7500	£
loss of earnings if infected	1200	2900	£
Expected economic loss			
Expected loss of earnings	1515	6120	£
Expected medical costs	5	2	£
Total	**1520**	**6122**	**£**
QALY equivalent	**0.051**	**0.204**	
total concern over health and economic losses	**0.744**	**0.845**	
Net benefit of Controlled Infection	**0.101**		

His major individual QALY loss under CI is the 0.182 QALYs from needing a ICU and dying. There is only a 0.6% chance of this happening, but he loses a lot of years of good health if it does. But he also loses 0.463 QALYs from concern about the rest of his household who would also be infected if he is. His major QALY losses under SD are from similar causes, 0.083 and 0.398 from loss of life and concern about family, but also his loss of quality of life during the lockdown (0.095). His concern about those outside the household he would infect while infectious (0.045) is lower. His expected economic losses of £6122 under SD are higher than the £1520 under CI, as he can get back to normal life much faster under CI. Adding in the QALY equivalent of his economic losses takes his total QALY losses to 0.744 under CI and 0.845 under SD. For him, the outcomes are close, with CI being slightly the better option.

Person C:

Length of infection	0.06	F	years
Remaining lifetime	15	L	years
Prob of needing ICU if infected	0.2	Pv	
Loss of earnings under SD	0	Esd	£/year
Normal quality of life	0.98	Qn	
Quality of life under SD	0.95	Qsd	
Quality of life if infected	0.9	Qi	
Quality of life while needing ICU	0.1	Qv	
Quality of life close to normal	0.97	Qcn	
Number of people in household	2	H	
Number of people outside household infected under SD	1.5	Nisd	

Concern for those outside household	0.3	Cnh
Concern for those inside household	1	Ch

He is still fairly fit and healthy so the illness would run its course in 3 weeks. His remaining lifetime is 20 years, but discounted down to 15 years for time and loss of quality in old age. He has no existing conditions but is older so would have a 20% chance of needing a ICU. He is retired, so would lose no income while under SD. His normal quality of life is very good, but he is not very sociable outside his family, and can keep himself busy building models such as this one (yes, person C is me) so this only drops to 0.95 under lockdown, and 0.9 if infected and quarantined. His life would be of very poor quality, 0.1, if under intensive care, but back to 0.97 once immune and allowed to resume activity. He has a partner in his household, and has contact with a few people even under lockdown, from shopping etc. He is moderately socially responsible, and cares 30% as much for those outside his household as he does for himself, or those inside his household.

The health outcomes for person C are shown below:

	CI	**SD**
Prob of no infection	**0.050**	**0.7**
Prob of infection	0.950	0.3
Prob of minor infection	**0.760**	**0.240**
Prob of needing and obtaining ICU	0.171	0.042
Prob of needing and obtaining ICU and recovering	**0.154**	**0.0378**
Prob of needing and obtaining ICU and dying	0.017	0.0042
Prob of needing and not obtaining ICU	0.019	0.018
Prob of needing and not obtaining ICU and recovering	**0.011**	**0.011**
Prob of needing and not obtaining ICU and dying	0.008	0.007
Prob of dying	**0.025**	**0.011**

He has a higher chance of dying as he is older, but still by far the most likely outcome is no infection under SD and minor symptoms under CI.

Expected QALY loss	**CI**	**SD**
No infection	0.001	0.016
Minor infection	0.010	0.004
Needing ICU and recovering	0.010	0.003
Needing ICU and dying	0.363	0.165
total	0.384	0.188
concern about rest of household total	0.384	0.188
concern about outside household total	0.000	0.173
total concern	**0.768**	**0.549**

Economic losses			
loss of earnings if not infected	0	0	£
loss of earnings if infected	0	0	£
Expected economic loss			
Expected loss of earnings	0	0	£
Expected medical costs	19	6	£

Total	**19**	**6**	**£**
QALY equivalent	**0.001**	**0.000**	
total concern over health and economic losses	**0.769**	**0.549**	
Net benefit of Controlled Infection	**-0.220**		

His major QALY loss under CI is the 0.363 QALYs from needing a ICU and dying. There is only a 2.5% chance of this happening, but he still loses several years of good health if it does. But he also loses 0.384 QALYs from concern about his partner who would also be infected if he is. His major QALY losses under SD are from similar causes, 0.165 and 0.188 from loss of life and concern about family, and from concern about those outside the household he would infect while infectious (0.173). His loss of quality of life during the lockdown (0.016) is lower. His expected economic losses are essentially zero under both scenarios as his pension will continue to be paid in full. His total QALY losses are 0.769 under CI and 0.549 under SD. For him, SD is clearly the better option, with a net benefit of -0.220 QALY for CI.

Appendix B Equations in the model

COVID-19 controlled infection model

Parameters in model

Time until emergency over	T	years

At some point the government will declare the COVID-19 emergency over and allow everyone to resume a normal life. Probably once a vaccine is available. Of the order of a year.

Length of infection	F	years

The length of time that an infection lasts. Assumed to be the same whether symptoms are minor or more major. Of the order of two weeks.

Date of infection if it occurs under SD	D	years

Probably near the middle of the infection, which is likely to be the order of three months away.

Time until those who have had COVID can resume better life	B	years

This will happen when people can prove that they are immune using an antibody test. Of the order of a month or two away.

Remaining lifetime	L	years

Expected remaining lifetime if not killed by COVID-19, discounted for time and loss of quality towards the end of life. Will vary by person, up to about 50 years for a healthy young adult.

Prob of infection under CI	Pci

As the virus seems to transmit easily, assume this is close to 100%

Prob of infection under SD	Psd

There have been different views about this, ranging from 80% in some early work with no social distancing. Possibly around 30% now.

Prob of needing ICU if infected	Pv

For healthy people, over 90% of infections result in no or mild symptoms. Assume this is the order of 5%. ‘ICU’ is shorthand in this paper for all intensive medical care.

Prob of obtaining ICU if needed under SD	Pvsd

If the health service does become overwhelmed, not all patients who need ICUs will get one. Some early work suggested only one in eight would get them, but now it seems the proportion could be 70% or more.

Prob of obtaining ICU if needed under CI	Pvci

As the infection occurs early in the pandemic, assume the health service will not be overstretched, so assume to be close to 1

Prob of death if need ICU and obtain it	Pdv

Of the order of 10%, giving a death rate of about 0.5% for previously healthy people.

Prob of death if need ICU and do not obtain it	Pdnv

Assume this is much higher, maybe close to 50%

Value of full quality life year	Eqaly	£/year

Government uses a value of about 30,000 for this.

Loss of earnings under SD Esd £/year

Will depend on the individual. Government support has reduced this loss by up to 80%. Maybe of the order of 10,000 to 30,000.

Normal quality of life Qn

Full quality life is rated as 1 in the QALY system. This will vary by person, but for many will be close to or at 1.

Quality of life under SD Qsd

Will vary by person. Some might feel badly affected, some are quite able to withstand it. Probably 0.5 to 0.95

Quality of life if infected Qi

Will involve mild symptoms and quarantine. Less than Qsd. Maybe around 0.5

Quality of life while needing ICU Qv

The major symptoms of pneumonia are very unpleasant. Probably close to 0.

Quality of life close to normal Qcn

Not everything will be back to normal. There will be other people still socially distancing, and other disruptions still continuing. Above Qsd but not back to Qn.

Number of people in household H

Assume all these people will be infected if you are. The model assumes their QALY loss from illness is the same as yours, but they have no economic losses. Obviously an oversimplification, but may not be too bad as older people probably lose more and children less. Maybe count a child as half an adult for the purposes of the model, as they seem to be less affected by the illness than adults.

Number of people outside household infected under SD Nisd

These are people you encounter while infectious but before you know it. Will be lower the more effective social distancing is, but will not be zero. Maybe around 2. Their health losses are assumed to be the same as yours if you were infected, which is an obvious oversimplification.

Concern for those outside household Cnh

People differ in their social responsibility. For some who only think of themselves this will be close to zero. For others with a strong social conscience it will be higher, but almost certainly less than 1, maybe around 0.5. The model assumes this applies only to their health losses, as you infecting them does not consistently change their economic losses.

Concern for those inside household Ch

For people in a happy family or social unit this will be close to 1, or even above 1. For others it could be significantly lower.

Medical costs if hospitalised Cm £

Under the NHS this will be zero or close to zero. It’s included in the model so that it can be used in other countries without healthcare that is free at point of use.

Equations

First calculate the probability of the different medical outcomes

Prob of no infection

Pnici = 1 – Pci

Pnisd = 1 - Psd

Prob of minor infection

Pmici = Pci x (1 – Pv)

Pmisd = Psd x (1 – Pv)

Prob of needing and obtaining ICU

Pnvci = Pci x Pv x Pvci

Pnvsd = Psd x Pv x Pvsd

Prob of needing and obtaining ICU and recovering

Pnvrci = Pnvci x (1 – Pdv)

Pnvrsd = Pnvsd x (1 – Pdv)

Prob of needing and obtaining ICU and dying

Pnvdci = Pnvci x Pdv

Pnvdsd = Pnvsd x Pdv

Prob of needing and not obtaining ICU

Pnvnci = Pci x Pv x (1 – Pvci)

Pnvnsd = Psd x Pv x (1 – Pvsd)

Prob of needing and not obtaining ICU and recovering

Pnvnrci = Pnvnci x (1 – Pdnv)

Pnvnrsd = Pnvnsd x (1 – Pdnv)

Prob of needing and not obtaining ICU and dying

Pnvndci = Pnvnci x Pdnv

Pnvndsd = Pnvnsd x Pdnv

Prob of dying

Pdci = Pnvdci + Pnvndci

Pdsd = Pnvdsd + Pnvndsd

There are five mutually exclusive and exhaustive outcomes, so

Pnici + Pmici + Pnvrci + Pnvnrci + Pdci = 1

Pnisd + Pmisd + Pnvrsd + Pnvnrsd +Pdsd = 1

This is used to check the coding of this portion of the model is correct.

Next calculate the relevant dates

Date infection starts

Dsci = 0

Dssd = D

Date infection ends or death

Deci = Dsci + F

Desd = Dssd + F

Date better life resumes if infected

Dblci = max (Deci, B)

Dblsd = max (Desd, B)

Now calculate the direct QALY losses for the outcomes

No infection

Qnici = Qnisd = T x (Qn – Qsd)

Minor infection

Qmici = Deci x (Qn – Qi) + (Dblci – Deci) x (Qn - Qsd) + (T -Dblci) x (Qn - Qcn)

Qmisd = D x (Qn - Qsd) + (Desd – Dssd) x (Qn -Qi) + (Dblsd -Desd) x (Qn-Qsd) + (T - Dblsd) x (Qn -Qcn)

Needing ICU and recovering

Qnvrci = Deci x (Qn - Qv) + (Dblci - Deci) x (Qn - Qsd) + (T - Dblci) x (Qn – Qcn)

Qnvrsd = D x (Qn - Qsd) + (Desd – Dssd) x (Qn -Qv) + (Dblsd -Desd) x (Qn-Qsd) + (T - Dblsd) x (Qn -Qcn)

Needing ICU and dying

Qdci = Deci x (Qn - Qv) + (L - Deci) x Qn

Qdsd = D x (Qn - Qsd) + (Desd - Dssd) x (Qn - Qv) + (L - Desd) x Qn

Multiply these direct QALY losses by their probability to get expected QALY losses

No infection

EQnici = Pnici x Qnici

EQnisd = Pnisd x Qnisd

Minor infection

EQmici = Pmici x Qmici

EQmisd = Pmisd x Qmisd

Needing ICU and recovering

EQnvrci = (Pnvrci + Pnvnrci) x Qnvrci

EQnvrsd = (Pnvrsd + Pnvnrsd) x Qnvrsd

Needing ICU and dying

EQdci = Pdci x Qdci

EQdsd = Pdsd x Qdsd

These can be summed to get a total expected direct QALY loss

EQtci = EQnici + EQmici + EQnvrci +EQdci

EQtsd = EQnisd + EQmisd + EQnvrsd + EQdsd

Now calculate concern for others in household and outside household

EQhci = EQtci x (H-1) x Ch

EQhsd = EQtsd x (H-1) x Ch

Outside household

EQnhci = 0 (as there is no chance of infecting anyone outside household)

Under sd, the probabilities of minor infection, need ICU and recovering and dying are in the same ratio as for individual under sd, they just don't have Psd at the start.

Prob of minor infection

Pminhsd = 1 – Pv

Prob of needing and obtaining ICU

Pnvnhsd = Pv x Pvsd

Prob of needing and obtaining ICU and recovering

Pnvrnhsd = Pnvnhsd x (1 – Pdv)

Prob of needing and obtaining ICU and dying

Pnvdnhsd = Pnvnhsd x Pdv

Prob of needing and not obtaining ICU

Pnvnnhsd = Pv x (1 – Pvsd)

Prob of needing and not obtaining ICU and recovering

Pnvnrnhsd = Pnvnnhsd x (1 – Pdnv)

Prob of needing and not obtaining ICU and dying

Pnvndnhsd = Pnvnnhsd x Pdnv

Prob of dying

Pdnhsd = Pnvdnhsd + Pnvndnhsd

There are four mutually exclusive and exhaustive outcomes, so

Pminhsd + Pnvrnhsd + Pnvnrnhsd +Pdsnhd = 1

This is used to check the coding of this portion of the model is correct.

The expected QALY losses are these probabilities times the QALY losses under sd

Minor infection

EQminhsd = Pminhsd x Qmisd

Needing ICU and recovering

EQnvrnhsd = (Pnvrnhsd + Pnvnrnhsd) x Qnvrsd

Needing ICU and dying

EQdnhsd = Pdnhsd x Qdsd

These can be summed to get a total expected direct QALY loss

EQtnhsd = EQminhsd + EQnvrnhsd + EQdnhsd

The total concern for those outside household needs to subtract the expected QALY losses under sd from this, and multiply by the number infected and the concern for those outside household.

EQnhsd = Nisd x Cnh x (EQtnhsd – Eqtsd)

Total concern

CEQci = EQtci + EQhci +EQnhci

CEQsd = EQtsd + EQhsd + EQnhsd

Economic losses

Loss of earnings if not infected

ELnici = ELnisd = T x Esd

Loss of earnings if infected

ELici = Dblci x Esd

ELisd = Dblsd x Esd

(These both assume minor infection or recovery from more serious infection. If death occurs, expenses cease as well as income. The losses from death are fully covered by the direct QALY losses)

Expected loss of earnings

EELci = (1 – Pci) x ELnici + Pci x ELici

EELsd = (1 – Psd) x ELnisd +Psd x ELisd

(should really be a small reduction to account for the possibility of death, but it will be negligible)

Expected medical costs

Emcci = (Pnvci + Pnvnci) x Cm

Emcsd = (Pnvsd +Pnvnsd) x Cm

These are zero or very minor for the individual under the UK's NHS, but could be significant in other countries.

Total expected economic losses

ELtci = EELci + Emcci

ELtsd = EELsd +Emcsd

Conversion of expected economic loss to QALY loss

EQEci = ELtci/Eqaly

EQEsd = ELtsd/Eqaly

Total concern for QALY loss including from economic loss

Cci = CEQci +EQEci

Csd = CEQsd +EQEsd

The better option is the one with the lower value of C. The net benefit of CI is

NBci = Csd - Cci

These equations are implemented in an Excel spreadsheet with the @RISK add-in to perform the probabilistic calculations. Anyone wanting a copy of the spreadsheet should contact the author.