THE COSTS AND BENEFITS OF COVID-19 LOCKDOWNS IN AUSTRALIA

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Abstract

This paper has considered the costs and benefits of Australia's lockdown strategy relative to pursuit of a mitigation strategy in March 2020. The estimate is 4,000 - 17,000 additional deaths to 30 December 2020 from mitigation, plus further deaths over the next several months until mass vaccination of high-risk groups will be achieved. The result is that the cost per Quality Adjusted Life Year saved by locking down is estimated to be at least 11 times the generally employed figure of $100,000 for health interventions in Australia. Consideration of the information available to the Australian government in March 2020 yields a similar ratio and therefore strongly supported adoption of a mitigation strategy at that time. If Australia experiences a new outbreak, and cannot contain it without resort to nationwide lockdowns, the death toll from adopting a mitigation strategy at this point would be even less than had it done so in March 2020, because the period over which the virus would then inflict casualties would now be much less than the period from March 2020. This would favour a mitigation policy even more strongly than in March 2020.

1.   Introduction

As with most other countries, in early 2020, Australia's federal and state governments implemented substantial curtailments of economic activities in order to reduce the death toll from Covid-19 ("lockdowns"). Since then, the curtailments have been substantially relaxed, but with temporary reinstatements in different parts of the country. This paper attempts to assess the comparative merits of this lockdown strategy and a milder mitigation strategy across the country (involving limiting large gatherings, case isolation, quarantining of members of their households, and social distancing for high-risk groups). The paper commences by examining this issue using data available as at 30 December 2020. It then considers the optimal choice based on information available at the time of the initial lockdown decision. Finally, it considers the optimal course of action if a new outbreak occurs that cannot be contained without resort to lockdowns.

2.   The Costs and Benefits of Lockdowns in March 2020

2.1 Deaths

The purpose of lockdowns is to reduce deaths, and the deaths suffered under the lockdown policy are known. Much less clear is what the death toll would have been under a mitigation policy. In mid March the Australian government estimated that, without lockdowns, up to 60% of the population would be infected and 1% of these would die, leading to up to 150,000 deaths.[1] Shortly afterwards, in late March 2020, Blakely and Wilson (2020) estimated deaths from an eradication (lockdown) policy at 5,000, those from a mitigation strategy at 25,000 – 55,000, and a worst-case scenario of 134,000 arising from no mitigation measures and 60% of the population then being infected. Subsequent estimates by Bailey and West, drawing upon analysis by Moss et al (2020) using data to 31 March, involved 27,000 deaths under eradication (lockdown), 141,000 deaths under mitigation, and 287,000 deaths with no mitigating actions. Subsequent estimates by Holden and Prescott (2020) involved 90% of the population being infected, and 1% of these would die, yielding 225,000 deaths. Subsequent estimates by Kompas et al (2020, pp. 8-9) using data to 1 June involved 100 deaths from adoption of the suppression measures actually adopted, 35,000 if implementation had been delayed by 28 days, and 260,000 if no actions were taken by government or individuals. Blakely et al's (2020) estimates use mortality rates by age group from the Ferguson et al

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[1]   See https://www.smh.com.au/politics/federal/australia-prepares-for-50-000-to-150-000-coronavirus-deaths-20200316-p54amn.html.

(2020) study in the UK. These in turn are based upon an epidemiological model in which each infected individual is estimated to infect R others (the reproduction rate) and this process extrapolated until so many people are infected that the virus dies out for lack of new targets. The estimates of Bailey and West (2020), derived from Moss et al (2020), and those of Kompas et al (2020), share this crucial feature.

These predictions suffer from three significant defects. Firstly, the deaths estimated by these models under a lockdown policy (up to 27,000) are well in excess of the actual deaths incurred to date under a lockdown policy. Secondly, the deaths estimated by these models under a mitigation policy (up to 141,000 deaths, which is 5,500 per 1m of Australia's population of 26m) are vastly in excess of the death rate per 1m to date in any country pursuing a mitigation policy.[2] Thirdly, the obvious explanation for these overestimates is the fact that such models do not allow for the fact that, as the number of deaths rises, people will react by engaging in more and more protective actions that will reduce the future death rate, such as hand washing, mask wearing, reducing social interactions, working from home, etc. Similarly, predictions about the deaths from a prolonged campaign of air raids arising from a model predicated on the target population taking no evasive action as the number of casualties rises will also be far too high.

In view of these empirical and theoretical deficiencies, I estimate the additional deaths under a mitigation rather than a lockdown strategy in Australia by examining the death rates in other countries. Foster (2020) uses the death rate in Sweden to estimate the additional Australian deaths under a mitigation approach at 10,000 (at the time of her analysis in August). However, Sweden was not the only mitigator; Iceland, Finland and Latvia did likewise. Even better would be to use the full set of countries with reliable data. One such approach would be to conduct a cross-country regression of death rates on variables found to influence such death rates, and include amongst the explanatory variables the strength of government restrictions. The coefficient on this latter variable would then provide an estimate of how many extra deaths would arise if the restrictions were less onerous. Chaudhry et al (2020) examines the 50 countries with the highest case counts as at 1 April 2020, and regresses cross-country death rates per 1m of population (up to 1 May 2020) on a

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[2] Within Europe, the mitigating countries have been Iceland, Finland, Latvia and Sweden, with death rates per 1m up to 30 December of 82, 99, 321, and 859 respectively.

number of independent variables, including various measures of government intervention, and find that *none* of these latter variables were statistically significant. Gibson (2020) conducts a similar analysis, using the 34 OECD member countries, death rates up to 18 August 2020, and various independent variables including the average level of government restrictions over the period of the crisis. [3] He finds that policy stringency (averaged over the whole crisis period) is *not* statistically significant in explaining cross-country variation in death rates (ibid, Table 2). He also examines average stringency both before and after the estimated infection peak for each country, and finds mild statistical significance for average stringency prior to the estimated infection peak along with a negative coefficient (ibid, Table 2). He also uses average stringency in other countries within the same OECD group as an instrumental variable, to test for reverse causality between stringency and death rates, and finds no evidence of reverse causality. Hale et al (2020b) conduct a similar analysis, using 170 countries and data to 27 May 2020, and find that both the speed of government response (number of days from the first reported case till the government restrictions reach 40 on the Hale et al, 2020a Stringency index) and the severity of the restrictions (using the Stringency index of Hale et al, 2020a) affect death rates in the expected way.

Given the actual or probable unreliability of data from many countries, it is desirable to limit the analysis to countries for which the data is likely to be very reliable. It is also desirable to eliminate countries with federal systems, in which restrictions varied by state or province, because the Hale et al (2020a) data is only available at the country-level. This leaves European countries and the East Asian democracies (Japan, South Korea, Taiwan, Singapore, plus Hong Kong). Hale et al (2020a) have constructed a set of indexes, which assign a daily score to each country for the severity of their restrictions imposed by government, ranging from 0 to 100 and taking account of different types of restrictions. I use their Stringency Index, which takes account of 8 different types of government restrictions.[4] Death rates per 1m of population are drawn from https://www.worldometers.info/coronavirus/. All five East Asian countries have very low death rates regardless of the severity of restrictions, and the possible reasons (a culture of mask wearing, not shaking hands, compliance with government directives, extensive contact tracing and testing, and pre-existing immunity) are or were not

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[3] The latter is quantified using the Stringency Index of Hale et al (2020a), which assign a daily score to each country for the severity of their restrictions imposed by government, ranging from 0 to 100 and taking account of different types of restrictions: see https://covidtracker.bsg.ox.ac.uk/ for the data.

[4] See https://covidtracker.bsg.ox.ac.uk/ for the data. Their other indexes produce similar results.

applicable to the same degree in Australia. So, I use only the European countries, of which there are 33.[5] They are similar (on average) to Australia in ethnicity, cultural norms, demographics, GDP per capita, and the quality of their health care systems

In using the Stringency Index, there is a choice of the average and maximum values, and both have merits. The maximum reflects only government policy on one day whilst the average (crudely) takes account of it over the entire period of the crisis. However, a given average value could arise from a wide range of different policies. An extreme case of this would arise if one country adopted its maximum stringency index value of 100 on the first day, retained it for six weeks and then removed all restrictions because eradication had been achieved, whilst a second country maintained a stringency index value of 50 throughout the 12 weeks of the analysis. Both would have an average Stringency of 50, but would have adopted entirely different policies. The maximum avoids this problem. It also avoids the problem that the average over the entire crisis period is affected by the post-peak death rate reductions in the index, which are likely to have been affected by the reduction in the death rate after the peak death rate point, which yields a reverse causality problem.

Death rates are likely to be affected by many variables other than the severity of government restrictions, and it is desirable to include them. I consider
- (a) population density (higher values increase the transmission rate of the virus),
- (b) the date of the first death (in days after the first recorded death on 15 February in France), because later dates provide more time for people, doctors and their governments to learn from others and adjust their behavior, [6]
- (c) population (higher values provide a higher pool of virus targets before national borders constrict the movement of people and therefore the transmission of the virus),
- (d) GDP per capita (as a proxy for the quality of the health care system),

[5] Malta is excluded because Hale et al (2020a) does not include data on them. In addition the political entities with very small populations (under 100,000) are all excluded because many of the data sources used for this analysis do not provide data on them. For example, Hale et al (2020a) does not include data on the Faeroe Islands, Monaco and Liechtenstein, whilst the "List of Countries by Age Structure" does not include data on Andorra, San Marino, Gibraltar, and Greenland.

[6] A closely related variable is the number of days from the date on which the Stringency Index reached 54 (the lowest of the cross-country maxima and therefore defined for all countries) until the date of the first death, because higher values indicate a faster response by a government to the crisis. Hale et al (2020b) use a similar variable. Each of these two variables is highly statistically significant and the R^2 results from them are almost identical, but that from 'Date of First Death' are slightly better. I therefore report only the results from the use of 'Date of First Death'.

(e) the population proportion over 65 (higher values imply a larger proportion of the population in the high risk group),

(f) the average household size (higher values increase the pool of virus targets before household borders restrict interactions and therefore the transmission of the virus), and

(g) the number of nursing and elderly home beds per 100,000 of population (because higher values implies a higher concentration in the high-risk group, which increases or lowers the death rate depending upon the effectiveness of the quarantine procedures).

(h) Flu intensity in the last two flu seasons.[7]

The first two variables are statistically significant, and substantially raise the adjusted R^2, whilst the last five variables (added and tested separately) are not statistically significant and their inclusion each lowers the adjusted R^2. I therefore retain only the first two variables. Regressing the death rate per 1m (D) up to 30 December on the maximum Stringency Index value (S), the population density (PD, in millions per 1,000 square miles), and date of first death (FD, in days from 15 February) yields the following result:

$$D = 273.9 + 7.34S + 473.1PD - 12.3FD \qquad (1)$$

The R^2 is 0.29, and the p values are 0.66, 0.27, 0.10 and 0.10 respectively. The coefficient on S is statistically insignificant and the sign on it is 'wrong' (positive rather than negative).[8] Even using the lower bound on the 95% CI for S of -6.05, the expected increase in a country's death toll from moving from the most restrictive policy (Bosnia with $S = 100$) to the least restrictive policy (Iceland with $S = 54$) would be to raise its death rate by only

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[7] For the population of countries, see the last column of https://www.worldometers.info/coronavirus/. For area of countries, see third column of https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_area. For GDP per capita of countries, see the first column (IMF data) of https://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal)_per_capita. For the population proportion over 65, see https://en.wikipedia.org/wiki/List_of_countries_by_age_structure. For average household size, see https://www.un.org/en/development/desa/population/publications/pdf/ageing/household_size_and_composition_around_the_world_2017_data_booklet.pdf, pp. 20-24, except for Cyprus, which comes from https://population.un.org/Household/index.html#/countries/196. For the number of nursing and elderly home beds per 100,000 of population, see https://gateway.euro.who.int/en/indicators/hfa_490-5100-nursing-and-elderly-home-beds-per-100-000/, which does not contain data for Bosnia, Cyprus and Portugal so these numbers were estimated from those for Croatia, Greece and Spain respectively. For flu intensity, see Appendix to Hope (2020). The dates of the first deaths come from https://www.worldometers.info/coronavirus/.

[8] Using the average Stringency Index (from the first European death on 14 February to 30 December) instead of the maximum Stringency Index also yields a coefficient that is positive and statistically insignificant.

6.05*(100 – 54) = 278 per 1m of population. So, the evidence for government restrictions substantially reducing the death rate is minimal.

This result may seem counterintuitive, but explanations are available. One possibility is that reverse causality applies, i.e., the choice of policy is influenced by the death rate as well as the death rate being affected by the policy choice. The Appendix investigates this possibility and concludes that it does not operate. Another possibility is that, even without government restrictions, people will take actions to lower their risks in a pandemic and the incremental effect of government actions may then be too little to be statistically significant. A second possibility is that lockdowns will in some cases increase the risk of transmission to high-risk individuals, and this at least partly offsets the reduction in risks achieved in other ways. For example, lockdowns will have caused some young people to return to live with their older parents, perhaps because of the loss of their job or closure of the university they were attending, and if already infected to thereby infect their parents, who are at much greater risk of death. A third possibility is that some of the European lockdowns were not instituted quickly enough to be effective, and all of those that were instituted quickly enough were relaxed before eradication had been achieved (because their land borders were too porous to achieve eradication) leading to a resurgence in cases when the lockdowns were relaxed.

This third possibility is very relevant to Australia, because its lockdown strategy was successful in epidemiological terms, i.e., the two major outbreaks were suppressed, leading to a very low death rate (of only 35 per 1m). By contrast, European countries can be classified as having experienced

  (a) mitigation strategies (Finland, Iceland, Latvia, and Sweden, with death rates ranging from 82 to 861 per 1m up to 30 December), or

  (b) lockdown strategies that failed to suppress the virus (the rest, with death rates ranging from 80 to 1,656 per 1m up to 30 December).

Because the European data contains only cases of these two types, it does not provide an estimate of the death rate difference between a lockdown strategy that substantially succeeded and mitigation, and this differential is required for Australia. Accordingly, the coefficient on S in equation (1) is not useful for Australia. Accordingly, a different approach is required, as follows.

Since the evidence presented above is that lockdowns were not effective in Europe it follows that the European data is equivalent to that from a set of countries that pursued mitigation. So, an estimate of the Australian death rate under mitigation would be the average European death rate (680 per 1m as at 30 December), corrected for differences in variables that are statistically significant in explaining the death rate. For Europe, these are population density (*PD*) and date of first death (*FD*), and the resulting model using death rate data to 30 December is

$$D = 887 + 497PD - 12.9FD \qquad\qquad (2)$$

The R^2 is 0.26 and the *p* values on the coefficients are 0.002, 0.09 and 0.09 respectively. Substitution of Australia's values for the regressors, of *PD* = 0.009 and *FD* = 15, yields an estimated death rate *D* under mitigation of 699 per 1m.

This analysis uses data from European countries, because the quality of the data is judged to be sufficient, and conservatively excludes East Asian democracies (with very low death rates regardless of government policy) because cultural norms may differ significantly from Australia. I now examine the next best source of data, which appears to be that from the Americas, but with the exclusion of the US and Canada (because they are federal systems with variation in policy by state) and exclusion also of Cuba, Nicaragua and Venezuela (because authoritarian regimes are likely to deliberately understate deaths). I also exclude countries with less than 50,000 people because death rates expressed per 1m of population (as the data source does) are only then expressible in multiples of 20 or more. Across the countries for which both Hale et al (2020a) provides the Stringency data and the www.worldometers.info website provides death rate data, there are 28 countries: Brazil, Argentina, Colombia, Mexico, Peru, Chile, Ecuador, Bolivia, Panama, Dominican Republic, Costa Rica, Guatemala, Honduras, Paraguay, El Salvador, French Guyana, Jamaica, Haiti, Trinidad and Tobago, Suriname, Aruba, Guyana, Belize, Uruguay, Cayman Islands, Barbados, Bermuda, and Dominica. Unlike the European data, population density and date of first death are not statistically significant, but the following two regressors are statistically significant:

(a) population (higher values provide a higher pool of virus targets before national borders constrict the movement of people and therefore the transmission of the virus),

(b) having no land borders with other countries (water barriers rather than land borders better restrict the flow of people and hence the virus into a country).

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If the maximum Stringency index is added, it is not statistically significant and the estimated coefficient on it is positive rather than the expected negative. With P denoting population in millions and I denoting no land borders (1 if so and 0 otherwise), the model exclusive of S is thus:

$$D = 434 + 3.47P - 313I \qquad (3)$$

The R^2 is a respectable 0.43, and the p values on the three coefficients are 0, 0.01 and 0.01 respectively. Substitution of Australia's values for the regressors, of $P = 26$ and $I = 1$, yields an estimated death rate under mitigation of 211 per 1m.

If the European and Americas data are pooled, P, I and date of first death (FD) are statistically significant at the 10% level, with all coefficients having the expected signs. Addition of S yields a coefficient that is not statistically significant, and with the wrong sign. The resulting model exclusive of S is thus:

$$D = 860 + 2.4P - 333I - 8.6FD \qquad (4)$$

The R^2 is a respectable 0.36, and the p values on the four coefficients are 0, 0.07, 0.02 and 0.02 respectively. Substitution of Australia's values for the regressors, of $P = 26$, $I = 1$, and $FD = 15$, yields an estimated death rate under mitigation of 460 per 1m.

Across these three models (2), (3) and (4), the estimated death rate for Australia under a mitigation policy is 211 to 699 per 1m. With 26m people in Australia, this implies 5,000 - 18,000 deaths in Australia up to 30 December had a mitigation policy been pursued. The estimate of 18,000 uses the best quality data (from Europe) but is likely to be too high because Australia is an island, and this reduces its death rate, but there are too few islands in the European data (only two) for the dummy variable "Island" to be statistically significant and therefore warrant inclusion in equation (2). This additional analysis also amplifies the point that Australia was in a favourable position had it pursued mitigation, because it has favourable values for three of the four variables found to reduce the Covid-19 death rate: low population, no land borders, and low population density.

These estimates presume that Covid-19 deaths are accurately recorded. However, some Covid-19 deaths may be mistakenly attributed to another cause, or deaths from other causes mistakenly attributed to Covid-19, with the latter error possible simply because most victims have co-morbidities. By analogy, if a person is shot in the heart and then the head, and then dies, the cause of death may not be the head shot. In addition, lockdown discourages or prevents some people suffering from non Covid-19 conditions from seeking medical attention, leading to some deaths in lockdown countries that would not otherwise have occurred, and these should be included in the incremental deaths from lockdown. In addition, mitigation increases the load on hospitals, leading to more deaths from other causes (through lack of care) in mitigation countries, and these should be included in the incremental deaths from mitigation. An estimate of the Covid-19 deaths that accounts for all of these phenomena is the actual deaths in 2020 less the predicted number sans Covid-19 ("Excess Deaths"). The Euromomo Network has done so and estimated the number of deaths across 18 European countries progressively through 2020, 2019 and 2018 relative to a prediction ("baseline"). The Excess Deaths for 2020 exhibit sharp increases in March-April and November-December, consistent with the pandemic. The Excess Deaths to 31 December relative to the baseline are 290,000 for 2020 (from 15 February when the first Covid-19 death occurred in any of these 18 countries), 70,000 for 2019 and 115,000 for 2018.[9] By contrast, the deaths attributed to Covid-19 across these 18 countries (to 31 December) were 334,000.[10] Thus, if the baseline were used, the Excess Deaths in 2020 would be 290,000 and therefore the deaths attributed to Covid-19 of 334,000 would be too high by 15%. However, the baseline is an imperfect prediction, as evidenced by the results for 2018 and 2019 (which would be zero if the predictions were accurate). This is simply a consequence of the fact that deaths in these countries in a typical year are about 3m, so that the prediction error of 115,000 for 2018 is a small proportion.[11] All of this suggests that the deaths attributed to Covid-19 are approximately correct.

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[9] See https://www.euromomo.eu/graphs-and-maps#excess-mortality.

[10] The countries are Austria, Belgium, Denmark, Estonia, Finland, France, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the UK. For the deaths, see https://www.worldometers.info/coronavirus/.

[11] See https://www.ined.fr/en/everything_about_population/data/europe-developed-countries/population-births-deaths/.
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In summary, the estimated deaths in Australia had it followed a mitigation strategy are 5,000 - 18,000 up to 30 December. By contrast, deaths to 30 December under a lockdown policy have been almost 1,000. So, the extra deaths resulting from a mitigation rather than a lockdown policy would be 4,000 - 17,000. This analysis provides an estimate of the deaths Australia would have suffered had it pursued a mitigation policy, but only deaths up to 30 December are estimated and there will be more deaths to come until mass vaccination is achieved.[12] Letting N denote the covid-19 deaths in the European countries up to the end of the pandemic divided by the deaths until December 30, the extra deaths resulting from a mitigation rather than a lockdown policy would be up to 17,000N. Since mass vaccination has already commenced in Europe, and will presumably progressively reduce the death rate to zero over the next several months, and deaths to 30 December reflect deaths over a ten month period, a reasonable estimate of N would be less than 2.

2.2 Quality Adjusted Life Years

In assessing the merits of health interventions, the standard methodology amongst health economists is to multiply the expected lives saved from a health intervention by the average residual life span of the victims sans intervention, to yield the "Life Years" saved by the intervention, followed by some discount if the quality of these life years saved would be less than that of a normal healthy person. The result is called the Quality Adjusted Life Years (QALY) saved by the intervention, which is then compared to a benchmark figure.

Kompas et al (20290, page 8) estimates the average residual life expectancy of the victims at 6.9 yrs, by comparison of the average age of the Australian victims (75.6) with the life expectancy of Australians at birth (82.5). Such an estimate does not recognize that the set of people who reach the age of 75.6 excludes those who have died at an earlier age and therefore this set will have an average residual life expectancy greater than 6.9 yrs. The corrected estimate will then be too high because it does not recognize that covid-19 victims are unusually unwell relative to those of age 75.6 in general. Blakely and Wilson (2020) adopt an average residual life expectancy for the victims of five years, but provide no supporting evidence. Foster (2020) does likewise.

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[12] Mass vaccination will at best reduce rather than eliminate deaths, because some people are unresponsive to vaccines or will not consent to them. However, it is very unlikely that lockdowns would be pursued beyond this point. So, in assessing the merits of lockdowns and mitigation, the relevant deaths are those up to this point.

Analysis of European data supports this figure of five years. I illustrate this with Sweden, which adopted a mitigation policy and incurred the highest death rate amongst countries that did so. The age distribution of the Covid-19 victims is shown in the first two columns of Table 1, and the residual life expectancy (RLE) of Swedish people in each such age group is shown in the third column. Using this data, the average residual life expectancy of Swedish people with the same age distribution as the Covid-19 victims is 10.9 years.[13] However, the Covid-19 victims differ from Swedish people of the same age distribution in two very significant ways.

The first of these differences is that a large proportion of the victims were residents of nursing homes, whose average residual life expectancy sans Covid-19 was very low and might be even lower than suggested by their ages. If so, conditioning on residency of a nursing home as well as age would reduce the average residual life expectancy of the victims. In respect of Sweden, Stern and Klein (2020, page 5) estimate that 53% of the Covid-19 victims aged at least 70 were residents of nursing homes, and that their average residual life span sans Covid-19 was only seven months (ibid, pp. 16-17). Conservatively treating this subset of victims as the oldest in Table 1, they represent the entire 85+ group (47%) plus additional victims in the 80-84 group constituting 6% of the entire set of victims (6/21 of that group). Replacing the residual life expectancy of these people by seven months (0.6 years), the average residual life expectancy calculated from the data in Table 1 would fall to 7.7 years as shown in the fourth column of Table 1.[14] By contrast, if this nursing home group were spread through the 70+ groups in proportion to the size of these groups, 28% would be in the 85+ group, 13% in the 80-84 group, and 13% in the 70-79 group. Replacing the residual life expectancy of these people by 0.6 years, the average residual life expectancy calculated from the data in Table 1 would fall to 6.4 years.

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[13] See https://www.statista.com/statistics/1107913/number-of-coronavirus-deaths-in-sweden-by-age-groups/ and https://apps.who.int/gho/data/?theme=main&vid=61600. The age distribution is only available in ten-year blocks whilst life expectancy is only available in five year blocks up to age 85 followed by an 85+ group. So, Table 1 shows the number of victims in ten-year blocks up to age 80as per the source data, the number of victims assigned to the 80-84 block is half of that reported in the 80-89 block, the other half of that block plus the 90+ block is combined to form an 85+ block, the life expectancies for the ten-year blocks up to age 80 are averaged over the data for each ten-year block, and the life expectancies for the last two blocks are as per the source data. The life expectancy data is also separately reported for males and females, unlike the age distribution of the victims, and the former data is therefore averaged over the sexes (since the Miles et al, 2020, data reveal that the sex split of the victims is close to 50/50, at 56% men).

[14] The figure of 6.67 years in this column of the table is a weighted average of 0.6 years for the nursing home residents, with weight 6/21, and 9.1 years for the rest.

The second unusual feature of these Covid-19 victims is that they were unusually unwell, even for their age; virtually all had at least one co-morbidity, which is presumably well in excess of the rate for the general population of the same age distribution.[15] A common such ailment was type 2 diabetes. The NHS (2018, Figure 8) provides estimates for the increase in mortality risk from this disease (relative to the general population) by age and sex. Averaging over these categories, the increase is about 50%. However the group of interest here excludes those in nursing homes, because the estimate for the residual life expectancy of these victims already reflects co-morbidities. This exclusion lowers the average age of the remaining victims, and suggests an increase in their mortality risk of about 80%. In addition, a person with a residual life expectancy of 10 years (the average for the Covid-19 victims) would have a current mortality risk of about 5% over the next year, growing at about 11% per year compounded:[16]

$$RLE = .05(1) + (1 - 0.05)[.05(1.1)]((2) + (1 - .05)[.05(1.1)(1.1)](3) + \cdots = 9.52\ yrs$$

Raising this initial mortality risk by 80%, from 5% to 9%, along with the same growth rate of 11%, reduces the residual life expectancy from 9.52 yrs to 6.68 yrs, i.e., a reduction of 30%. A similar percentage reduction applies to the average residual life expectancy of a group. As noted above, virtually all of the victims had at least one co-morbidity, and multiple co-morbidities would reduce the average residual life expectancy of a group by even more than estimated here.

Allowing for this additional feature of the covid-19 victims is simplified by the fact that virtually all covid-19 victims had co-morbidities. So, the subset of Swedish victims from nursing homes have their residual life expectancy set as before at 0.6 years (which will also reflect their co-morbidities), and all others have their residual life expectancy reduced by

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[15] In respect of those dying in New York City up to 13 May 2020, and in those cases where the existing medical condition of the patient was known (no underlying condition or at least one underlying condition), 98% had at least one underlying condition (the set of conditions includes diabetes, cancer, heart disease, lung disease, and hypertension). See https://www.worldometers.info/coronavirus/coronavirus-age-sex-demographics/.

[16] Data from the Period Life Tables 2012-2014, Table 5: http://archive.stats.govt.nz/browse_for_stats/health/life_expectancy/NZLifeTables_HOTP12-14/Data%20Quality.aspx#gsc.tab=0. The table gives medians rather than means and therefore is not directly usable here.

(conservatively) 30%. The results are shown in the penultimate column of Table 1, with the nursing home group conservatively assumed (as before) to be the oldest, and the last column of Table 1, in which the nursing home group is spread throughout the 70+ groups in proportion to their sizes.[17] The average residual life spans are 5.5 and 4.7 years respectively, and a good estimate would lie between these figures. So, starting with 10.9 years, the reduction is to 6.4 - 7.7 years to account for the nursing home group, and then to 4.7 – 5.5 years to additionally account for co-morbidities in the rest. This supports the estimate of Blakely and Wilson (2020) and Foster (2020), of five years.

Table 1: Residual Life Expectancy of Swedish Covid-19 Victims

Age Group	Victims	RLE	RLE	RLE	RLE
0-9	2	79.55	79.55	79.55(0.7)	79.55(0.7)
20-29	10	60.25	60.25	60.25(0.7)	60.35(0.7)
30-39	19	50.5	50.5	50.5(0.7)	50.5(0.7)
40-49	45	40.8	40.8	40.8(0.7)	40.8(0.7)
50-59	164	31.3	31.3	31.3(0.7)	31.3(0.7)
60-69	406	22.4	22.4	22.4(0.7)	22.4(0.7)
70-79	1268 (22%)	14.3	14.3	14.3(0.7)	4.45
80-84	1219 (21%)	9.1	6.67	4.72	2.80
85+	2747 (47%)	6.3	0.6	0.6	2.14
Average (yrs)		10.9	7.7	5.5	4.7

The last step here is the discount to reflect the imperfect health of virtually all of these victims sans Covid-19. Miles et al (2020, page 69) use 20% based on prevailing discounts for type 2 diabetes with and without additional problems. In particular, they cite Beaudet et al (2014, Table 3), who favour a quality of life discount of 21% for Type 2 diabetes without complications, and substantial additional discounts for further problems including 9% for

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[17] The figure of 4.72 years in the penultimate column of the table is a weighted average of 0.6 years for the nursing home residents, with weight 6/21, and 9.1(0.7) years for the rest. The figure of 2.80 in the final column is a weighted average of 0.6 years for the nursing home residents, with weight 13/21, and 9.1(0.7) years for the rest.

heart disease and 16% for stroke. These discounts in Beaudet et al (2014) suggest that Miles et al's (2020) 20% discount for an average covid-19 victim is low. Consistent with this, Briggs (2020, Figure 3) uses a discount of about 30% for Covid-19 victims, based upon norms arising from survey data from Szende et al (2014). Furthermore, a large proportion of the victims were residents of nursing homes, for which the quality of life discount could reasonably be even higher. I adopt a conservative estimate of the discount, of 20%.

A further step undertaken by Briggs (2020, Figure 3) is to discount future QALY losses, and the reduction is substantial. Briggs does not disclose the discount rate used, but use of the yield on ten-year Australian government bonds (averaged over the period Feb 2020-Jan 2021, of 0.9%) reduces the result in Table 1 above from 4.7 years to 3.9 years. Since this does not seem to be standard practice amongst health economists, I do not incorporate this additional adjustment.

In conclusion, the QALYs saved by the Australian government pursuing lockdown rather than mitigation are estimated at up to $17,000N*5*0.8 = 68,000N$. This estimate is likely to be too high, because 17,000 is too high and the 20% discount is too low.

2.3 Expected GDP Losses

Turning now to the costs of the lockdown policy, this principally takes the form of lost GDP. Shortly before the pandemic arose, in December 2019, the Australian Treasury (2019, Table 1.2) forecasted Australia's real GDP growth rates for 2019-20 till 2022-23 at the rates shown in the first row of Table 1.[18] This is an estimate of growth in the absence of the pandemic. Arbitrarily designating 2018-19 GDP as 100, the GDP results under this path are shown in the next row of the table. In December 2020 they released updates as shown in the third row of the table (Australian Treasury, 2020, Table 1.1), with the implied GDP path in the fourth row. The last row of the table shows the difference between the two paths, which aggregates to 21.3, i.e., 21.3% of Australia's 2018-19 GDP. Since Australia's 2018-19 GDP was $1,950b, this is $415b.[19] This estimate is conservative because the two real GDP forecast paths in Table 2 have not converged over the period for which the forecasts are available (out to mid 2024). By comparison, Pujol (2020, Table 1) reports estimates of this type from nine

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[18] The figure for 2023-24 does not appear in the document, and is extrapolated from the series for comparison with the forecasts one year later, which do include 2023-24.

[19] The GDP figure comes from Table H1 on the website of the RBA: https://www.rba.gov.au/statistics/.

advanced economies that locked down, using data from Consensus Economics, and the median loss is 25%. Gomez-Pineda, 2020, Figure 1) also graphically presents annual estimates of this type for both advanced and developing economies (each aggregated), and the Australian estimates are lower than the former and even more so for the latter.

Some of these GDP losses of $415b would have arisen without any Australian government-imposed lockdowns, because some people would have reduced their interactions with others anyway; for example, a foreigner electing not to make a trip to Australia that they would otherwise have made, or an Australian choosing to avoid cafes. Further losses would have arisen due to the additional actions of foreign governments; for example, foreign governments preventing or discouraging their citizens from making foreign trips. Further losses would have arisen if the Australian government had followed merely a mitigation strategy, which includes border closures. Finally, further losses would have arisen from the Australian government instead following a lockdown strategy. It is only the last category of these losses that can be attributed to the Australian government choosing a lockdown policy rather than a mitigation policy.

Table 2: GDP Forecasts

	19-20	20-21	21-22	22-23	23-24	Sum
Dec 2019 Forecasts	2.25%	2.75%	3.0%	3.0%	3.0%	
Implied GDP	102.3	105.1	108.2	111.5	114.8	
Dec 2020 Forecasts	-0.2%	0.75%	3.5%	2.5%	2.75%	
Implied GDP	99.8	100.5	104.1	106.6	109.6	
Shortfall	2.5	4.6	4.1	4.9	5.2	21.3

Estimating the proportion arising from this last category is difficult. Estimates by the New Zealand Treasury coupled with analysis in Lally (2020, section 3.3) suggests that the fraction was 29% for New Zealand. Andersen et al (2020) examine the drop in consumer spending in the early stages of the pandemic (11 March to 5 April), relative to 2 January till 15 February in both Denmark (which adopted a lockdown policy) and Sweden (which adopted a mitigation policy). They find that the drop in Sweden was 86% of that in Denmark (25% drop versus 29% drop), implying that 14% of the drop in Denmark was due to a lockdown

rather than a mitigation policy. In a similar study (Goolsbee and Syverson, 2020) examine adjoining US counties with one area subject to lockdown and the other not; the drop in consumer activity in the latter area was 88% of the former, implying that only 12% was due to the lockdown. Aum et al (2020) estimate the effect of increased infections upon the unemployment rate in Korea (which did not lockdown), the US and UK (which did), and conclude that the effect is twice as great in the US and UK, leading to the conclusion that lockdowns explain half the loss of employment. In a much broader study, the IMF (2020, Chapter 2) examined 28 countries and concluded that lockdowns contributed 40% of the reduction in 'Google Mobility Data' in advanced economies, which is a proxy for the GDP loss. In an approach directly comparable with Table 2 above, Pujol (2020, Table 1) presents estimates of the GDP losses for nine advanced economies that locked down (US, Canada and seven Western European economies), and two that did not (Sweden and Japan); the median of the first group is 25% and that of the latter is 16%, which implies that 36% of the loss is due to lockdowns. The best estimates here are the last two, because they each cover a wide range of countries. I adopt the median estimate of 39%. Applying it to the Australian GDP loss of $415b yields a loss due to the lockdowns of $160b.

Foster (2020) estimates the GDP loss at 0.5% for each month of lockdown, based upon the RBA's August 2020 forecast of a 6% decline in GDP in 2020 (RBA, 2020c, Table 6.1), multiplies this by 38% (the share of government expenditure in GDP), and then attributes half of this to the lockdowns. In respect of Foster's first step, the RBA's (2020c, Table 6.1) full set of forecasts is -6% in 2020, 5% in 2021 and 4% in 2022. In addition, the RBA's November 2019 forecasts were 2.75% for 2020 and 3% for 2021 (RBA, 2019, Table 5.1), to which I add an extrapolated forecast of 3% for 2022. The shortfall calculated in the same way as in Table 2 then aggregates to 22.2% of 2019 GDP. This is almost four times Foster's figure of 6%. Foster's second step is very conservative, as the full welfare loss is the GDP loss rather than merely the government share of it. In respect of Foster's third step, analysis by Aum et al (2020) is offered in support. This is the highest of the estimates I have cited above.

Holden and Preston (2020) estimate the GDP loss at 10% of one year's GDP "..consistent with IMF forecasts of a fall in GDP of 6.7% in 2020 and a sharp rebound of 6.1% growth in 2021." They attribute up to half of this to lockdowns, based upon the study by Andersen et al (2020). It is not apparent how these IMF forecasts give rise to a loss of 10% but, in any

event, the loss is the entire shortfall between the GDP forecasts immediately preceding the pandemic and subsequent forecasts (as in Table 2).

Kompas et al (2020, pp. 11-14) estimate the GDP losses at $928m per day of lockdown, scale this up for 8 weeks of lockdown (56 days) to yield $52b, and then allow up to four months for transition back to "normal" yielding a GDP loss of up to $120b. However, their transition path is speculative, and use of the Australian Treasury's transition path leads to a GDP loss of $415b rather than $120b (see Table 2 above). Furthermore Kompas et al (2020) fail to then ascribe only a fraction of their GDP losses of $120b to lockdowns.

2.4 Cost per QALY Saved

In summary, the QALYs saved by locking down rather than mitigating are estimated at up to 68,000N whilst the associated GDP losses are expected to be at least $160b. If these GDP losses were the only cost of lockdowns, the cost per QALY saved would then be as follows:

$$C = \frac{\$160b}{68,000N} \qquad\qquad (5)$$

I now attempt to quantify all of the additional costs of mitigation. Firstly, there are the medical costs of those requiring short-term hospitalization under a mitigation policy. Gros (2020, section 2.2) assumes that the entire population of a country becomes infected, and estimates that 20% would require general hospital care at a cost per patient equal to 30% of GDP per capita, and ¼ of these would also require Intensive Care treatment at a further cost per patient of 60% of per capita GDP, yielding a total cost equal to 9% of GDP. However the assumption that everyone in a population would become infected is excessive. Blakely and Wilson (2020) estimate that the infection rate would not exceed 60% because the epidemic would by then peter out through herd immunity, Boyd (2020, page 3) adopts a base case of 40% based upon the experience from past pandemics, and Aguas et al (2020) estimate it to be even lower.[20] Furthermore, even if Gros's estimates of the proportion infected requiring medical care were correct, this would (even at a 40% infection rate) imply 2m Australians

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[20] Blakely and Wilson assume a basic reproduction rate of $R_0 = 2.5$ coupled with the classical formula that the "Herd Immunity Threshold" $= 1 - (1/R_0)$. This formula overestimates the Herd Immunity Threshold because it assumes no change in behavior by people as the death toll rises. It also assumes that all members of a population are equally exposed to the virus and equally susceptible to it, which is not the case and this implies that herd immunity is achieved at a much lower proportion of the population infected (Aguas et al, 2020).

requiring hospitalization (8% of its population), and 500,000 of these requiring an ICU. However, there would not be enough hospital beds or ICUs in the country or medical staff to cater for even a fraction of them.

By contrast, Bailey and West (2020, Appendix A) estimate hospitalized cases at 960,000, ICU cases as 256,000, and deaths at 141,000 under a mitigation policy. Since my upper bound on the number of dead under a mitigation policy is 18,000N, this implies 122,000N hospitalised cases and 33,000N ICU cases. I assume (again to be conservative) that the Australian hospital system could accommodate all of them. Furthermore, whatever number of cases were accommodated, they would be to some degree permanently displacing other types of patients so the incremental costs would be even less. Even without displacement, most of these costs would be fixed (staff, buildings, and equipment) and therefore irrelevant. In the interests of being conservative, I assume no displacement of other types of patients and all costs being variable. With Australia's GDP per capita of \$75,000, the upper bound on the resulting incremental costs would be \$4.2bN as follows:

$$75,000[122,000N(0.3) + 33,000N(0.6)] = \$4.2bN$$

Kompas et al (2020, section 4.3) estimates the costs at \$23.3b under their no suppression scenario, which involves 260,000 deaths. Scaled down to reflect the 18,000N deaths forecasted by me under a mitigation scenario, the result is \$1.6bN. Using the higher figure of \$4.2bN to modify equation (5), the cost per QALY is now as follows:

$$C = \frac{\$160b - N\$4.2b}{68,000N} \qquad (6)$$

Secondly, mitigation gives rise to some survivors who may experience significant long-term adverse consequences. Arnold et al (2020) report that, amongst Covid-19 cases in the UK who were hospitalized, 26% died and 74% of the rest had ongoing problems after 12 weeks, implying a ratio of slow recovery patients to dead of 74*0.74/26 = 2.1. However, this ratio will be too low because it excludes slow recovery patients who were never hospitalized. Using data from the Covid Symptom Study, Couzin-Frankel (2020) estimates that 10-15% of *all* of those infected do not recover quickly. More recently, and using the same data source, Greenhalgh and Knight (2020) estimate that 10% of those who have tested positive remain

unwell after three weeks and a smaller (but unquantified) proportion for months. More recently, in October, Sudre et al (2020) estimate that 13.3% of those who tested positive remained unwell for at least four weeks, with 8.8% resolved in 4 - 8 weeks, a further 2.2% resolved in 8 – 12 weeks, and the remaining 2.3% unresolved after 12 weeks. A pattern consistent with this data is that, amongst this group who are still unwell after 4 weeks, 68% experience symptoms for 4 – 8 weeks, 16% for 8 – 12 weeks, 8% for 12 – 16 weeks, etc. The average time unwell is then

$$Average = 0.68(6) + 0.16(10) + 0.08(14) + 0.04(18) + \cdots$$

This series can be decomposed into a set of geometric progressions and then added, to yield an average of 9 weeks (0.16 years). As of 15 October 2020, there were 38.6m recorded cases and 1.1m deaths worldwide.[21] So, the ratio of these long-recovery covid cases to deaths is 38.6m*0.133/1.1m = 4.7. Furthermore, consistent with the figure used earlier for Covid-19 victims suffering from serious pre-existing conditions, their quality of life is thereby initially reduced by 20%. Allowing for all this is then equivalent to increasing the QALYs saved from lockdown rather than mitigation by 3% as follows:

$$\frac{1(5)(0.8) + 4.7(0.133)(0.2)}{1(5)(0.8)} = \frac{4.0 + 0.125}{4.0} = 1.03$$

This raises the denominator in equation (6) by a factor of 1.03. There will also be medical costs associated with these very long-term sufferers. For example, if each such person's medical costs average $10,000 per year in which symptoms are experienced, the cost for 85,000 survivors (18,000 victims*4.7) for 0.16 years on average is $135m. Both the denominator adjustment of 1.03 and the numerator addition of $135m are too small to warrant inclusion, and alternative (reasonable) assumptions about the time profile of the resolution of these cases and the cost per year per patient do not change this conclusion.

Thirdly, mitigation gives rise to work absences amongst those who are infected and must self-isolate. Gros (2020, section 2.1) assumes all members of a population are infected, 30%

[21] See https://www.worldometers.info/coronavirus/.

require a work absence of four weeks and a further 20% require six weeks, leading to a GDP loss of 5% of one year's GDP:

$$.30\left(\frac{4}{52}\right) + .20\left(\frac{6}{52}\right) = .05$$

However the assumption that everyone in a population would become infected is excessive. As noted previously, Blakely and Wilson (2020) estimate that the infection rate would not exceed 60% because the epidemic would by then peter out through herd immunity, Boyd (2020, page 3) adopts a base case of 40% based upon past pandemics, and Aguas et al (2020) estimates an even lower rate. Furthermore, even if Gros's estimate of 50% of those infected requiring a work absence were correct, this does not yield a proportionate decline in GDP for various reasons. In particular, many of the people required to isolate could still perform their work from home. Furthermore, even where those isolated could not thereby perform their tasks for this period of weeks, other employees of the organization would increase their productivity or hours of work to at least partly compensate, and/or customers of the businesses would experience longer wait times with no loss of output, and/or the absent employees would be able to perform at least some of the work upon their return in addition to their normal workloads. Accordingly, a more reasonable estimate of the GDP loss than Gros's would involve 40% of the population being infected, and 30% of those requiring isolation able to still perform their jobs at home, and 75% of the rest having their work performed by others or by them upon their return to work or addressed through longer customer queues. The resulting GDP loss would then be only 5%*0.4*0.7*0.25 = 0.35% rather than 5% of one year's GDP. In dollar terms this is $1,950b*0.0035 = $6.8b. Modifying equation (6), the cost per QALY saved would be at least as follows:

$$C = \frac{\$160b - \$6.8b - N\$4.2}{68,000N} \qquad (7)$$

This figure is too low for three principal reasons. Firstly, the estimate of 68,000 QALYs saved by locking down is likely to be too high because it uses the highest estimate of additional deaths from locking down (from the European data). Secondly, the estimate of $160b for the GDP losses from the lockdowns is too low because the two real GDP forecast paths in Table 2 have not converged over the period for which the forecasts are available (out to mid 2024).

Thirdly, no allowance has been made for various phenomena that would raise the costs of lockdowns but cannot readily be quantified: problems arising from the increased unemployment (addiction, crime, domestic violence, mental health problems, and premature death), loss of social interactions, increased anxiety, disruption to the education of the Covid-19 student cohort, and the deprival of liberties that people would otherwise enjoy. Lockdowns also disrupt the normal operation of the health care system, leading to deaths that would not otherwise occur (such as people who fail to have cancer screening tests done), but failure to lockdown may also saturate the system with covid-19 cases, leading to deaths amongst other types of patients who have been crowded out. The net effect of this point is very unclear, because it depends inter alia on how quickly a society expands its health care system to accommodate the increased caseload, but the net short-term effect is likely to be small because the deaths attributed to covid-19 approximate the excess deaths relative to pre-pandemic forecasts (as discussed in section 2.1).

Foster (2020) attempts to quantify the adverse psychological impact of lockdowns on the average Australia, and concludes that it dominates all other considerations. The estimates are inherently subjective. Nevertheless, to illustrate their importance, I consider the psychological effect of unemployment on the unemployed during the period of unemployment. Table 3 shows forecast growth rates for the Labour Force in December 2019 (Australian Treasury (2019, Table 1.2) and in December 2020 (Australian Treasury, 2020, Table 1.1).[22] Arbitrarily designating the 2018-19 Labour Force as 100, the Labour Force results are shown under each forecast path, and the shortfall for each year shown in the last row, which aggregates to 21.8, i.e., 21.8% of Australia's 2018-19 Labour Force. Since Australia's 2018-19 Labour Force was 12.9m, this is the equivalent of 2.8m unemployed for one year.[23] This estimate is conservative because the two Labour Force forecast paths in Table 3 have not converged over the period for which the forecasts are available (out to mid 2024).

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[22] The figure for 2023-24 does not appear in the document, and is extrapolated from the series for comparison with the forecasts one year later, which do include 2023-24.

[23] For the Labour Force figure, see https://www.abs.gov.au/statistics/labour/employment-and-unemployment/labour-force-australia/latest-release.

Table 3: Employment Forecasts

	19-20	20-21	21-22	22-23	23-24	Sum
Dec 2019 Forecasts	2.25%	2.75%	3.0%	3.0%	3.0%	
Implied Employment	102.3	105.1	108.2	111.5	114.8	
Dec 2020 Forecasts	-0.2%	0.75%	3.5%	2.5%	2.75%	
Implied Employment	99.8	100.5	104.1	106.6	109.6	
Shortfall	2.5	4.6	4.1	4.9	5.2	21.3

Some of these Labour Force shortfalls would have arisen from the pandemic without any Australian government-imposed lockdowns, and it is only the fraction due to the lockdowns that are of interest. Section 2.3 estimate the proportion of the GDP shortfalls due to lockdowns at 39%, and the same proportion is applied here. So, lockdowns are expected to have reduced the size of the Labour Force by the equivalent of 2.8m*0.39 = 1.1m for one year, i.e., 1.1m people lost their jobs for one year. Frijters (2020) estimates that the loss of employment for one year reduces a person's quality of life during that year by the equivalent of 0.12 years of life.[24] This estimate is subjective, but so too is the estimate of the reduction in life quality of a typical covid-19 victim by 20% to reflect their co-morbidities (in section 2.2 above). So, the loss of employment for 1.1m people for one year is equivalent to the loss of 1.1m*0.12 = 132,000 QALYs. Netting this off against the 68,000N QALYs saved by the lockdown, equation (7) becomes

$$C = \frac{\$160b - \$6.8b - N\$4.2b}{68,000N - 132,000} \tag{8}$$

For $N = 1.5$, which is plausible, this QALY effect from unemployment is almost equal to the QALY effect of the covid-19 deaths under a mitigation policy. So, in the interests of being conservative, I halve the QALY impact of unemployment for a year from 0.12 years of life to 0.06 years of life. The loss of employment for 1.1m people for one year would then be

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[24] Frijters (2020) estimates that this loss reduces a person's WELLBYs (a measure of happiness) by 0.7 and the loss of life by a healthy person would reduce WELLBYs by 6. So, the loss of employment for one year is equivalent to the loss of 0.7/6 = 0.12 years of healthy life.

equivalent to the loss of 1.1m*0.06 = 66,000 QALYs. The cost per QALY saved by lockdown would then be as follows:

$$C = \frac{\$160b - \$6.8b - N\$4.2b}{68,000N - 66,000} \tag{9}$$

2.5 The Benchmark Valuation of a QALY

In respect of Australia, Blakely and Wilson (2020) use a benchmark of $100,000 per QALY saved, based upon "rules of thumb in the Australian health system". Foster (2020) uses the same figure. By contrast, the WHO recommends a benchmark equal to a country's per capita GDP (Bertram et al, 2016), which is currently $75,000.[25] Interestingly, Blakely and Wilson also co-authored an almost identical paper for New Zealand (Blakely et al, 2020), and they adopted a benchmark figure of GDP per capita in that case. In other recent health interventions in Australia, Cheng et al (2016) used $50,000 in assessing cardiac rehabilitation programs as does Kularatna et al (2020, page 5) in assessing oral health interventions. Using survey evidence on willingness to pay, Huang et al (2018) estimate the value at $22,000 - $67,000 while Lewkowski et al (2020) estimate it at $100,000 for men and $50,000 for women. In the interests of being conservative, I favour the largest figure here of $100,000.

A related concept is the "Value of a Statistical Life" (VSL), which values all lost years of an average aged person's life. This is recommended in decisions on reducing physical harm, such as in traffic safety and occupational safety, and the current value is $4.9m (Office of Best Practice Regulation, 2019, page 2). This figure is derived from Abelson (2008), who recommends use of its annual equivalent (the Value of a Life Year or VSL: ibid, page 16), which is performed for a person with a 40-year residual life span using a discount rate of 3% (ibid, page 3). Abelson's (2008) use of a 40-year residual life span presumably arose from it representing half of the life expectancy of an Australian (at birth) at that time. This life expectancy is now 41.4 years.[26] Furthermore, Abelson's discount rate of 3% presumably reflected market discount rates at that time. These are now considerably lower. In respect of

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[25] Miles et al (2020, page 68) reports a guideline figure of 30,000 pounds used in hospitals in the UK (which is close to its 2019 GDP per capita of 32,000 pounds) and the larger figure of $125,000 in the US (ibid, page 72), which is approximately double its 2019 GDP per capita of $65,000.

[26] 80.7 years for men and 84.9 for women. See https://www.aihw.gov.au/reports/life-expectancy-death/deaths-in-australia/contents/life-expectancy.

New Zealand, Pharmac (2015, pp. 51-52) recommended that all costs and benefits in health expenditure assessments be discounted by 3.5% per year, based on the five-year average real government bond rate. Following this, I use the average yield on ten-year inflation-indexed Australian government bonds over the last five years (January 2016 to December 2020), of 0.75%.[27] Applying this discount rate of 0.75%, the VLY would be such that

$$\$4.9m = \frac{VLY}{1.0075} + \cdots + \frac{VLY}{(1.0075)^{41}}$$

The solution is VLY = $141,000. By contrast, the Office of Best Practice Regulation (2019, page 2) recommends $213,000, derived using a 40-year period and a discount rate of 3%. Kompas et al (2020) uses this latter figure. In choosing between a VLY and the value of a QALY, Gros (2020, page 6) favours the latter because it is the approach that is "practiced routinely by the medical profession" whilst Miles at al (2020, page 76) also favours it because it is consistent with the approach to other health expenditures. I concur and therefore favour a QALY value of $100,000.

Interestingly, some analyses of the Covid-19 issue have been conducted by simply coupling the VSL by the expected number of lives saved rather than coupling the value of a QALY or a VLY with the expected number of (quality adjusted) life years saved (for example, Chapple, 2020; Thunstrom, 2020; Holden and Preston, 2020). This may reflect a belief that Covid-19 victims have a typical average residual life span and perfect health sans Covid-19, which may be true in safety interventions but is not the case here, and would therefore significantly overestimate the benefits in QALYs saved. Alternatively, it may reflect their belief that all lives saved are equally valuable, which implies that one would spend as much to extend the life of a person by one day (or even one hour) as one would spend to extend the life of a different person for fifty years. If the latter interpretation is correct, it would be perverse to do so. It would also be inconsistent with prevailing views amongst public health experts in Australia and elsewhere, in which the impact of health interventions on the residual life expectancy of the targets is estimated and converted to a monetary figure using a value per year (Bertram et al, 2016; Cheng et al, 2016; Blakely and Wilson, 2020).

2.6 Comparison of Cost with Benchmark

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[27] The RBA reports the yield on these bonds at Table F2: https://www.rba.gov.au/statistics/tables/#interest-rates.

In summary, the cost per QALY saved is shown in equation (7), (8) and (9), and the benchmark figure is $100,000. Whether the cost per QALY saved exceeds this benchmark figure of $100,000 depends upon the value of N. Table 4 shows costs per QALY saved according to the choice of equation and the value of N, which must be at least 1.

The lowest results are from equation (7). Even at $N = 2$, which is an upper bound, the cost per QALY saved is $1.06m, which is almost 11 times the benchmark figure of $100,000. Equation (8) allows for the loss of quality of life of the unemployed whilst unemployed, at 12% of the value of a healthy life. At $N = 1$ or $N = 1.5$, this allowance is so large as to fully offset the QALY losses amongst the dead. At $N = 2$, the cost per QALY saved is $36.2m, which is 362 times the benchmark value. Equation (9) allows for the loss of quality of life of the unemployed whilst unemployed, at only 6% of the value of a healthy life. At $N = 2$, the cost per QALY saved is $2.07m, which is almost 21 times the benchmark value.

Table 4: Costs Per QALY Saved

	$N = 1$	$N = 1.5$	$N = 2$
Equation (7)	$2.19m	$1.44m	$1.06m
Equation (8)	N/A	N/A	$36.2m
Equation (9)	$74.5m	$4.1m	$2.07m

In respect of the lowest cost outcomes, which arise from equation (7), N would have to be 14 before the cost per QALY in equation (5) fell to $100,000, i.e., the eventual death toll in Europe from the pandemic would have to be 14 times the death toll to 30 December. To gain some sense about the plausibility of such a value of N, suppose that completion of mass vaccination of the high-risk groups is ten months away (from 30 December 2020).[28] So, for $N = 14$ to prevail, the expected loss in lives in Europe over the next ten months would have to be 13 times that for the ten months up to 30 December (since the first deaths in Europe in late February), which would require a daily death rate over the next ten months that is 13 times that for the ten months up to 30 December. This does not seem plausible, especially in view of the fact that mass vaccination has already begun.

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[28] Ten months seems like an upper bound in view of the fact that mass vaccination has commenced in Europe.

Thus, the cost per QALY saved by lockdown is well in excess of the standard benchmark figure. This conclusion is strengthened by the fact that many of the parameter estimates in equations (7), (8) and (9) are towards the end of their probability distributions that yield the lowest possible cost per QALY, most particularly the 68,000 extra QALYs lost from mitigation (likely to be too high) and the $160b GDP loss due to lockdown rather than mitigation (likely to be too low). This conclusion is also strengthened by the fact that, apart from the allowance within equations (8) and (9) for the contemporaneous effect of being unemployed on the unemployed, no allowance has been made for various phenomena that would raise the costs of lockdowns but cannot readily be quantified: problems arising from increased unemployment (addiction, crime, domestic violence, mental health problems, and premature death), loss of social interactions, increased anxiety, disruption to the education of the Covid-19 student cohort, and the deprival of liberties that people would otherwise enjoy.

3. The Merits of Lockdown Versus Mitigation Using Data Available in March 2020

I now consider the merits of the lockdown decision using data available in March 2020. I focus upon equation (7). The denominator there must be replaced by an estimate derived from contemporaneous data. In mid March 2020, the Australian government believed that the death toll without lockdown would be 50,000 – 150,000 dead, arising from 20% - 60% of the population being infected and an Infection Fatality Rate of 1% (see page 2). A few days later, Blakely and Wilson (2020) estimated the death toll under lockdown at 5,000 if successful and that under mitigation at 25,000 – 55,000 along with 134,000 dead and 60% infected if no mitigating actions were taken. This suggests that the Australian government's worst case assumed no mitigating actions, and therefore the best estimates in March 2020 of the death tolls under mitigation and lockdown were 40,000 (the midpoint of 25,000 and 55,000) and 5,000 respectively. Assuming lockdown was bound to be successful, this implies (40,000 – 5,000)*5*0.8 = 140,000 QALYs saved by locking down. The medical costs in the numerator of equation (7) must also be raised to be consistent with the revised denominator value. Kompas et al (2020, section 4.3) estimates them at $23.3b under a worst-case death toll of 260,000. Scaled to reflect 35,000 additional deaths rather than their worst case, the costs fall to $3.1b.

In addition, GDP forecasts are required for March 2020 and from the same source just before the pandemic struck. The Australian Treasury provides forecasts only six monthly, in July and December. By contrast, the RBA provides forecasts every three months, and the relevant ones are for November 2019, February 2020 and May 2020. The first of these predate the pandemic, the second recognizes some GDP losses from the pandemic but only due to its impact on China, whilst the third fully recognizes the pandemic. I use the May 2020 forecasts as a proxy for views in March, along with the November 2019 forecasts. For the years ended June 2020, 2021 and 2022, the November 2019 forecasts are 2.5%, 3% and 3% (RBA, 2019, Table 5.1), whilst the May 2020 forecasts for the same years are -8%, 7% and 5% respectively (RBA, 2020b, Table 6.1).[29] Using these to estimate the GDP shortfall in the same way as Table 2, the result is 21.5% of 2019 GDP. Since Australia's 2018-19 GDP was $1,950b, this is $420b.[30] I attribute 39% of this to the lockdown, as in section 2.3, to yield $164b. This estimate is conservative because the two real GDP forecast paths here have not converged over the period for which the forecasts are available (out to mid 2022). Substitution of these parameter values into equation (7) yields a cost per QALY saved of

$$C = \frac{\$164b - \$6.8b - \$3.1b}{140,000} = \$1.1m$$

So, the cost per QALY saved is 11 times the benchmark value of $100,000. This strongly favoured mitigation in March 2020. Allowing for the possibility that the lockdown would fail (Blakely and Wilson, 2020, ascribed only a 25% probability to this), the cost per QALY saved would be even higher and therefore mitigation would be even more strongly favoured.

This leaves the question of why the Australian government chose to lockdown in March 2020. A natural candidate for explaining this is that it was extremely risk averse, i.e., it focused upon the worst case death toll from mitigation over lockdown, of 150,000 – 5,000, which implies 580,000 QALYs. Substituting this into the denominator of the last equation, and scaling up the medical costs consistent with this incremental death toll of 145,000 (from $3.1b to $13.0b), the cost per QALY falls to $250,000. Even this is well above the

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[29] The November 2019 forecasts do not provide a forecast for the year ended June 2022, and the forecast for the year ended December 2021 is used as a proxy for it.

[30] The GDP figure comes from Table H1 on the website of the RBA: https://www.rba.gov.au/statistics/.

benchmark of $100,000. So, even extreme risk-aversion does not explain the government's decision to lockdown.

A complementary possibility is that the Australian government was prepared to pay more than the worst-case scenario just described (at the conventional price of $100,000) to buy 'peace of mind' insurance for the whole population. Assuming that a lockdown would succeed, the additional payment would be P satisfying the following equation:

$$\frac{\$164b - P - \$6.8b - \$13b}{580{,}000} = \$100{,}000$$

The solution is P = $86b, i.e., the Australian government was prepared to pay $86b in addition to the payment consistent with applying the usual QALY benchmark to the worst case death toll scenario under mitigation coupled with lockdown being successful. Doing this is not consistent with standard methodology in health interventions.

4. Comparison with Other Australian Studies

Table 5 below compares the analysis conducted here with three other Australian studies that have estimated the additional death toll from mitigation over lockdowns, the value per life, and the additional GDP losses from lockdowns rather than mitigation. I focus upon the crucial issues by reporting only the additional deaths expected, the value per life saved (usually the product of value per QALY, the average residual life expectancy of the victims and a discount for imperfect health of these victims sans covid-19), the product of these two effects, and the additional GDP losses expected (usually the product of current annual GDP, the pandemic losses as a proportion of this, and the share of this due to the lockdowns). The product of the first two effects (additional deaths and value per life) is the value of the extra lives saved by lockdown, which can be offset against the extra GDP losses, to yield the net benefit or loss from lockdowns.

The most significant differences across the studies are in the Extra Deaths or equivalent (highest to lowest ratio of 26), followed by the Value per Life (highest to lowest ratio of 12), and finally the Extra GDP losses (highest to lowest ratio of 2.7). The first two studies have the lowest values on both of these phenomena, and accordingly strongly favour mitigation

(with benefits at least 12 times costs), whilst the last two studies are the reverse and strongly favour lockdowns (with benefits at least three times costs). The most important issue then is the estimate of the extra deaths under a mitigation policy, with the first two studies drawing upon actual death rates from foreign countries whilst the latter two studies use predictions from epidemiological models.

Table 5: Comparison of Studies

Authors	Extra Deaths	Value per Life	Product	Extra GDP Losses
Current Study	17,000*1.5	$0.1m*5*0.8 = $0.4m	$10b	$2t*0.21*0.39 = $160b
Foster	10,000	$0.1m*5 = $0.5m	$5b	$2t*0.06*0.5 = $60b
Kompas et al	260,000	$0.213m*6.9 = $1.5m	$390b	$120b
Holden et al	225,000	$4.9m	$1.1t	$2t*0.1*0.5 = $100b

5.   Looking Forward on 30 December 2020

The analysis to date examines the possibility that mitigation was adopted by Australia in March 2020. However, Australia locked down in March 2020 and incurred 900 deaths to 30 December. The virus is currently suppressed but a new outbreak may occur at any time. If it does, hopefully it can be suppressed without further resort to lockdowns. If it cannot be, then the question of lockdowns arises again. If it does, an estimate of the deaths that would be experienced under a mitigation policy will be useful. Such an estimate will be much less than the estimate provided in the previous section, because the period over which the virus would then inflict casualties would now be much less, i.e., from the date at which such a decision must be made until mass vaccination (of high-risk groups) is completed in several months, rather than from March 2020 until this mass vaccination point.

To illustrate this point, suppose that adoption of a mitigation policy in the face of a new outbreak today that could not be contained without a nationwide lockdown will incur additional deaths (relative to a lockdown policy) equal to those that would have occurred under a mitigation policy from March 2020 till 30 December 2020, and the latter figure is the highest estimate provided above of 17,000. In addition, all other features of the preceding analysis prevail, i.e., QALY losses from these additional deaths will be four times the number

of deaths, GDP losses from this future lockdown will be $160b, the medical costs for sufferers will be $4.2b, and GDP losses from those absent from work will be $6.8b. With no allowance for the effects of unemployment, the cost per QALY saved through a lockdown rather than mitigation follows equation (7) with $N = 1$:

$$C = \frac{\$160b - \$6.8b - \$4.2b}{68,000} = \$2.19m \qquad (10)$$

This is 22 times the benchmark figure of $100,000, and therefore favours a mitigation policy at this point even more strongly than in March 2020.

By contrast, if an outbreak could be contained through locking down only part of the country, the GDP losses from doing so would be only some fraction (P) of the $160b in equation (10) whilst all other terms would be unchanged (because locking down any part of the country to prevent an outbreak that would otherwise spread to the entire country would warrant the same values for these other terms as for a nationwide lockdown). The cost per QALY saved by lockdown would then be

$$C = \frac{P\$160b - \$6.8b - \$4.2b}{68,000}$$

Thus, if $P = 0.10$, this cost would be $73,000, which is below the threshold of $100,000. So, lockdown would then be justified. In fact, lockdown would be justified for any value of P up to 0.11, i.e., a lockdown affecting a part of the country generating up to 11% of GDP would be warranted.

This analysis assumes that, if a lockdown occurs at some future point, only one such lockdown will be required before mass vaccination of the high-risk groups occurs. If more than one may be required, then the GDP loss of P160b in the last equation would be increased. For example, if there were a 50% probability of a second lockdown affecting the same proportion of the country, the last equation would become

$$C = \frac{P\$160b(1.5) - \$6.8b - \$4.2b}{68,000}$$

The lockdown policy would only then be justified if *P* were less than 0.07. Alternatively, if there were a 50% probability of a second lockdown affecting the entire country, the last equation would become

$$C = \frac{P\$160b + \$160b(0.5) - \$6.8b - \$4.2b}{68,000}$$

The lockdown policy would not then be justified for any value for *P*. All of this demonstrates that locking down only part of the country to contain an outbreak could seem attractive, but much less so if one allows for the possibility of future outbreaks.

Finally, the following is worth noting. Should a new outbreak arise (at some future time), then as this point in time moves further into the future, the period over which the additional deaths from mitigation rather than lockdown will arise (from this future point in time until mass vaccination of high-risk groups is completed) shrinks. Accordingly, the additional death toll from mitigation will fall. This will tilt the decision even more strongly towards mitigation.

6.   Conclusions

This paper has considered the costs and benefits of Australia's lockdown strategy relative to pursuit of a mitigation strategy in March 2020. The estimate is 4,000 - 17,000 additional deaths to 30 December 2020 from mitigation, plus further deaths over the next several months until mass vaccination of high-risk groups will be achieved. The result is that the cost per Quality Adjusted Life Year saved by locking down is estimated to be at least 11 times the generally employed figure of $100,000 for health interventions in Australia. Consideration of the information available to the Australian government in March 2020 yields a similar ratio and therefore strongly supported adoption of a mitigation strategy at that time. If Australia experiences a new outbreak, and cannot contain it without resort to nationwide lockdowns, the death toll from adopting a mitigation strategy at this point would be even less than had it done so in March 2020, because the period over which the virus would then inflict casualties would now be much less than the period from March 2020. This would favour a mitigation policy even more strongly than in March 2020.

APPENDIX 1

This Appendix examines the possibility of reverse causality in equation (1), i.e., causality runs from D to S (as well as S to D), because

    (a) some governments chose their S value at the commencement of the crisis based upon their predictions of D under both low and high S scenarios, and/or

    (b) some governments chose their S values based upon their observation of their country's death rate in the early stages of the crisis.

If either of these is true, the estimated coefficient on S in equation (1) may be biased. The traditional method of dealing with this is to use an "instrumental variable", but no good candidates are apparent. I therefore enquire into the extent of these problems.

In respect of the first possible problem, I will focus upon the death rates under mitigation ($S = 50$) and extreme lockdown ($S = 100$). Suppose that there are two types of countries (A and B) whose governments held the views shown in Table 6 (at the commencement of the crisis) about expected death rates under mitigation and extreme lockdown.

<p align="center">Table 6: Expected Death Rates under Various Scenarios</p>

	$S = 50$	$S = 100$
Country A	2,040	170
Country B	250	< 170

Suppose a regression like equation (1) yielded a coefficient on S of -1.6, and death rates for $S = 50$ and $S = 100$ of 250 and 170 respectively. These latter numbers are used in Table 6. The death rate for type A countries under mitigation (2,040) is 12 times that of their death rate under extreme lockdown, with the multiple reflecting the predictions of Ferguson et al (2020) for the UK, i.e., 20,000 deaths under suppression (which is 300 per 1m of the UK's population of 68m) and 250,000 deaths under mitigation (which is 3,700 per 1m of the UK's population). Type A countries chose $S = 100$ because the expected death rate is unacceptably high with $S = 50$. Type B countries have much lower expected death rates than type A countries under both mitigation and extreme lockdown, and chose $S = 50$ because the

expected death rate in that scenario is acceptable.[31]   If the governments' predictions are on average accurate, then the outcomes would be as follows:

Type A countries: $S = 100$ and $D = 170$ on average
Type B countries: $S = 50$ and $D = 250$ on average

Regressing D on S would then yield a coefficient on S of -1.6, consistent with the assumed regression result. However, the real coefficients on S are much lower, most particularly -37.0 for type A countries. Thus, the regression coefficient on S would be biased upwards.

It is plausible that some governments believed that their death rate under mitigation would be both large and vastly in excess of their death rate under extreme lockdown, as shown in Table 6, and acted accordingly in accordance with the predictions of experts like Ferguson et al (2020). It is also plausible that other governments believed that their death rates under mitigation would be much lower, as shown in Table 6, and acted accordingly in accordance with contrary expert opinions.[32] However, both types of governments' beliefs would need to be (on average) correct in order to be compatible with the coefficient on S in equation (1) of -1.6. Thus, there would have to be features of these two types of countries that would justify the markedly higher death rate in type A countries than in type B countries under mitigation (times 8 in Table 6), *and* governments would have to have been capable of recognizing these at the commencement of the crisis. Experts' predictions, such as those of Ferguson et al (2020), would not have helped. For example, Ferguson et al (2020) used Chinese data to generate predictions for only the UK and US, which differed only slightly (3,700 per 1m for the UK and 3,500 for the US) due to demographics and population density (ibid, pp. 6-7 and 16). Furthermore, his numerous critics believed his death rates for the UK and US under mitigation were too high rather than that they were correct for those countries but far too high for others. Furthermore, if by some other means governments believed that their death rates under mitigation would markedly differ due to some variable other than the regressors used in equation (1) or those tested and rejected by me, and their beliefs were correct, they would have to have been aware in advance of a variable that I have not been able to locate even with

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[31] I have not proffered a death rate for type B countries under extreme lockdown because it is not required in the analysis, but it would be lower than for type A countries.

[32] See for example https://thehill.com/opinion/healthcare/489962-what-if-the-sky-is-falling-coronavirus-models-are-simply-wrong.

the advantage of subsequently obtaining and testing the data that has become available since the commencement of the crisis. These conditions are not plausible, and this implies that the estimated coefficient on S of -1.65 is not materially biased for reasons of this type.

The second potential problem with equation (1) is that some governments may have chosen their S values in light of their observation of their country's death rate in the early stages of the crisis, believing it would predict the final death rate. To illustrate this, suppose there are two types of countries, with average death rates under mitigation and extreme lockdown thus:

Table 7: Average Death Rates under Various Scenarios

	$S = 50$	$S = 100$
Country A	600	170
Country B	250	< 170

At the commencement of the crisis, it is unknown which category each country lies in but it is revealed by the death rates in the early stages of the crisis. So, upon observing their early stage death rates, the governments of type A countries then understood that they were of that type and chose extreme lockdown, yielding $S = 100$ and an average death rate of $D = 170$. At the same point, the governments of type B countries then understood that they were of that type and chose mitigation, yielding $S = 50$ and an average death rate of $D = 250$. Regressing D on S would then yield a coefficient on S of -1.6, consistent with the assumed regression result. However, the real coefficients on S are much lower, most particularly -8.6 for type A countries. Thus, the regression coefficient on S would be biased up.

This scenario can be tested as follows. For each country, I regress its Stringency value ten days after its first reported death (S_{10}) on its death rate up to that point (D_{10}), to assess whether D_{10} can explain S_{10}. I repeat the process for 20 and 30 days after each country's first death. I also test whether any of these three early stage death rates can explain the maximum S value chosen by governments (S_m). These regressions yield the results shown in the first six columns of Table 8 below. Only two of these regressions even yield a positive coefficient on early death rate (consistent with the scenario in Table 7) and none of them yields a statistically significant coefficient on it. So, the hypothesis that early stage death rates did not

affect governments' choice of *S* cannot be rejected. This is surprising because the death rates up to day 20, and even more so for up to day 30, are good predictors of the death rate in the first wave of the crisis (to 22 August, and designated *D*), as shown in the last three columns of Table 8. So, at least from day 20, the death rate data up to that point could have been used to set the *S* value at that point or the maximum *S* value but governments did *not* seem to have done so.

Table 8: Stringency Levels and Death Rates

Dep Var (DV)	S_{10}	S_{20}	S_{30}	S_m	S_m	S_m	D	D	D
Indep Var (IV)	D_{10}	D_{20}	D_{30}	D_{10}	D_{20}	D_{30}	D_{10}	D_{20}	D_{30}
Mean DV value	68	77	79	81	81	81	198	198	198
Mean IV value	3	17	50	3	17	50	3	17	50
Coeff on DV	1.9	-.07	.002	-.57	-.10	-.02	7.8	7.4	2.8
P Value for DV	.09	.59	.96	.37	.37	.52	.53	0	0
Adjusted R^2	.06	-.02	-.03	-.01	-.01	-.02	-.02	.40	.66

This raises the interesting question of what does then explain the maximum *S* values. Regressing this variable on the variables used in or tested for inclusion in equation (1), being population density, date of first death, proportion of population over 65, beds per 100,000 people, GDP per capita, and household size, yielded no statistically significant coefficients. However, ranking the maximum *S* values from highest to lowest reveals that the four countries arising from the breakup of Yugoslavia occupy four of the 'top' six slots (with an average *S* value of 95) and the five Scandinavian countries occupy four of the 'bottom' five slots (and have an average *S* value of 68). This suggests that the *S* choice was in part driven by mimicry of neighbouring countries. Consistent with this, Sebhatu et al (2020) finds that the speed with which restrictions were adopted by the OECD members was influenced by the behavior of nearby countries.

In summary, the cross-sectional regression in equations (1) does not seem to suffer from reverse causality from *D* to *S*.

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