

THE COSTS AND BENEFITS OF COVID-19 LOCKDOWNS

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Abstract

This paper considers the merits of the New Zealand government adopting lockdowns rather than a milder mitigation policy in response to the covid-19 pandemic, with the actions of individuals and other governments taken as given. Based upon the information available at the time of the first lockdown in March, the cost in the form of GDP losses per Quality Adjusted Life Year (QALY) saved from doing so was well in excess of all generally used values for a QALY. Consideration of alternative parameter values and recognition of factors omitted from the analysis would not likely reverse this conclusion. The lockdown policy was therefore inconsistent with generally used values for a QALY. Taking account of information that has since become available strongly reinforces this conclusion. Applying the same analysis to the Auckland lockdown, the decision would have been justified only using parameter estimates most favourable to such a decision and a minimal chance of subsequent substantial lockdowns. Applying the same analysis to the possibility of future outbreaks that could not be contained with only quarantining of cases, lockdowns would be justified only if the proportion of the country subject to a lockdown were very small or the death rate arising from future outbreaks without a lockdown would be much more severe than indicated by currently available data, or some combination of these. Such combinations are possible but unlikely.

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1. Introduction

As with most other countries, early this year, the New Zealand government implemented a substantial curtailment of normal activities in order to reduce the death toll from Covid-19 (“lockdown”). Since then, the curtailments have been substantially relaxed, apart from being substantially but temporarily reinstated for the Auckland area. This paper presumes that this lockdown policy will save lives and attempts to estimate the cost of such a policy (especially in terms of the GDP losses) relative to the additional lives saved, so as to compare this to generally employed ratios for guiding public health spending in general. It also conducts this exercise at four different points: a forward-looking exercise at the time of the first lockdown (23 March), a retrospective view of that decision, a retrospective view of the second lockdown decision on 12 August, and a forward-looking view at the present time.

2. Looking Forwards on 23 March

2.1 Expected Deaths

At the time of the first lockdown in New Zealand, death toll forecasts had already been presented by Ferguson et al (2020) for the UK. They estimated that a China style “suppression” policy (which might have to be maintained for several months) would yield about 20,000 deaths in the UK (ibid, Table 4) whilst that from a much milder “mitigation” policy (involving case isolation, quarantining of members of their households, and social distancing for the elderly) would yield about 250,000 deaths (ibid, page 16). Ferguson et al therefore recommended suppression, and their recommendation appears to have significantly influenced UK government policy. However, and remarkably, the paper contains no information on the costs of adopting a suppression policy rather than a mitigation policy. Implicitly, their goal seems to have been to minimize the number of deaths regardless of the cost. This is not a rational goal, it is inconsistent with the small GDP share allocated to health care in every society, and could involve inflicting on a country a ‘cure that was worse than the disease’.

Applied to New Zealand, Ferguson et al’s (2020) expected saving in lives from a suppression policy rather than a mitigation policy (of 230,000) would translate into 17,000 lives saved in New Zealand if the results here were proportional to the difference in populations (5m for NZ and 68m for the UK). These 17,000 people would be mostly old and almost all would be

suffering from pre-existing conditions.¹ Ferguson et al (2020, page 7) also estimate the casualties at 510,000 from no control measures, implying a worst case saving in lives from a suppression strategy over (totally ineffective) mitigation efforts at 490,000, implying a saving in lives in New Zealand of 36,000. As noted by Ferguson et al (2020, page 7), this presumes no change in people's behavior in the face of the pandemic, which is extremely unrealistic.

Shortly afterwards, and at the commencement of the first lockdown here, predictions for New Zealand were presented by Blakely et al (2020), who estimated the deaths from an "eradication" policy (equivalent to lockdown) at 500 and those from a "mitigation" policy (involving isolation of the over 60s) at 6,500-13,000.² The expected saving in lives from eradication (if successful) rather than mitigation was therefore 6,000 - 12,500. Blakely et al (2020) also proffered an estimate for the average residual life expectancy of the victims sans Covid-19 at five years, implying the number of life years saved at $6,000 * 5 = 30,000$ to $12,500 * 5 = 62,500$. They did not reduce this further to reflect the imperfect health of these victims sans Covid-19, so that their estimate of the Quality Adjusted Life Years (QALY) saved per victim was still five years. However the fact that most of the victims had co-morbidities would imply the need for some such deduction, and Miles et al (2020, page 69) subsequently proposed a reduction of 20%. The saving in QALYs would then range from a lower bound of $6,000 * 5 * 0.8 = 24,000$ to an upper bound of $12,500 * 5 * 0.8 = 50,000$. Blakely et al's (2020) worst case scenario was 30,600 deaths, yielding a saving in QALYs of $30,100 * 5 * 0.8 = 120,400$ from eradication (if successful) rather than mitigation.³ Blakely et al (2020) recognized that eradication may fail, and assigned a 25% probability to this, so that the expected QALY saving from seeking eradication is $[9750 - (.25 * 9750 + .75 * 500)] * 5 * 0.8$

¹ It was believed at this time that most of the victims were old and/or suffering from co-morbidities (see Blakely et al, 2020). The more precise data that subsequently became available confirmed this. In respect of those dying in New York City up to May 13, 96% were at least 45, and 74% at least 65. Furthermore, 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/>.

² Blakely et al (2020) do not indicate whether mitigation also includes case isolation and quarantining of members of their households, as with Ferguson et al, but I presume this is intended.

³ One of the authors (Wilson, 2020) also provided advice to the Ministry of Health shortly afterwards on the worst-case scenario, which was similar to that in Blakely et al (2020).

= 27,750.⁴ Interestingly, Blakely et al (2020) recognize that lockdowns involve costs (health expenditures and GDP losses), that these are relevant to the decision, and they estimated the maximum expenditure consistent their valuation of a QALY at \$2.5b.

Contemporaneously, James et al (2020a, Table 2) presented predictions of the death tolls in New Zealand from a range of possible control strategies. Lockdown corresponds to the last strategy in their Table 2, and involves predicted deaths of 20 (0.0004% of the population). However, none of the other strategies examined by them in their Table 2 corresponds to “mitigation” as defined by Ferguson et al (2020) and Blakely et al (2020). The fourth strategy in their Table 2 embodies case isolation and quarantining of members of their households, but not also social distancing of the elderly, and therefore (unsurprisingly) yields a predicted death toll much higher than that of Blakely et al (2020), at 62,500. Table 2 also includes a no control strategy, with a predicted death toll of 83,000 (1.67% of the population). James et al (2020a, page 7) do consider a strategy they describe as mitigation, with a predicted death toll of 25,000 (0.508% of the population), but it involves a combination of periods of low control (case isolation plus household quarantining) with periods of lockdown as required to keep the number of cases within the capacity of the hospital system. I therefore treat the work of Blakely et al (2020) as providing the best estimate of the death toll from mitigation (as defined by them) that was available on 23 March. Interestingly, and unlike Blakely et al but like Ferguson et al, James et al do not present any information on, or even recognize the relevance of, costs of adopting the various strategies considered by them, and therefore their goal seems to be to minimize the number of deaths regardless of the cost.

2.2 Expected Costs

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 Treasury (2019, page 3) forecasted New Zealand’s real GDP growth rates for 2020-2024 at the rates shown in the first row of Table 1. This is an estimate of growth under the pandemic but with *no* curtailment of economic activity to reduce its spread. In April 2020, they released figures revised to reflect several different scenarios differing by the time for which Level 3 and 4 operated and the

⁴ This figure is the product of three expectations, and should be the expectation of the product, and the latter would be larger because the three variables are positively correlated. Estimating the increase would be difficult, but not very important here because the focus here will be on the extreme QALY values.

situation elsewhere in the world, of which the least severe (S1), the most severe (S3), and an intermediary scenario (S2) are shown in the other rows of the table (The Treasury, 2020a, page 7). Arbitrarily designating 2019 GDP as 100, the GDP results under these paths are as shown in Table 1. The aggregate difference between the no curtailment scenario and S1 is $539.1 - 511.4 = 27.7$, which represents 28% of New Zealand 2019 GDP. Since New Zealand's 2019 GDP was \$311b, this is \$87b.⁵ Even this figure may be too low because the 2024 GDP level under S1 is below that from the no-curtailment scenario (112.3 versus 113.3) and such GDP losses relative to the counterfactual would continue until these levels were equal. All other scenarios considered by The Treasury yield even more severe GDP losses.

Table 1: GDP Forecasts

	2020	2021	2022	2023	2024	Sum
Dec 2019 Forecasts	2.2%	2.8%	2.7%	2.5%	2.4%	
Implied GDP	102.2	105.1	107.9	110.6	113.3	539.1
April 2020 Forecasts: S1	-4.5%	-2.5%	10.0%	5.5%	4.0%	
Implied GDP	95.5	93.1	102.4	108.1	112.3	511.4
April 2020 Forecasts: S2	-8.0%	-3.0%	13.0%	5.5%	4.0%	
Implied GDP	92.0	89.2	100.8	106.4	110.6	499.0
April 2020 Forecasts: S3	-8.0%	-23.5%	30.0%	13.0%	6.5%	
Implied GDP	92.0	70.4	91.5	103.4	110.1	467.4

Some of these GDP losses of \$87b would have arisen without any New Zealand government-imposed restrictions, because some people would have reduced their interactions with others anyway; for example, a foreigner electing not to make a trip to New Zealand that they would otherwise have made, or a New Zealander choosing to avoid cafes. Further losses would have arisen due to the additional actions of foreign governments; for example, foreign governments preventing their citizens from making foreign trips. Further losses would have arisen if the New Zealand government had followed merely a mitigation strategy, which includes border closures. Finally, further losses would have arisen from the New Zealand government instead following a lockdown strategy. It is only the last category of these losses

⁵ The GDP figure comes from Table M5 on the website of the RBNZ (www.rbnz.govt.nz).

that can be attributed to the New Zealand government choosing a lockdown policy rather than a mitigation policy. Estimating the proportion arising from this last category is problematic. However, the difference between the S1 and S3 scenarios shown in Table 1 is simply in how long Levels 3 and 4 persist (two months in S1 and twelve months in S3, which is a multiple of 6). In addition, going from S1 to S3 adds a further loss in GDP equal to 44% of the 2019 GDP (511.4 – 467.4), and this relates wholly to the last category of loss (the loss from lockdown rather than mitigation by the New Zealand government, with all other effects held constant). This suggests that the GDP loss within S1 arising from the New Zealand government’s adoption of a lockdown rather than a mitigation policy would be about 1/5 of that in moving from S1 to S3, which is 44%/5 = 8.8%. So, under S1, the GDP loss from lockdown rather than mitigation would be 8.8% of 2019 GDP, i.e., \$27b. The remainder of the 28% GDP loss in S1 is due to the other contributors listed above.

2.3 Cost per QALY Saved

Coupling this \$27b loss with the highest estimate of QALYs saved of 120,400, the cost per QALY saved would then be \$224,000 as follows:

$$\frac{\$27b}{120,400} = \$224,000 \quad (1)$$

This is a lower bound on the cost per QALY saved from lockdown rather than mitigation because the GDP loss of \$27b is a lower bound arising from this policy choice (because it reflects The Treasury’s least severe scenario S1) and the 120,400 QALYs saved is the upper bound from this policy choice (from Blakely et al’s upper bound).

Conover (2020) notes that it is conventional practice in the US to further discount QALY figures by about 3% per year to recognise that an additional life year saved immediately is more valuable than one saved later. This would depress the denominator in equation (1), and therefore raise the cost per QALY saved. Furthermore, Pharmac (2015, pp. 51-52) recommends 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. The longest term inflation-indexed bonds for which data is available for the last five years are those maturing

in September 2035, and the average rate over the last five years has been 1.58%.⁶ Since the GDP losses are also spread out over time, the same discounting adjustment should be made there, but the GDP losses are on average much closer to the present moment, and therefore the effect of such discounting for the future adjustments in both the denominator and numerator of equation (1) would slightly raise the cost per QALY saved (by about 2%).

Turning now to the value of a QALY saved, Blakely et al (2020) used a QALY value of \$45,000, consistent with the *BODE*³ project (which estimates the cost effectiveness of various health interventions in New Zealand). Kvizhinadze et al (2015, page 3) used the same figure for New Zealand, based upon a WHO recommendation of per capita GDP. However, with a current population of 5.0m and 2019 GDP of \$310b, New Zealand's current per capita GDP is \$62,000. Pharmac (2015, page 12) does not prescribe a value, because other factors influence its decisions and any value would depend upon its budget. However, Pharmac's highest average cost per QALY saved in recent years is \$27,027 in 2016/17, which implies \$33,306 in 2020.⁷ In evaluating the merits of extending the Level 4 lockdown for five extra days, Heatley (2020, page 9) used the figure just referred to. In the interests of being conservative, I use the highest number here of \$62,000.⁸

A related concept is the "Value of a Statistical Life" (VOSL), which values all lost years of an average aged person's life. This is generally employed in decisions on road safety and the current value is \$4.37m (Ministry of Transport, 2019, page iii). To convert to a value per year (called the Value of a Statistical Life Year or VOSLY), which can be compared to the value of a QALY, it would be necessary to first determine the average residual life span of a road accident victim. The median age of a victim is 41, and 2/3 are male.⁹ The median residual life span of a 41 year old is 43 years for a female and 40 for a male.¹⁰ This implies

⁶ See Table B2 on the website of the RBNZ: www.rbnz.govt.nz.

⁷ This figure is used by The Treasury in its CBAX2020 model: see <https://www.treasury.govt.nz/publications/guide/cbax-spreadsheet-model-0>, tab "Impacts Database", cell D135.

⁸ 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.

⁹ See <https://www.transport.govt.nz/mot-resources/road-safety-resources/road-deaths/>, for 2020 to date.

¹⁰ See Tables 5 and 6 of the NZ Periodic Life Tables: http://archive.stats.govt.nz/browse_for_stats/health/life_expectancy/NZLifeTables_HOTP12-14.aspx#gsc.tab=0.

an average residual life span for a median aged road victim (of age 41) of 41 years. Applying Pharmac’s recommended discount rate of 1.58% (see penultimate paragraph), the value per QALY would be V such that

$$\$4.37m = \frac{V}{1.0158} + \dots + \frac{V}{(1.0158)^{41}}$$

The solution is $V = \$146,000$. This \$4.37m estimate of the VOSL was derived from a 1991 survey (Ministry of Transport, 2019, page 14), as is usually the case for such estimates, whilst the value of a QALY comes from public health experts or deduced from the health expenditure decisions by government; the latter would then seem to be more relevant to the present situation involving a health policy choice by government. Furthermore, amongst the authors I am aware of who consider both approaches (Miles et al, 2020; Gros, 2020), both favour the latter approach over the VOSL approach, with Gros (2020, page 6) noting that it the approach that is “practiced routinely by the medical profession” and Miles at al (2020, page 76) that it is consistent with the approach to other health expenditures. Thus I favour a QALY value of \$62,000 but also consider the effect of using the VOSL derived figure of \$146,000.

Interestingly, some analyses of the Covid-19 issue have been conducted by simply multiplying the VOSL by the expected saving in lives (for example, Chapple, 2020; Thunstrom, 2020; Holden and Preston, 2020). This may reflect the mistaken view that Covid-19 victims have a typical average residual life span and perfect health sans Covid-19, which is not the case, and would therefore significantly overestimate the benefits in QALYs saved. Alternatively, it may reflect the view 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 as one would spend to extend the life of a different person for ten years. If the latter interpretation is correct, it is inconsistent with prevailing views in the health sector. In particular, Pharmac (2015, page 36) recommends that residual life expectancies be estimated and further adjusted for the patient’s quality of life, and this is also the orthodox view amongst New Zealand public health experts (see Kvizhinadze et al, 2015; Blakely et al, 2020).

Since the lower bound on the cost per QALY saved from lockdown rather than mitigation is \$224,000 as shown in equation (3), use of a QALY value of \$62,000 implies that the cost of

adopting a lockdown policy rather than a mitigation policy per additional QALY saved would be at least 3 times the QALY value of \$62,000. Had one instead used Blakely et al’s (2020) expected extra lives lost of 7,000, and therefore $7,000 \times 5 \times 0.8 = 28,000$ QALYs saved, the cost per QALY saved would have risen to \$960,000, which is 15 times the QALY value of \$62,000. Had one also used The Treasury’s S2 scenario rather than its S1 scenario (see Table 1), which could be viewed as a mid-case scenario, the *extra* GDP loss would have been 12.4% of the 2019 GDP entirely due to lockdown rather than mitigation by the New Zealand government (511.4 – 499.0), which would imply a total GDP loss from lockdown over mitigation of 21.2% (8.8% in S1 plus 12.4% extra in S2), which would be \$66b. The cost per QALY saved would then be \$2.36m as follows:

$$\frac{\$66b}{28,000} = \$2.36m \quad (2)$$

This is 38 times the QALY value of \$62,000. Table 2 shows a range of combinations of incremental deaths and incremental GDP losses. For S3, the total GDP loss from lockdown over mitigation is 52.8% of 2019 GDP (8.8% in S1 plus 12.4% extra in S2 plus 31.6% extra in S3), which would be \$164b. In Table 2, all of these costs per QALY saved are a multiple of the QALY value of \$62,000. Furthermore, all of them are in excess of the QALY value of \$146,000 derived from the VOSL. In relation to the central estimate, involving the saving of 9,000 extra lives at an estimated cost of \$62b, consistency in government action would require spending \$62b to extend the lives of 9,000 people suffering from heart disease, cancer or diabetes, which is three times the entire annual government spending on health care in New Zealand.

Table 2: Cost per QALY Saved by Lockdown Versus Mitigation

Incremental Deaths	6,000	7,000	30,100
GDP Loss (S1): \$27b	\$1.12m	\$0.96m	\$0.22m
GDP Loss (S2): \$66b	\$2.75m	\$2.36m	\$0.55m
GDP Loss (S3): \$164b	\$6.83m	\$5.86m	\$1.36m

It is implicit in all of this that the worst case scenario is the 30,100 additional lives in Blakely et al (2020), and that the value of a QALY does not exceed \$62,000. However, if one focused on a worst-case scenario of 47,000 additional lives saved from lockdown versus mitigation, and a GDP loss from lockdown over mitigation of as little as \$27b as above, the cost per QALY saved would be \$144,000 as follows:

$$\frac{\$27b}{47,000(5)(0.8)} = \$144,000$$

Additionally using a value per QALY of \$146,000 from the VOSLY approach, the decision to lockdown would have then (just) been justified within this framework. However this would require the lowest estimate for the GDP loss, the highest possible value for a QALY, and a loss of lives well beyond Blakely et al's (2020) expectation and even their worst case scenario.

Returning to the GDP loss, whatever the figure is, it may not be 'evenly' shared (through the tax system in the usual way with medical expenditures to extend lives). It may fall largely on two groups. The first own businesses and would suffer a loss in profits, possibly to the point the business fails. The second would lose their jobs and remain unemployed for some period. By adopting a lockdown rather than a mitigation policy, in order to moderately extend the lives of 9,000 largely old and sick people, these two other groups might suffer substantial financial losses. The extent to which this actually occurs will depend upon the extent to which their fellow citizens compensate them for these losses. Furthermore, even if the government does intervene in an attempt to protect some vulnerable groups, other vulnerable groups may be inadvertently hurt. For example, if rent payments were suspended by government for some period, landlords will suffer and some of them will be retired people who derive a considerable proportion of their modest incomes from this source. In addition, prospective landlords will not rent out their properties, to the disadvantage of both parties.

This analysis omits many relevant features, some of which would reduce the cost per QALY saved by a lockdown rather than a mitigation policy. Firstly, with a mitigation rather than a lockdown policy, the health system may be so overwhelmed by Covid-19 cases that many other people may die or suffer reduced quality of life from lack of care. Secondly, there are direct medical costs of dealing with the demand surge from a mitigation rather than a

lockdown policy. Boyd (2020, Table 3) estimates these at \$1b if the system is saturated with cases, which only trivially lowers the cost per QALY saved. Thirdly, lockdown reduces road deaths and pollution. Layard et al (2020, page 2) examines this issue and concludes that these additional factors are slight relative to the higher deaths from Covid-19.

This analysis also omits many features that would raise the cost per QALY saved. Firstly, some of the lives seemingly saved from a lockdown rather than a mitigation policy would be lost anyway if the lockdown restrictions were lifted before a vaccine arrived and then gave rise to additional deaths (Holden and Preston, 2020). So, the additional lives saved by lockdown rather than mitigation would be overestimated. Secondly, lockdown increases unemployment and therefore leads to an increase in a host of attendant problems: addiction, crime, domestic violence, mental health problems, and premature death. Thirdly, the normal operation of the health care system would be disrupted by a lockdown policy, leading to deaths that would not otherwise occur. In respect of the UK, Miles et al (2020, page 68) notes that referrals for cancer investigations were 70% down in April 2020, and outpatient visits were 64% down between mid March and early June. Some of these reductions are a consequence of the pandemic rather than pursuit of a lockdown policy by government, but at least some of them will have arisen from the policy choice. Fourthly, there are adverse long-term consequences for the Covid-19 student cohort from not attending school. Fifthly, lockdowns deprive people of liberties that they would otherwise exercise. All of these raise the cost per QALY saved.

In addition, the appropriate cost from the GDP losses is not the GDP losses themselves but the “economic surplus”, which is the consumer surpluses (the aggregate amount consumers are willing to pay in excess of the amounts actually paid for all goods and services) plus the producer surpluses (the aggregate amounts received by producers less the amounts they would be willing to accept to produce at this level), and this sum could be more or less than the GDP losses. Again, there is considerable room for large adjustments before lockdown involves a cost per QALY saved no higher than generally employed value of a QALY.

All of this suggests that, based upon information available to the government at the time of the first lockdown in March, the cost per QALY saved of a lockdown rather than a mitigation approach by the New Zealand government would be dramatically inconsistent with long-established views on the value of a QALY. Consideration of non-quantifiable factors does

not appear to alter this conclusion. There are ethical judgements here, reflected in the conventional QALY approach to health decisions. In particular, a life with one year left is worth ten times that of a life with ten years left. Naturally, there is room for different views, but one could not reasonably view all lives equally because that would lead to being willing to spend as much to extend the life of a person by one day as one would for a different person for ten years. I limit myself here to applying the QALY methodology, which is used by Pharmac (2015) and public health experts (Kvizhinadze et al, 2015; Boyd et al, 2018; Blakely et al, 2020).

3. Looking Back to 23 March

3.1 Deaths

In the months since the first lockdown, significant new information has become available, on deaths, GDP losses, and other issues. In respect of deaths under its lockdown policy, New Zealand's toll to date has been 25. This is vastly less than Blakely et al's (2020) estimate of 500 from an eradication policy.

In respect of the deaths that would have occurred under a mitigation policy, the Blakely et al (2020) forecasts are displaced by estimates from the actual experience of other countries. One such source of evidence is the variation in death rates between US counties that did and did not lockdown; Gibson (2020a) finds no statistically significant difference, after controlling for various other factors. Another source of evidence is the timing of the death peaks relative to the timing of the lockdowns, in various countries or regions that implemented lockdowns; Stone (2020) examines Spain, France and Lombardy and finds in all three cases that these intervals are shorter than the minimum 20 day period between infection and death, which implies that the lockdowns did not induce the reduction in the death rate and therefore at most enhanced the rate of decline. Similarly, Homburg (2020) uses death data to estimate the peak of the curve for nine countries, of which seven adopted lockdowns. For each country, he deducts 23 days from the death peak to determine the infection peak (because the interval from infection to death is about 23 days), and then compares this infection peak to the timing of the lockdowns. In all countries which adopted lockdowns, the lockdown occurred after the infection peak, with a median difference of four days (ibid, Table 2). Again, this reveals that the lockdowns did not cause the decline in the deaths and therefore at most enhanced the rate of decline. Gibson (2020b, pp. 3-5) extends this analysis to the 34 OECD countries and uses a longer time period to estimate the peak

infection date, and finds that this peak predates the maximum stringency of their restrictions in half of these countries.

A more direct source of evidence is variation in death rates across countries that did and did not lockdown. Chaudhry et al (2020) examine the 50 countries with the highest case counts as at 1 April, and regresses cross-country death rates per 1m of population (up to 1 May) on a number of independent variables, including various measures of government intervention, and find that none of these latter variables were statistically significant. Gibson (2020b) conducts a similar analysis, using the 34 OECD member countries, death rates up to 18 August, and various independent variables including the average level of government restrictions over the period of the crisis.¹¹ 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). However, using that estimated coefficient, the estimated saving in lives lost from New Zealand instead adopting restrictions at the Swedish level would have been only 310 (ibid, page 6). 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.

Appendix 1 further examines this issue and concludes that the expected increase in New Zealand's death toll from moving from its lockdown policy to a mitigation policy like Sweden's would be to raise the death rate by 55 per 1m of population, which would yield an increase in New Zealand's deaths of $55 \times 5 = 275$ (data to 10 November). This is similar to Gibson's result. A more conservative estimate would be the lower limit of the 95% CI, involving a death rate of 384 per 1m of population, which would yield an increase in New Zealand's deaths of $384 \times 5 = 1,920$. Given that deaths are still occurring and presumably will continue to do so until a vaccine arrives, it might be thought that the use of death rate data to date will underestimate the saving in lives from lockdown rather than mitigation. However, using data only up till 22 August, the expected increase in deaths is 863 rather than 275 and

¹¹ The latter is quantified using the Stringency Index of Hale et al (2020), 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.

the lower bound on the 95% CI yields 2,135 additional deaths rather than 1,920. So, despite deaths rising (substantially) since 22 August, the expected saving in lives from lockdown rather than mitigation is smaller. This implies that the effect of further deaths to come will likely further lower the figures of 275 and 1,920 and therefore use of these figures is conservative.

An alternative approach adopted by many commentators has been to focus upon the ‘Scandinavian natural experiment’, in which Sweden did not lockdown (maximum Stringency Index value $S = 46$) but its Nordic neighbours Denmark and Norway did ($S = 72$ and 80 respectively). The death rates in these countries were 595 for Sweden, 129 for Denmark, and 52 for Norway. Averaging over Norway and Denmark yields 90, and Sweden’s rate of 595 was therefore 505 more. Thus, the effect in going from a Norway/Denmark lockdown to a Swedish mitigation approach would be to raise the death rate by 505 per 1m, which equates to 2,525 additional deaths in New Zealand. However, this approach uses only three data points rather than the entire set of European countries. Furthermore Sweden is unusual because, amongst countries that did not lockdown, it has the highest death rate (not merely in Europe but worldwide), and Klein et al (2020) provide 15 reasons other than failure to lockdown why Sweden’s death rate was higher. Had Iceland or Finland been used instead of Sweden ($S = 54$ and 60 respectively, and $D = 67$ and 65 respectively), and their death rate(s) been compared with Norway and Denmark, one would have concluded that increased restrictions increased the death rate. Alternatively, if one had compared Latvia ($S = 66$ and $D = 54$) with its neighbor Lithuania ($S = 87$ and $D = 78$), one would have again concluded that increased restrictions increased the death rate. The appropriate approach is to use all of the European data, yielding an estimate of the additional deaths in New Zealand under a Swedish-style mitigation policy of 275 (central estimate), and 1,920 at most.

These estimates presume that Covid-19 deaths are accurately recorded. However, some deaths may be mistakenly attributed to another cause, or 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 disrupts the normal operation of the health system, 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

increased the load on hospitals, leading to more deaths from other causes 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 to date (15 September) relative to the baseline was 210,000 for 2020, 65,000 for 2019 and 120,000 for 2018.¹² By contrast, the deaths attributed to Covid-19 across these 18 countries (to 15 September) were 169,000.¹³ Thus, if the baseline were used, the excess deaths in 2020 would be 210,000 and therefore the deaths attributed to Covid-19 of 169,000 would be too low by 20%. 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 a typical year are about 3m, so that the prediction error of 120,000 for 2018 is a small proportion.¹⁴ Furthermore, even if the baseline were used, the fact that the first deaths attributed to Covid-19 in these countries did not occur until 15 February suggests that excess deaths be counted from only that point, which would yield excess deaths from 15 February to 15 September of 190,000. This is sufficiently close to the actual deaths attributed to Covid-19 to accept the latter figure.

Turning to the average residual life expectancy of these victims sans covid, I focus upon the European countries used to estimate the additional death toll under mitigation rather than lockdown. I start with Sweden. The age distribution of the covid-19 victims is shown in the first two columns of Table 3, 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 the Swedish victims sans covid-19 is 10.9 years.¹⁵ This calculation assumes

¹² See <https://www.euromomo.eu/graphs-and-maps#excess-mortality>.

¹³ 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/>.

¹⁴ See https://www.ined.fr/en/everything_about_population/data/europe-developed-countries/population-births-deaths/.

¹⁵ 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 3 shows the number of victims in ten-year blocks up to age 80 as 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

that the victims are typical of Swedish people of the same ages. However, they differ in two very significant features.

The first of these features 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 3, 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 3 would fall to 7.7 years as shown in the fourth column of Table 3.¹⁶ 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 3 would fall to 6.4 years.

The second unusual feature of these covid victims is that they were unusually unwell, even for their age; as noted in footnote 1, 98% of the victims had at least one co-morbidity, which is presumably well in excess of the rate for the general population of the same age distribution. 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

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 data reveal that the sex split of the victims is close to 50/50, at 56% men).

¹⁶ 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.

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:¹⁷

$$RLE = .05(1) + (1 - 0.05)[.05(1.1)](2) + (1 - .05)[.05(1.1)(1.1)](3) + \dots = 9.52 \text{ yrs}$$

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 (conservatively) 30%. The results are shown in the penultimate column of Table 3, with the nursing home group conservatively assumed (as before) to be the oldest, and the last column of Table 3, in which the nursing home group is spread throughout the 70+ groups in proportion to their sizes.¹⁸ 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.

Table 3: Residual Life Expectancy of Swedish Covid-19 Victims

¹⁷ Data from the New Zealand 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.

¹⁸ 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.

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

This process could be repeated for other European countries. Miles et al (2020, Table 1) performs an analysis akin to that in the first three columns of Table 3, but matching on both age and sex, and thereby estimates the average residual life expectancy of people matching the UK's covid-19 victims by age and sex at 10.1 years. In addition, Bell et al (2020, Table 3) notes that 40% of UK covid-19 victims were residents of nursing homes. Forder and Fernandez (2011, page 3) estimates the average length of stay for UK nursing home residents at 801 days, and therefore the residual life expectancy of a randomly selected resident would be 400 days (1.1 years). Conservatively treating this 40% subset of victims as the oldest in Miles et al's set of victims, they correspond to all of those at least 85 in Miles et al's Table 1. Alternatively, they could be spread across all 75+ groups in Miles et al's Table 1, in proportion to the size of these groups, and would therefore constitute 54% of each such group. Either way, their life expectancy is set at 1.1 years and all others have their life expectancy reduced by 30%. The result is an average residual life expectancy of 5.7 to 6.3 years.

In summary, the average residual life span of covid-19 victims in Europe would be about 10 years if they were typical of their age. However they are not typical, in that co-morbidities were almost universal and the proportion who were residents of nursing homes very high. Allowance for both factors suggests a reduction in average residual life expectancy to about five years. This matches the estimate of Blakely et al (2020).

In respect of a 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 heart disease and 16% for stroke. These discounts in Beaudet et al suggest that Miles et al's 20% discount for an average covid-19 victim is low. Furthermore, a large proportion of the victims were residents of nursing homes, for which the quality of life discount could reasonably be even higher.

The QALYs saved by locking down would then be $275*5*0.8 = 1,100$ (central estimate) or $1,920*5*0.8 = 7,700$ (most extreme estimate).

3.2 GDP Losses

Turning now to the GDP losses, since March 2020, The Treasury has produced two updates to its GDP forecasts. In May, The Treasury (2020b, page 3) revised its December 2019 forecasts and these are shown in Table 3 (along with The Treasury's December 2019 forecasts). These May forecasts are in aggregate very similar to The Treasury's S1 forecasts shown in Table 1, which were at that time The Treasury's least severe scenario. Thus, in May, The Treasury essentially reached the view that its S1 scenario was then the best forecast, implying a GDP loss from the pandemic of \$87b, of which the loss due to lockdown over mitigation was 8.8% of GDP or \$27b. This represents 31% of the total expected GDP loss of \$87b under S1. In September, The Treasury (2020c, page 82) further revised its forecasts as shown in Table 4. For the years 2020-2024, the aggregate GDP shortfall from the pandemic is now $539.1 - 505 = 34.1$, which is 34.1% of 2019 GDP. This is larger than the shortfall estimated in May 2020. Furthermore this is not the full extent of the shortfall; this is the accumulation of the annual GDP shortfalls for the September 2020 forecasts relative to the December 2019 forecasts until the annual GDP under the former reaches the latter and this is not even close to equality in 2024 with the implied 2024 GDP from these September 2020 and December 2019 forecasts of 108.0 and 113.3 respectively. Table 4 shows The Treasury's September 2020 forecasts for 2025-2027 (The Treasury, 2020c, page 82), and extrapolation of the December 2019 forecasts for 2025-2027. Accumulating the GDP forecasts out to 2027 yields 895.6 for the December 2019 forecasts and 847.8 for the

September 2020 forecasts, as shown in the table. The difference is 47.8, i.e., 47.8% of 2019 GDP, which is \$148b. Even this is not the full extent of the shortfall because the forecast GDP in 2027 under the September 2020 forecasts is still short of that under the December 2019 (extrapolated) forecasts.

Table 4: GDP Forecasts

	2020	2021	2022	2023	2024	2025	2026	2027
Dec 2019 Forecasts	2.2%	2.8%	2.7%	2.5%	2.4%	2.4%	2.4%	2.4%
Implied GDP	102.2	105.1	107.9	110.6	113.3	116.0	118.8	121.7
Sum					539.1			895.6
May 2020 Forecasts	-4.6%	-1.0%	8.6%	4.6%	3.6%			
Implied GDP	95.4	94.4	102.6	107.3	111.1			
Sum					510.8			
Sept 2019 Forecasts	-3.1%	-0.5%	3.6%	3.9%	4.1%	2.8%	2.9%	2.9%
Implied GDP	96.9	96.4	99.9	103.8	108.0	111.0	114.2	117.6
Sum					505.0			847.8

Since the expected GDP loss from the pandemic is now at least \$148b rather than \$87b, one might suspect that the GDP loss due to lockdown rather than mitigation would be more than the \$27b estimated earlier. Two possibilities consistent with this exist. The first is that the expected GDP loss per additional month of lockdown is now larger than the 4.4% of GDP estimated from The Treasury's March 2020 scenarios. The other possibility is that The Treasury now expects the lockdowns to be longer than the two months envisaged in scenario 1 in March 2020. The lockdowns envisaged by The Treasury in scenario 1 were one month nationally in Level 3 and one in Level 4. Since Level 4 is 60% more stringent than Level 3 (The Treasury, 2020a, page 7), this is equivalent to 2.6 months in Level 3. By contrast the lockdowns to date have been 33 days nationally in Level 4, 18 days nationally in Level 3, and 18 days for the Auckland region in Level 3. Since Auckland constitutes 38% of national GDP, this is equivalent to 77.6 days at Level 3 nationally, which is 2.6 months.¹⁹ So, lockdowns to date match The Treasury's March 2020 scenario 1. However the fact that the

¹⁹ See <https://www.stats.govt.nz/information-releases/regional-gross-domestic-product-year-ended-march-2019>.

Auckland lockdown happened raises the possibility of further such lockdowns, and therefore that The Treasury’s less favourable GDP forecasts in September compared to March reflect its belief that further lockdowns will happen. Both interpretations are possible. However, in the interests of being conservative, I assume that The Treasury still believes that each month of lockdown rather than mitigation cost 4.4% of GDP, in which case the less favourable forecasts in September relative to May are attributable to greater pandemic costs in the other categories. The expected cost of the lockdown is then at least \$27b. At the lower bound of \$27b, this represents 18% of the pandemic cost of \$148b.

Further evidence on this matter comes from natural experiments involving adjoining geographical regions, with only one subject to lockdown. 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. This evidence is compatible with the conclusion that the lockdown versus mitigation decision constituted at least 18% of the pandemic cost.

3.3 Cost per QALY Saved

In summary, the QALYs saved by locking down rather than mitigating are estimated at 1,100 (central estimate) or 7,700 (upper bound) whilst the associated GDP losses are expected to be at least \$27b. Using the central QALY estimate, the cost per QALY saved would be \$24.5m as follows:

$$\frac{\$27b}{1,100} = \$24.5m$$

In the interests of being conservative, I use the upper bound on the QALYs saved by locking down, of 7,700, yielding a cost per QALY saved of at least \$3.51m as follows:

$$\frac{\$27b}{7,700} = \$3.51m \quad (3)$$

This is a lower bound on the cost per QALY saved because the QALYs saved of 7,700 are an upper bound and the expected GDP cost is a lower bound. This figure of \$3.51m is 57 times the QALY value of \$62,000 (and 24 times that of the QALY value of \$146,000).

In addition, I attempt to quantify all of the additional costs of mitigation, for which considerably better information has become available since March 25. 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 $\frac{1}{4}$ 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 et al (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 400,000 New Zealanders requiring hospitalization (8% of its population), and 100,000 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, as there are only about 13,000 hospital beds in the country and 440 ICU units (Wilson, 2020).

By contrast, Wilson (2020) estimates hospitalized cases at 146,000 and ICU cases as 36,600 under a "worst-case scenario" of 27,600 dead. Since my upper bound on the number of dead under a mitigation policy is 1,900, this implies 10,000 hospitalised cases and 2,500 ICU cases. An alternative estimate comes from Sweden, which averaged about 350 ICU cases over the March – September period.²¹ This implies $350 \times 180 = 63,000$ ICU days. With a ten-

²⁰ Blakely et al 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).

²¹ See https://covid19.healthdata.org/sweden?view=resource-use&tab=trend&resource=icu_beds.

day spell in ICU (Ferguson et al, 2020, page 5), this implies 6,300 ICU patients.²² Scaled for the difference in deaths (1,900 at most in New Zealand and 5,800 in Sweden), this implies about 2,100 ICU patients in New Zealand under a mitigation policy. Using Wilson’s 4:1 ratio of hospitalized cases to ICU cases, this implies 8,800 hospitalised cases. In the interests of being conservative, I choose the latter pair (10,000 hospitalised cases and 2,500 ICU cases) and assume (again to be conservative) that the New Zealand hospital system could accommodate all of them. Furthermore, whatever number of cases were accommodated, they would be to a large degree permanently displacing other types of patients so the incremental costs would be even less.²³ 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 New Zealand’s GDP per capita of \$62,000, the upper bound on the resulting incremental costs would be \$0.3b as follows:

$$62,000[10,000(0.3) + 2,500(0.6)] = \$0.3b$$

Using this to modify equation (3), the cost per QALY falls from at least \$3.51m to at least \$3.47m as follows:

$$\frac{\$27b - \$0.3b}{7,700} = \$3.47m \quad (4)$$

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 $74 \times 0.74 / 26 = 2.1$. 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

²² Gros (2020, page 5) assumes two weeks in ICU. I use the lower estimate of Ferguson et al, because it gives rise to a larger number of ICU patents, and therefore higher medical costs, which is conservative.

²³ The permanent displacement of other patients arises because the New Zealand public health system has insufficient capacity to even deal with the pre-covid demand, as is evident from the long queues. In respect of these queues, see https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12365158.

unwell after three weeks and a smaller (but unquantified) proportion for months. As of 15 October 2020, there have been 38.6m recorded cases and 1.1m deaths worldwide.²⁴ So, the ratio of these slow recovery cases to deaths is $38.6\text{m} \times 0.1 / 1.1\text{m} = 3.5$. These sufferers seem to be similar to the fatalities in their age and the presence of pre-existing conditions.²⁵ However, given the lack of precision about this, I conservatively assume a residual life expectancy for these long-term sufferers to be double that of the fatalities, which is therefore 10 years. Furthermore, consistent with the figure used earlier for people suffering from serious pre-existing conditions, their quality of life is thereby initially reduced by 20%. Since Greenhalgh and Knight (2020) imply that some of them do recover, I assume an average loss in their quality of life over their remaining life equal to half of this, which is 10%. Allowing for all this is then equivalent to increasing the QALYs saved from lockdown rather than mitigation by a factor of approximately 2.0 as follows:

$$\frac{1(5)(0.8) + 3.5(10)(0.1)}{1(5)(0.8)} = \frac{4.0 + 3.5}{4.0} = 1.88$$

This raises the denominator in equation (4) by a factor of approximately 2.0. There will also be medical costs associated with these long-term sufferers. For example, if each such person's medical costs average \$5,000 per year of their residual life, the cost for 10,000 survivors (5 times the estimated upper bound Covid-19 deaths of $1,930 + 25 = 1,955$) for 10 years each is \$0.5b. So, making these adjustments to equation (4) reduces the cost per QALY to at least \$1.70m as follows:

$$\frac{\$27b - \$0.3b - \$0.5b}{7,700(2)} = \$1.70m$$

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% 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:

²⁴ See <https://www.worldometers.info/coronavirus/>.

²⁵ Arnold et al (2020, Table 1) report that most of these slow recovery cases had co-morbidities, their mean BMI was 32, and their median age was 60. See also <https://www.healthline.com/health-news/what-we-know-about-the-long-term-effects-of-covid-19#Who-is-most-at-risk?> and <https://www.mayoclinic.org/diseases-conditions/coronavirus/in-depth/coronavirus-long-term-effects/art-20490351>.

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

However the assumption that everyone in a population would become infected is excessive. As noted previously, Blakely et al (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 $\$310b * 0.0035 = \$1.1b$. Modifying the penultimate equation, the cost per QALY saved would be at least \$1.63m as follows:

$$\frac{\$27b - \$0.3b - \$0.5b - \$1.1b}{7,700(2)} = \$1.63m \quad (5)$$

This is still 26 times the QALY value of \$62,000 or 11 times that of a value of \$146,000. Thus, with the benefit of information that has arisen since the first lockdown, the conclusion that mitigation would have been a much better choice than lockdown in March still holds. This conclusion is strengthened by the fact that many of the parameter estimates in equation (5) are from the end of their probability distributions that yield the lowest possible cost per QALY, most particularly the 7,700 extra QALYs lost from mitigation and the \$27b GDP loss due to lockdown rather than mitigation. The conclusion is also strengthened by the fact that no allowance has been made for various phenomena that would raise the costs of lockdowns

but cannot be quantified: problems arising from the increased unemployment (addiction, crime, domestic violence, mental health problems, and premature death), disruption to the normal operation of the health care system leading to deaths that would not otherwise occur, disruption to the education of the Covid-19 student cohort, and the deprivation of liberties that people would otherwise enjoy.

3.4 Evolution in the Views of Government Advisers

It is also interesting to observe the evolution in the views of advisers to the government whose views have been well publicised. At the commencement of the crisis, professors Blakely, Baker and Wilson supported a quantitative cost-benefit analysis of the merits of different possible strategies (Blakely et al, 2020). Consistent with this, they supported the same quantitative approach to health interventions in the pre-covid period; for example, Kvizhinadze et al (2015) estimated the maximum amount that should be spent as a function of a patient's age on life-saving interventions that returned the patients to average mortality and morbidity for their age group, Boyd et al (2018) estimated the net present value of a border closure in response to a generic pandemic threat, and Boyd et al (2019) estimated the cost per QALY saved by cataract surgery. However, all subsequent published comment on the pandemic from these public health experts (professors Blakely, Baker and Wilson) has been in support of an elimination strategy but without any accompanying cost-benefit analysis, or even the merest mention of QALYs (for example: Baker et al, 2020; Durrheim and Baker, 2020). So, despite promoting the cost-benefit approach to health interventions for many years, and adopting the same approach in the initial stages of the pandemic, these public health experts seem to have abandoned this approach in favour of the goal of minimizing lives lost regardless of the cost.

The case of Professor Baker is even stranger. He was a co-author of Blakely et al (2020), which was published on 23 March (and it cannot have been finalized before 16 March because it cited an article with that date). In this article, the authors noted that substantial savings in life were likely from elimination but that there were costs of doing so in the health system and across the economy, that expenditures of up to \$2.5b were justified by a QALY value of \$45,000, that these were "quick calculations", and that they "could and should be improved". However, despite so urging government to improve the cost-benefit analysis so that a sensible decision could be made, Prof Baker was already advocating lockdowns and doing so without any cost-benefit analysis. In particular, he advocated lockdown on 22

March whilst recognizing the severe economic costs of doing so but without any analysis of the trade-off.²⁶ Furthermore, in an interview granted to a journalist after the lockdown announcement, explaining the evolution in his thinking, he stated that he switched in late February to favouring lockdowns to achieve elimination because the evidence from China was that such a strategy *could* succeed, but he makes no mention of the costs of doing so or even that cost considerations were important.²⁷ Consistent with this newfound absolute prioritization of lives over costs, he reports weeping when the lockdown was announced (on 23 March).

Turning now to James et al (2020a), in March 2020, they presented predictions of the death tolls in New Zealand from a range of possible control strategies (ibid, Table 2). However, none of the strategies examined by them corresponds to “mitigation” as defined by Ferguson et al (2020) and Blakely et al (2020). Furthermore, James et al did not present any information on, or even recognize the relevance of, costs of adopting the various strategies considered by them, and therefore their goal seemed to be to minimize the number of deaths regardless of the cost. By contrast, in a November 2020 paper with most of the same authors as James et al (2020a), Binny et al (2020, page 19) do recognize that differing strategies have different costs, and that a cost-benefit analysis would be necessary to determine this, but they do not carry this out. In the absence of such analysis, the usefulness of their analysis to policy makers is minimal unless those policy makers are indifferent to costs and seek only to minimise the death rate. Furthermore, as with their earlier paper, none of the strategies examined in their latest paper examines the consequences of a mitigation strategy as defined by Ferguson et al (2020), involving case isolation, quarantining of members of their households, and efforts to shield the elderly. The nearest such strategy examined by them appears to be the adoption of only Level 2. Furthermore, in estimating the death toll from adoption of only Level 2, Binny et al (2020, Table 3) estimate it at 32,000 by 31 October 2020 (and more if the health system is saturated with cases, as it would be at that casualty level). However, their model generating this result has no provision for individuals not yet infected changing their behavior in response to the observable spread of the virus, in the form of reduced social contacts, working from home if possible, increased hand washing, increased

²⁶ See <https://www.stuff.co.nz/national/health/coronavirus/120435284/coronavirus-how-close-is-new-zealand-to-lockdowns>.

²⁷ See <https://www.nzherald.co.nz/nz/my-story-professor-michael-baker-i-wept-when-pm-announced-that-nz-was-going-into-lockdown/GFCRGQ4DUEXDQOMFTRVYR7BH7E/>.

use of masks, etc. Implicitly and implausibly, they treat uninfected humans like rabbits, who do not react to a virus spreading through their population because they do not understand how it is transmitted. Equivalently, they treat uninfected human beings like fissile elements in a nuclear chain reaction, which are unable to alter their behavior so as to avoid the neutrons that facilitate the chain reaction. Consistent with this highly implausible feature of the model, its prediction of 32,000 deaths in New Zealand (6,400 per 1m) by 31 October exceeds the highest death rate observed in any country up to October 31 (Belgium with 986 per 1m) by a multiple of over 6.²⁸

4. Looking Back to 12 August

On 12 August, and consequent upon an outbreak of cases in Auckland, the government locked down the Auckland region for 18 days. This section considers the merits of that decision.²⁹ Had lockdown not been undertaken, the outbreak may have spread throughout the country, yielding a situation comparable to that on 23 March.

In respect of the *additional* QALYs saved from the Auckland lockdown decision, the 7,700*2 estimate from the previous section is still the upper bound from continued pursuit of a lockdown policy here, for reasons given there and for two additional reasons. Firstly, the outbreak might have been contained through continued testing and tracing, in which case a mitigation policy might not have led to all of these deaths. Secondly, policy and medical lessons have been learned since the first lockdown that would have reduced deaths if a mitigation policy had been adopted on 12 August, including the importance of properly quarantining rest homes, the best use of ventilators, and the merits of awake prone positioning.³⁰ The lower bound on the extra QALYs saved from continuation of the lockdown policy is zero. So, the upper bound on the QALYs saved is 7,700*2.

²⁸ Data on Belgium from <https://www.worldometers.info/coronavirus/>.

²⁹ Unlike March, the resort to lockdown seemed to have occurred here because contact tracing and testing seemed to have failed to contain the Auckland outbreak. However, given that failure, the choice of lockdown or mitigation still existed.

³⁰ See <https://www.statnews.com/2020/04/08/doctors-say-ventilators-overused-for-covid-19/>, and https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12322501, and Koeckerling et al (2020).

In respect of the *additional* GDP loss from the Auckland region lockdown decision, this lasted 18 days (12 August – 30 August in Level 3) whereas the first lockdown lasted 51 days (23 March till 13 May in Levels 3 and 4), and the Auckland region generates 38% of New Zealand’s GDP.³¹ In addition, all of the Auckland lockdown was at Level 3 whilst 33 of the 51 days of the first lockdown were at Level 4. Assuming Level 4 curtails output by 60% more than Level 3 (see The Treasury, 2020a, page 7), the first lockdown was then 39% more stringent than the second, on average. So, the Auckland lockdown for only 18 days at Level 3 was equivalent to 10.0% of the first lockdown (18/51*0.38/1.39). Thus, the estimated further GDP loss from this would be 0.10*\$27b. Substituted into equation (5), the cost per QALY saved from continued pursuit of the lockdown policy was then at least \$52,000 as follows:

$$\frac{\$27b(0.10) - \$1.9b}{7,700(2)} = \$52,000 \quad (6)$$

Since this is less than \$62,000, the Auckland lockdown would now seem to have been justified. However this conclusion rests upon using estimates for the parameters in equation (5) that are most favourable to a lockdown decision. It also rests upon ignoring various phenomena that would raise the costs of lockdowns but cannot be quantified: problems arising from the increased unemployment (addiction, crime, domestic violence, mental health problems, and premature death), disruption to the normal operation of the health care system leading to deaths that would not otherwise occur, disruption to the education of the Covid-19 student cohort, and the deprivation of liberties that people would otherwise enjoy. It also assumes that on 12 August it was reasonable to believe that no further outbreaks would occur elsewhere in the country or again in Auckland that would have led to further lockdowns under the lockdown policy. If further lockdowns were even expected to yield GDP losses equal to even 6% of the GDP loss from the Auckland lockdown, the first term in the numerator of equation (6) would be multiplied by 1.06 while all other terms would be unaffected, leading to a cost per QALY saved of at least \$62,000 as follows:

$$\frac{\$27b(0.10)(1.06) - \$1.9b}{7,700(2)} = \$62,000$$

³¹ See <https://www.stats.govt.nz/information-releases/regional-gross-domestic-product-year-ended-march-2019>.

So, as of 12 August, the policy of continued lockdowns would now be marginal. Thus, the only situation in which continued lockdowns from 12 August might be justified would be that in which there is virtually no chance of subsequent substantial lockdowns. This is possible but unlikely.

James et al (2020b) have also examined the Auckland lockdown decision, but focused upon the relative merits of Level 3 versus 4 lockdowns. In their earlier paper concerned with the March lockdown decision, James et al (2020a) did not present any information on, or even recognize the relevance of, the costs of adopting the various strategies considered by them, and therefore their goal seemed to be to minimize the number of deaths regardless of the cost. By contrast, James et al (2020b) estimate the economic costs of Level 3 and 4 lockdowns, and in particular the GDP losses that would have been incurred under Level 3 and 4 lockdowns if each were sustained for the period necessary to raise the probability of eliminating the outbreak to 50%. They find a modest such advantage to Level 4, because the expected time in lockdown to reach their epidemiological target is shorter in Level 4, which more than compensates for the higher costs per day. However, and despite referring to the use of the QALY approach in other papers and even appearing to recommend such an approach to the Auckland decision (ibid, page 10), they do not adopt it themselves nor offer a reason for failing to do so. Furthermore, their GDP losses are merely for the days in which the lockdown operates, and therefore they implicitly assume that removal of restrictions leads to the immediate reversion of GDP to the path it would otherwise have followed. However, as shown in Table 1 and Table 4 above, it is expected to take several years to fully recover from a lockdown and there is no reason to suppose the entire such costs are the same multiple of the costs during the lockdown for both Level 3 and 4. In addition, they attribute all GDP losses to the lockdown, whereas a substantial fraction would be due to actions taken by individuals in response to an outbreak.

In conclusion, the 12 August lockdown decision for Auckland would only have been justified using parameter estimates most favourable to such a decision and a minimal chance of subsequent substantial lockdowns. This is possible but unlikely.

5. Looking Forward on 10 November

I now consider the appropriate course of action looking forwards at the present time (10 November). Deaths and GDP losses to date are sunk, and therefore should be ignored. Since the Auckland lockdown there have been a number of cases in which a person outside the border quarantine zone has tested positive (“community cases”). These cases have been dealt with so far by quarantining of the infected individuals and any of their contacts also found to be infected. However, at any time, such an approach might prove to be insufficient to contain an outbreak, and therefore the question of lockdown would again arise (as it did with the August Auckland lockdown decision). Any such lockdowns may be only regional rather than national. Furthermore, since viruses generally evolve over time, the death rate arising from any future outbreaks without a lockdown may be more or less severe than indicated by currently available data. I therefore consider both issues.

Let P denote the proportion of the national GDP generated by the region subject to lockdown, so $P = 1$ means lockdown of the entire country. Let N denote the severity of the future outbreak without a lockdown relative to the experience to date, so that N in excess of 1 is more severe and N less than 1 is less severe. Following equation (5), the \$27b would be proportional to P , the \$1.1b would be independent of P and N , and both the denominator and the \$0.8b in the numerator would be proportional to N . So, the expected cost per QALY saved from a lockdown rather than a mitigation policy would then be as follows:

$$\frac{\$27b(P) - \$1.1b - N\$0.8b}{7,700(2)N} \quad (7)$$

For this to be less than the threshold figure of \$62,000, which would support lockdown, then P would have to be small or N large or some combination of the two. For example, if $N = 1$, then P would have to be no more than 11%. Alternatively, if $P = 1$, N would have to be at least 14. Such combinations are possible but very unlikely.

This analysis assumes that, if lockdown were pursued, only one such lockdown would be necessary. This cannot be guaranteed. So, the GDP losses from a lockdown policy may exceed \$27b and cannot be less. In so far as they are more, even lower values of P and/or higher values of N would be required to justify a lockdown policy. For example, if there is a 20% chance of a second future lockdown, the expected GDP losses from future (nationwide) lockdowns rise from \$27b to $\$27b + \$27b(0.2) = \$32.4b$. So, if $N = 1$, then P would have to

be no more than 9% to justify future lockdowns. Alternatively, if $P = 1$, N would have to be at least 18 to justify future lockdowns.

In conclusion, in considering the possibility of future outbreaks that could not be contained with only quarantining of cases, lockdowns would be justified only if the proportion of the country subject to a lockdown were very small or the death rate arising from future outbreaks without lockdowns would be much more severe than indicated by currently available data, or some combination of these. Such combinations are possible but unlikely.

6. Conclusions

World-wide, many governments have implemented substantial curtailments of normal economic activity in order to reduce the expected death toll from Covid-19. This paper considered the merits of the New Zealand government adopting a lockdown rather than a milder mitigation policy, with the actions of individuals and other governments taken as given. Based upon the information available at the time of the first lockdown in March, the cost per QALY saved from doing so was well in excess of generally used values for a QALY. Consideration of alternative parameter values and recognition of factors omitted from the analysis would not likely reverse this conclusion. The lockdown policy was therefore inconsistent with generally used values for a QALY.

This paper then considered the implications of information that subsequently became available, most particularly the death rate evidence from other countries. This information reinforced the conclusion that the March lockdown was unwarranted.

The paper then considered the merits of the subsequent Auckland lockdown. This would only be justified using parameter estimates most favourable to such a decision and a minimal chance of subsequent substantial lockdowns. This is possible but unlikely.

Finally, in considering the possibility of future outbreaks that could not be contained with only quarantining of cases, lockdowns would be justified only if the proportion of the country subject to a lockdown were very small or the death rate arising from future outbreaks without lockdowns would be much more severe than indicated by currently available data, or some combination of these. Such combinations are possible but unlikely.

APPENDIX 1

This Appendix further examines data on death rates across countries that did and did not lockdown. 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 would vary by state or province. This leaves European countries and the East Asian democracies (Japan, South Korea, Taiwan, Singapore, plus Hong Kong). Hale et al (2020) 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, and use the maximum rating for each country assigned during the crisis.³² Death rates per 1m of population are drawn from the previously mentioned source. All five East Asian countries have very low death rates regardless of the severity of restrictions, and the likely reasons (a culture of mask wearing, not shaking hands, extensive contact tracing and testing, etc) are or were not applicable to the same degree in New Zealand. So, I use only the European countries, of which there are 33. They are similar (on average) to New Zealand in ethnicity, cultural norms, demographics, GDP per capita, and the quality of their health care systems.³³

Unlike Gibson (2020), I use the maximum index value rather than the average. This avoids the difficulties in choosing a starting date for the averaging. Gibson uses the same date for all countries (7 January) but the first cases appeared in countries at different times, which will produce lower average index values in countries that were hit later rather even if their true policy response was equally stringent. Use of the maximum value 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 death rate (up to that point) as well as having contributed to it (beyond that point). This yields a reverse causality problem. An extreme case of this problem would arise if one country adopted its maximum stringency

³² See <https://covidtracker.bsg.ox.ac.uk/> for the data. Their other indexes produce similar results.

³³ Malta is excluded because Hale et al (2020) 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 (2020) 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.

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 imposed a stringency of 50 throughout the 12 weeks of the analysis. Both would have an average Stringency of 50, but would embody entirely different policies.

Death rates are likely to be affected by many variables other than 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,
- (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),
- (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.³⁴

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

³⁴ 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](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/>.

their inclusion each lowers the adjusted R^2 .³⁵ I therefore retain only the first two variables. The data are shown in Appendix 2. Regressing the death rate per 1m (D) up to 22 August 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:

$$D = 708.6 - 3.45S + 321.6PD - 12.0FD \quad (8)$$

The R^2 is a respectable 0.47, all coefficients on the regressors have the expected signs, and the p values are .005, .18, .018 and .001 respectively. In particular, the death rate falls as the stringency of the restrictions rises. However, unlike the other three coefficients in the model, the coefficient on S is not strongly statistically significant ($p = 0.18$), so the hypothesis that D is unrelated to S cannot be rejected. Furthermore, if Sweden is deleted from the regression model (1/33 data points), the coefficient on S becomes positive. So, the evidence for government restrictions reducing the death rate is minimal. This may seem counterintuitive, but the explanation may lie in the adjective. 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. This is consistent with the economic evidence that most of New Zealand's expected GDP losses from the pandemic are not attributable to the actions of the New Zealand government.

The epidemiological impact of all three independent variables on D is substantial relative to the observed variation in D (which ranges from 6 to 860); going from the minimum to the maximum value for S (0.46 to 1.0) is expected to lower D by 186 per 1m, going from the minimum to the maximum value for PD (0.008 to 1.06) is expected to raise D by 338 per 1m, and going from the minimum to the maximum value for FD (1 to 46) is expected to lower D by 540 per 1m. Interestingly, using this model, the predicted death rate (to date) for New Zealand (with its regressor values of $S = 96$, $PD = 5.0/103$ and $FD = 42$) is negative, so New Zealand (with an actual death rate of 4) underperformed relative to its regressor values.

It is fundamental to equation (8) that causality runs from the regressors to the death rate. However, it is possible that the causality also runs from D to S because

³⁵ Higher GDP per capita raises the quality of the health care system, which lowers the death rate, but presumably also the incidence of obesity etc, which increases the death rate.

- (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 (8) 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 5 (at the commencement of the crisis) about expected death rates under mitigation and extreme lockdown.

Table 5: Expected Death Rates under Various Scenarios

	$S = 50$	$S = 100$
Country A	1,560	130
Country B	300	< 130

The data for type A countries with $S = 100$ and type B countries with $S = 50$ is taken from equation (6) with the other regressors fixed at their average values ($PD = 0.313$ and $FD = 28$). The death rate for type A countries under mitigation (1560) 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.³⁶ If the governments’ predictions are on average accurate, then the outcomes would be as follows:

³⁶ 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.

Type A countries: $S = 100$ and $D = 130$ on average

Type B countries: $S = 50$ and $D = 300$ on average

Regressing D on S would then yield a coefficient on S of -3.4, consistent with the regression result shown in equation (8). However, the real coefficients on S are much lower, most particularly -29.0 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 5, 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 5, and acted accordingly in accordance with contrary expert opinions.³⁷ 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 (8) of -3.4. 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 (x5 in Table 5), *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 (8) 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 the advantage of subsequently obtaining and testing the data that has become available since

³⁷ See for example <https://thehill.com/opinion/healthcare/489962-what-if-the-sky-is-falling-coronavirus-models-are-simple-wrong>.

the commencement of the crisis. These conditions are not plausible, and this implies that the estimated coefficient on S of -3.45 is not materially biased for reasons of this type.

The second potential problem with equation (8) 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 6: Average Death Rates under Various Scenarios

	$S = 50$	$S = 100$
Country A	600	130
Country B	300	< 130

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 $D = 130$. 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 $D = 300$. Regressing D on S would then yield a coefficient on S of -3.4, consistent with the regression result shown in equation (8). However, the real coefficients on S are much lower, most particularly -9.4 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 7 below. Only two of these regressions even yield a positive coefficient on early death rate (consistent with the scenario in Table 6) 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 final death rate (D), as shown in the last three columns of Table 7. 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 7: 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 (8), 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 (see Appendix 2) 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 62). 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.

A further criticism of equation (8) is that many other independent variables have not been included, because of data limitations, and inclusion of them could materially alter the coefficient on S . Consistent with this, the adjusted R^2 for equation (6) is 0.47. Examples of these omitted variables are the extent of multi-generational households, which would facilitate the transmission of the virus to the high risk elderly group, and the extent of

quarantining of nursing homes, which would reduce the death rate amongst the high risk group. However, starting with the version of equation (8) with only S as the regressor and all countries included, and then progressively adding new regressors, the change in the estimate of S is not very substantial, with values ranging from -4.48 to -1.96. All of this suggests that, if further regressors could be added, the coefficient on S would not be materially less than -3.45.

With this value, the expected increase in New Zealand's death toll from moving from its lockdown policy ($S = 96$) to a mitigation policy alike Sweden's ($S = 46$) would be to raise the death rate by $-3.45*(46 - 96) = 173$ per 1m of population, which would yield an increase in New Zealand's deaths of $173*5 = 865$. Mindful that the coefficient of -3.45 is merely an estimate, and that there may have been some upward bias for the reasons described earlier, the most conservative approach would be to instead adopt the lower 95% confidence limit bound on the S coefficient, which is -8.54. In this case, reducing New Zealand's S value from 96 to 46 would raise the death rate by $-8.54*(46 - 96) = 427$ per 1m of population, which would yield an increase in New Zealand's deaths of $427*5 = 2,135$.

This analysis uses deaths up to 22 August. Since then (to 10 November), deaths have risen significantly, from an average of 195 per 1m to 310 per 1m. Repeating the analysis with deaths up to 10 November, the result is as follows:

$$D = 600.6 - 1.11S + 400.0PD - 11.7FD \quad (9)$$

So, relative to equation (8), the coefficient on S rises from -3.45 to -1.11 (which is closer to zero) and the lower bound on the 95% confidence interval rises from -8.54 to -7.67. With these values, the expected increase in New Zealand's death toll from moving from its lockdown policy ($S = 96$) to a mitigation policy alike Sweden's ($S = 46$) would be to raise its death rate by $-1.11*(46 - 96) = 55$ per 1m of population, which would yield an increase in New Zealand's deaths of $55*5 = 275$. For the lower bound on the 95% confidence interval, the corresponding figures are $-7.67*(46 - 96) = 384$ per 1m of population, which would yield an increase in New Zealand's deaths from mitigation over lockdown of $384*5 = 1,920$. These figures of 275 and 1,920 are *smaller* than from data up to 22 August (863 and 2,135 respectively). Given the trend since 22 August, these figures of 275 and 1,920 are likely to become even smaller as the pandemic unfolds.

This analysis also 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 New Zealand. As a robustness test, I 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 also 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 (2020) 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).

The coefficients on these latter two variables each have the expected sign (positive and negative respectively). 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 inclusive of the maximum Stringency Index (S) is thus:

$$D = -517 + 9.51S + 327P - 230.8I \quad (10)$$

The R^2 is a respectable 0.46, and the p values on the four coefficients are .32, .11, .006 and .046 respectively. If the European and Americas data are pooled, with addition of a dummy variable C for continent (1 for European countries and zero otherwise, to account for differences not reflected in any other regressor) C , 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 is thus:

$$D = 445 + 1.34S - 118C + 2.80P - 166I - 5.8FD \quad (11)$$

The R^2 is a respectable 0.37, and the p values on the six coefficients are .19, .66, .14, .005, .088 and .043 respectively. Across these three models (9), (10) and (11), equation (9) then yields the highest estimate of the incremental deaths from lockdown rather than mitigation, and use of it is therefore conservative. This additional analysis also amplifies the point that New Zealand was in a remarkably favourable position, even without resort to lockdowns, because it has favourable values for all of the variables found to reduce the Covid-19 death rate: low population, no land borders, low population density, and first death well after the first death in Europe.

One final feature of the European data is noteworthy. The increase in the death rate per 1m from 22 August to 10 November for European countries has varied significantly across countries, from a mere 3% more in the case of Sweden (576 to 595) to a multiple of 12.3 in the case of Czechia (38 to 469). Cross-sectionally regressing the change in proportional terms on the 22 August death rate (D) yields a negative and statistically significant coefficient on the 22 August death rate ($p = .03$):

$$\frac{\Delta D}{D} = 3.51 - .0043D$$

So, a country with an August 22 death rate of 100 per 1m would be expected to experience a threefold increase in that rate by 10 November whilst one with an August 22 death rate of 700 per 1m would expect to experience only a 50% increase. A plausible explanation for this is that a country's death rate up to a point in time reflects inter alia the collective actions of individuals and government ("interventions") up till that time, such interventions cannot be sustained at high levels for very long, and therefore countries with low death rates on 22 August (tending to be those with stronger interventions up to that time) subsequently experienced higher growth rates in their death rates as their interventions were inevitably scaled back. This suggests that interventions affect only the timing of deaths rather than the

number. This conclusion is not inconsistent with the conclusion that lockdowns do not have a statistically significant effect on the death rate because lockdowns (which are a government action) are only part of the total interventions by individuals and governments.

APPENDIX 2

Table 8: Covid-19 Death Rates and Explanatory Factors for European Countries

	Stringency	First Death	Density	Death Rate
Albania	90	25	0.26	85
Austria	85	26	0.28	81
Belgium	81	25	0.98	850
Bosnia	93	35	0.17	160
Bulgaria	73	25	0.16	77
Switzerland	73	19	0.55	231
Croatia	96	33	0.19	41
Czech Rep	82	36	0.35	38
Cyprus	94	35	0.33	17
Germany	77	23	0.61	111
Denmark	72	28	0.35	107
Spain	85	17	0.24	617
Estonia	78	39	0.07	47
Finland	60	35	0.04	60
France	88	1	0.31	467
UK	80	19	0.73	609
Greece	84	26	0.20	23
Hungary	77	29	0.27	63
Ireland	91	25	0.18	359
Iceland	54	35	0.008	29
Italy	94	7	0.52	586
Lithuania	87	34	0.11	31
Luxembourg	80	27	0.06	198
Latvia	66	48	0.08	18
Netherlands	80	20	1.06	361
Norway	80	26	0.04	49
Poland	83	26	0.31	51
Portugal	88	30	0.29	176
Romania	87	36	0.21	166
Serbia	100	34	0.26	79
Slovakia	87	46	0.29	6
Slovenia	90	28	0.27	63
Sweden	46	25	0.06	575

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