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School-closure is counterproductive and self-defeating[1]

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The Netherlands has recently closed down primary and secondary education in response to the covid-19 pandemic. Using a SIR (Susceptibles-Infected-Recovered) model for the Netherlands, this closure is shown to be counter-productive (as it increases future vulnerability to infection) and hard to reverse (since the increased vulnerability demands continuation). Though the rise of B117 ("the British version") has been used to argue for school-closure, B117 increases the negative effects of school-closure. School-closure has been based on a misunderstanding of the dynamics in a multi-group SIR model. Furthermore, immunity by prior infection is shown to provide a larger contribution to ending the pandemic than vaccination. Finally, a cost-benefit analysis shows school-closure to be extremely costly. Behavioural economics explains why decision making and the public debate are so distorted, to the detriment of youngsters.

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1 The author thanks Robin Fransman, Bas Jacobs and Thijs van Rens for useful suggestion. The data used for this paper are available at www.coenteulings.com/multigroup-sir-model-covid-19/.
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1 Introduction

In response to the ongoing covid-19 pandemic, the Dutch government has closed down primary and secondary school from December 16, 2020 onwards. The fear for B117 ("the British version") with a 30% higher infection rate has played a major role. Empirical evidence suggests indeed that school-closure has strongly reduced infections among youngsters in the short run, but the beneficial effects on health outcomes in the long run are less clear.

Solid evaluations of the corona-policies will appear in the years to come. However, these evaluations are to no avail for policy makers who have to decide here and now. Early provisional analyses on the effectiveness of various policies are therefore useful. This is exactly my aim in this article. I use a standard multi-group SIR (Susceptibles-Infected-Recovered) model calibrated on the pandemic's evolution in the Netherlands since September 2020. The wisdom of school closure turns out to be doubtful.

My analysis starts in Section 2 and 3 with the case if there were no vaccination. That is most helpful for understanding the mechanisms at play. Section 4 accounts for upcoming vaccination. This really changes the nature of the game, in favour of school-closure. A cost-benefit-analysis shows, however, that even with vaccination school-closure is a prohibitively costly. Section 5 then addresses the issue why society has nevertheless embarked on this policy.

2 Four conclusions

The defining feature of covid-19 is its highly differentiated impact between age-groups. Nearly all casualties occur among elderly. My SIR model has therefore three age-groups: youngsters (aged 10-39), middle aged (40-64) and elderly (65+). Table 1 list some critical dates since September 2020, the starting date of my model simulations. The table relates these dates to week numbers in the simulations. The number of infections has risen steeply from early September until late October, as I shall discuss below. The lockdown policies of October 24 brought down the growth of the number of infections.[1] My analysis focusses on the effect of school-closure on December 16. This analysis yields four conclusions.

Table 1 Crucial dates

Event	Date	Simulation week
Start simulation	Sept 7	1
Start lockdown	Oct 24	7
School closure	Dec 16	15
New year	Jan 1	17
End simulation	June 30	42

Conclusion 1: School-closure trades casualties today for casualties in May/June

Figure 1 shows the effect of school-closure for 8 weeks (week 15-22). The number of infections among youngsters falls sharply in the short run. However, starting from mid-April, after reopening schools, the number of infections is predicted to be higher with rather than without school-closure in week 15-22. The same holds for the other age-groups, but the effect is obviously smaller. Since the number of casualties is proportional to the infections among the elderly, both series follow the same

[1] This explains the kink in the number of infections at week 7,

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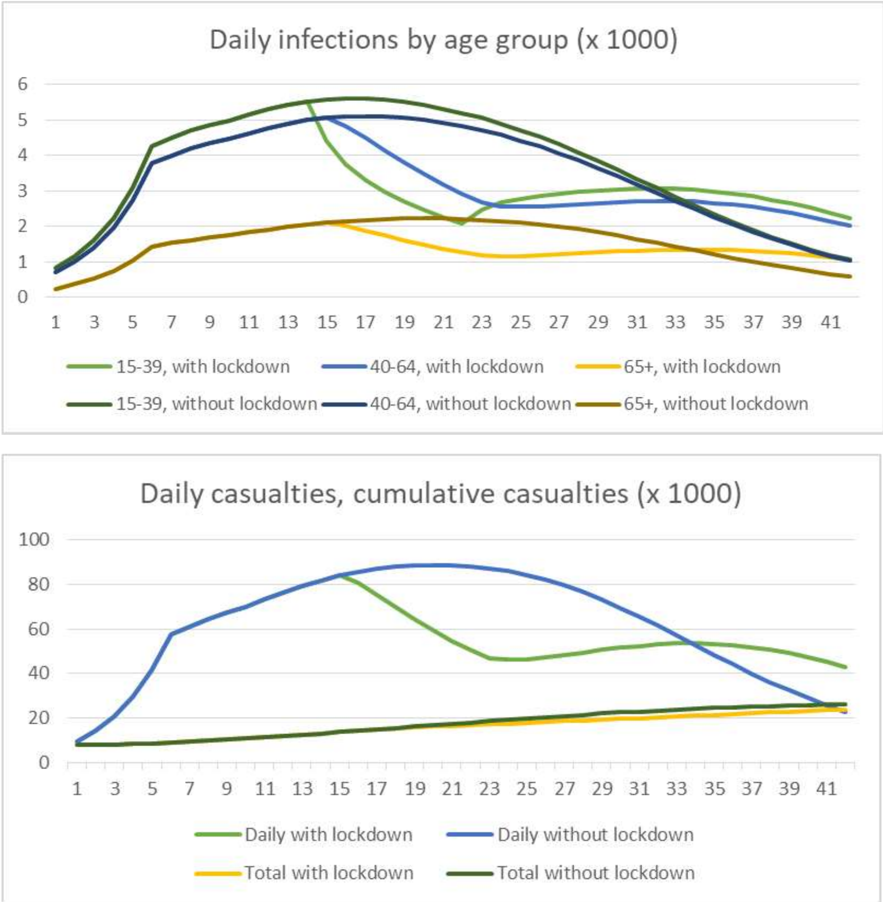
pattern: school-closure reduces them initially, but increase them in May and June.[2] The effect on the cumulative number of casualties by end of June is therefore limited: the initial reduction is offset by the subsequent increase.[3] This is the first conclusion: school-closure merely trades casualties today for casualties in a couple of months.

Figure 1 The effect of school-closure in week 15 (December 16) to 22 (February 8)



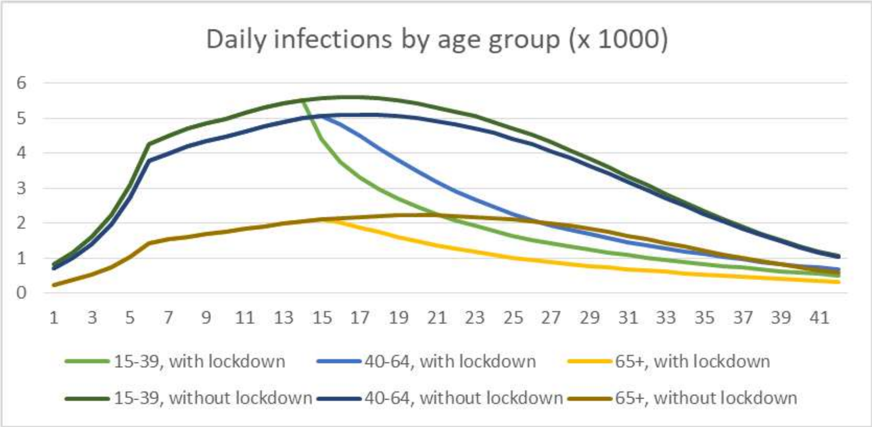
Conclusion 2: School-closure is hard to end

The second conclusion follows from the first. If reopening schools drives up daily infections above the level that would have been attained without school-closure, the temptation for policy makers is to keep schools closed until the end of the simulation, see Figure 2. Only a permanent school-closure can keep the number of infections with school closure below the number without until the end of the simulation period, as shown in Figure 1. However, a permanent school closure is extremely costly, as will be shown in Section 4.

[2] 23,800 casualties with closure versus 26,200 without.

[3] This holds also for Figure 2 and 3. Since the number of casualties is proportional to the number of infections among elderly, we don't report the number of casualties in these panels.

Figure 2 The effect of school-closure in week 15 (December 16) to 42 (June 30)



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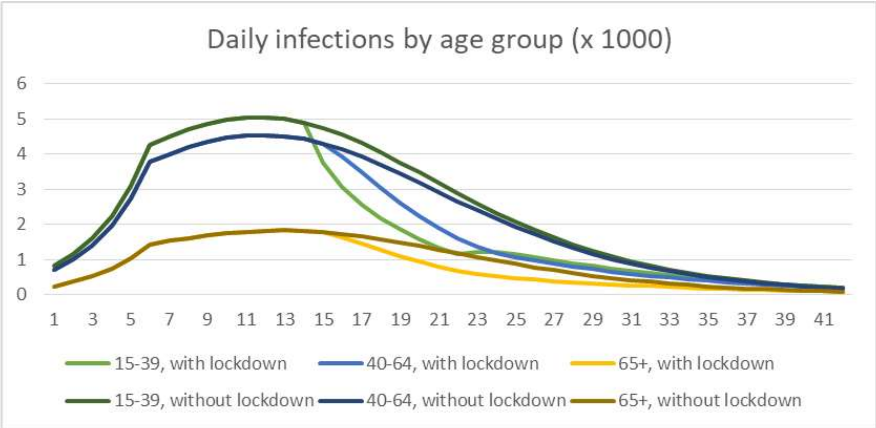
Conclusion 3: B117 only reinforces the arguments against school closure

The public motivation for advocating school-closure has been the arrival of B117 with a 30% higher infection rate. The simulations in Figure 1 and 2 include this version. As a thought experiment, Figure 3 presents a simulation of school-closure in week 15-22 without B117. Clearly, the number of infections and casualties would be substantially lower in that case. The surprise is in the effect of school-closure under this alternative scenario: it would be highly effective, without negative long run effects. The third conclusion is therefore exactly opposite to the public legitimation of school-closure: without B117, school-closure might have been effective; with B117, school-closure merely delays casualties and prolongs the pandemic.

Figure 3 The effect of school-closure in week 15 to 22 in the absence of B117



Conclusion 4: Immunity by previous infection offers a substantial contribution

In his first speech on covid-19,[4] prime-minister Mark Rutte stated as the main policy objective to avoid overburdening the health care system by smoothing the number of infections over time. In this way, we would gradually achieve immunity by previous infection. This notion quickly vanished from the debate, since this process was generally presumed to be too slow. Figure 1 and 3 show this presumption to be incorrect: without B117, the reproduction rate *R* would have got below unity by immunity due to previous infection in the beginning of December; with B117, one might expect this have to happen in course of February, even without school-closure.

What drives these counterintuitive conclusions? For this, one has to dig deeper into the surprising dynamics of a multi-group SIR model.

3 The unavoidable logic of the SIR model

For the simulations above, I use a standard SIR model with multiple age-groups analogous to Acemoglu et al. (2020). In its simplest form, this model consists of two difference equations for each age-group:[5]

$$\Delta I_i = \beta\, \alpha_i\, S_i\, [\Sigma_j\, I_j + (\theta - 1)\, I_i] - \gamma\, I_i \qquad (1)$$

$$\Delta S_i = -\, I_i \qquad (2)$$

Equation (1) describes the change in the number of infections as the difference between new infections (the first term on right hand side) and people who recover (the second term $\gamma\, I_i$, γ is the recovery rate). Since the disease is spread by infected people to others who are still susceptible, new infections in age-group *i* are proportional to two factors: (i) the number of people in age-group *I* still susceptibles S_i, and (ii) the weighed sum of infected people in all age-groups, $\Sigma_j\, I_j$. β is the general infection rate; B117 raises this parameter by 30%.[6] The infection rate varies by age-group, which is captured by the parameter α_i. Since infected people disproportionally infect their own age-group, this group overweighed in the sum of infected people by a factor θ greater than one.

The second equation describes the evolution of the number susceptibles: people who recover from an infection are immune afterwards and hence leave the pool of susceptibles. New infections therefore have a negative short run effect on the number of infections, as infected people spread the virus, but a positive long run effect, as they reduce the number susceptibles. The latter effect is key understanding the dynamics of the pandemic.

Table 2 Daily infections (by age-group) and casualties

Date	10-19	10-39		40-64		65+		Casualties
	Data	Data	Model	Data	model	data	model	Data
Sept 7	100	500	900	400	700	100	200	5
Oct 26	1000	4500	4300	4000	3800	1500	1400	75
Dec 21	1800	5000	5200	4500	5400	1700	2200	90
Jan 18	500	2000	2600	2000	3700	1000	1600	50

[4] On March 16, 2020.
[5] This representation of the SIR model is more parsimonious than the usual version. Technically, infections *I* are treated as a flow rather than a stock variable. It simplifies the exposition without affecting the analysis.
[6] The starting values are such that new infections are distributed 50-50 among the standard version and B117 on February 1, 2021.

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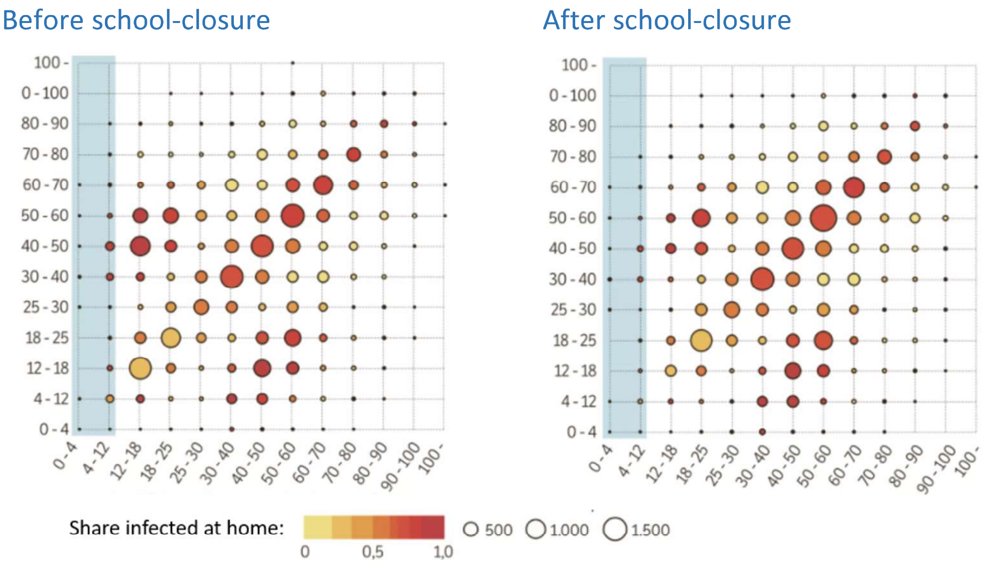
Source: RIVM https://www.rivm.nl/coronavirus-covid-19/actueel/wekelijkse-update-epidemiologische-situatie-covid-19-in-nederland

The parameters are set as to match the number of daily infections in each age-groups, see Table 2. There is direct evidence on the number of people who have antibodies against the virus.[7] This evidence shows that the registered number of infections is roughly half of the actual number of infections. A more recent quote by chief-epidemiologist Jaap van Dissel confirms this ratio.[8] The simulations use this number. Almost all fatalities are among elderly. The number of casualties has indeed moved parallel to the number of infections among the elderly. Figure 4 provides evidence on the parameter θ: the overweighing of the own age-group when infecting other people is visible from the relative sizes of the circles on- and off- the main diagonal. A comparison of the panels before and after school-closure documents the effectiveness in reducing the number of infections among youngsters. The model matches the data reasonably well.[9]

Figure 4 Who infects who?



x-axis: age infector; y-axis: age infected

[7] https://www.rivm.nl/pienter-corona-studie/resultaten

[8] See https://www.nu.nl/coronavirus/6095609/van-dissel-momenteel-twee-miljoen-nederlanders-beschermd-tegen-corona.html. In my simulations, 2.1 million people are immune by previous infections by December 2020.

[9] The parameters used in the simulation are: $\beta = 0.032$, $\alpha_1 = 2.4$, $\alpha_2 = 2.2$, $\alpha_3 = 1$, $\theta = 2$, $\gamma = 0.75$. The lockdown policies of October 24 reduce β by a factor 0.72, while school-closure reduces α_1 by a factor 0.72. The starting value of $S_i = 4.7$ million for each age-group. Excel-file is available for people who want to run their own experiments. These values imply R_0 before the lockdown policies of October 24 to be:
$\beta\ (\alpha_1 + \alpha_2 + 1)\ [(2 + \theta)/3]$ 5 mln $/ \gamma = 1.34$,
assuming the infection-rates to be equal subgroup. In fact, youngsters have a higher infection-rate, pushing R_0 up.

Source: RIVM
https://www.tweedekamer.nl/sites/default/files/atoms/files/20210204_technische_briefing_vws_presentatie_jaap_v_dissel.pdf

The analysis of Acemoglu et al. (2020)[10] is particularly helpful to understand the counterintuitive conclusions in Section 2. The mechanism is most easy to understand for the simple case $\alpha_1 = \alpha_2\ \alpha_3 = \theta = 1$. For this simple case, the reproduction-factor R_i for age-group i is defined as[11]

$R_j = (\beta / \gamma)\ S_i\ \Sigma_j\ (I_j / I_i)$ (3)

As soon as R_i gets below unity for all age-groups, the number or infections starts declining and the pandemic dies out. For a single age-group SIR model, this is the case when the total number of susceptibles S gets below γ/β. The same relations applies for multi age-group model

$S_1 + S_2 + S_3 < \gamma/\beta$ (4)

The pandemic dies out when the sum of the number of susceptibles in all age-groups gets below γ/β. Equation (4) shows that there is some freedom how to satisfy condition (4): fewer susceptibles S_1 among youngsters imply that more elderly can remain susceptible, while the pandemic nevertheless dies out. As long as there is no vaccine, previous infection is the only road out of susceptibility towards immunity. However, unlike youngsters, that road is fraught with the risk of a deadly fatality for elderly deadly. Hence, policy makers should try to let few elderly travel that road as possible. Hence, youngsters should get infected to safeguard elderly from infection. This is the positive long run effect of infections of youngsters for elderly. This explains why school closure is counter-productive: it merely reduces infections among youngsters, while these infections have a positive long run effect.[12]

This mechanism helps understanding the difference between Figure 1 and 3. In Panel 3 (without B117), R would have fallen below unity in December (week 17) anyway. After that, a forced reduction of infections speeds up the process of dying out of the pandemic. In Panel 1 (with B117), R is expected to remain above unity until February in the case of school-closure.[13] School-closure in December limits the number infections among youngsters, keeping the number of susceptibles high and delaying the moment at which R gets below unity. In the public discussion, the rise of B117 has been the legitimation for school-closure. This analysis shows that it is exactly the other way around: B117 is reason not to close schools, since it slows down the speed at which youngsters become immune and it prolongs the period during which elderly are at risk.

For the same reason, the regular public pleas for a short sharp lockdown are ill-conceived. As long as R is above unity, a short sharp lockdown is useless. It will bring down infections, but as soon as the

[10] See their Section 3, in particular Figure 3.1.

[11] In this case, the infection rate is the same for all age-groups and infected do not disproportionally infect their own age-group. For the general case, a more complicated, but similar relation holds. Equation (4) can be derived by realizing that for each age-group, $R_j < 1$. Hence: $\beta\ S_i\ \Sigma_j\ I_j < \gamma\ I_i$.
Dividing by I_3 and elimination of the ratios I_1/I_3 and I_2/I_3 yields equation (4)

[12] Following the logic of the model, middle aged can bear this burden equally well. The main argument against infecting the middle age group is that though they rarely die from corona, they need hospitalisation, see Baarsma et al. (2020, table 3). Since the pressure on the health care system is an important constraint, infections can better occur among youngsters than middle aged.

[13] There is considerable uncertainty regarding these dates, in particular on the peak of the B117-wave. There is a paradox in the communication of the government's medical advisors. On the hand, they warn for a high upcoming peak, on the other hand they claim that B117 already accounts for the half of the infections. If the latter is true, the peak of R under B117 cannot by much higher than today's value, which is close to unity.

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lockdown is relaxed, the inescapable logic of an *R* above one will resume, undoing all acclaimed benefits of the short sharp lockdown. Only after *R* has fallen below one, a sharp lockdown has lasting effects.

The main policy mistake made by RIVM and OMT (the medical advisors of the Dutch government) has been to target on total infections rather than infections among elderly (since they run the risk of dying) or the middle age-group (since they might end up in hospital, thereby putting stress on the health care system). Infections among youngsters do not impose any cost, except that they might infect other age-groups. However, the latter cost is offset by the benefit an infection a youngsters provides to future immunity. This article has shown that the latter benefit is substantial and outweighs the cost after just a couple of months, see Conclusion 4 in Section 2.

4 Upcoming vaccination and the costs and benefits of school-closure

The simulations in Figure 1-3 ignore the upcoming vaccination. Vaccination strengthens the case for school-closure in Figure 1. Postponing of infections among elderly for just a couple of months might be sufficient to safeguard them for ever, by their vaccination. Figure 1 allows us to estimate the maximum effect of school-closure in week 15-22 on the number of casualties. In the absence of vaccination, school-closure reduces casualties until week 33 (May 1) and increases them afterwards. Suppose that everybody gets vaccinated exactly at May 1. Then, all lives saved in our simulation are also actual lives saved, since nobody is vaccinated before that date, while all additional casualties after May 1 do not count, since people are vaccinated by that time and therefore do not die from covid-19 anymore. The cumulative reduction in the number of casualties at May 1 is therefore the maximum benefit in terms lower casualties that can be attributed to school-closure. Using this reasoning, school-closure saves at most 3,000 lives.

Is this gain worth the effort of an 8 week school-closure? In general, it is hard to make a credible cost-benefit-analyses of lock-down policies. There are so many moving parts that it is difficult to construct a solid counterfactual. However, for this particularly narrowly defined policy, one can give a sensible first shot. Let's assume that online education is about half as effective. A wide body of research shows that the return to a year of education can be bracketed between 5 and 10%. To be on the safe side, I use the lower bound. I ignore other (private or social) benefits of education: higher life expectancy and life satisfaction, lower criminality and agglomeration externalities. These are potentially large, but they tend to be more disputed among economists. Using these numbers as lower bound of the cost of school-closure, we obtain a cost of 30 billion for a gain of 15,000 life-years, hence at least 2 million for each life-year saved.[14] Other researchers reached similar conclusions for other countries, e.g. Van Rens and Oswald (2020) for the UK.[15] The conclusion is inevitable: the closure of primary and secondary education has been a major policy mistake.

[14] The remaining life expectancy of avoided casualties is about 5 years, see Baarsma et al. (2020), leading to 5 x 3,000 = 15,000 life-years. 2 months closure is 20% of a year education x 50% loss in effectiveness x 5% return to education = 0.5% loss of human capital for all affected cohorts; 10 cohorts aged between 5 and 15 are affected. The length of a labour market career is 40 years. During these 40 years, 10 out of 40 cohorts = 25% of the workforce is affected. Due to the low interest rate, we ignore discounting. The labour share in GDP is 2/3. Hence: 0.5% loss x 40 years x 25% of the workforce x 2/3 labour share = 3.3% of annual GDP = 30 billion
[15] See Van Rens' FT article for a short summary: https://www.ft.com/content/32b5a894-c0b1-49e7-9378-90b23774ed93

5 Why is the public discussion so one sided?

Why are the policy advices, the actual policy, and the corresponding public debate so one-sided? Remarkably, two emeriti professors in ethics, Heleen Dupuis and Marli Huijer, were among the few people who were most vocal in their opposition.[16] Many economists have been reluctant to contribute to the discussion.

This hasn't been a typical Dutch phenomenon: strict lockdown policies have been advocated world-wide. The director-general of the World Health Organisation (WHO) Tedros Adhanom Ghebreyesus has qualified policies that aim for immunity by previous infection as unethical.[17] This statement lets normative judgement precede positive analysis. From an economist's point of view this position is untenable. Trade-offs are part of our life, also in public health. One cannot impose policies by *a priori* ruling out all alternatives on acclaimed moral grounds, in particular for diseases where the risks are so asymmetrically distributed among age-groups, so that it is sensible to let one group with almost no fatality risk get infected to contribute to the group immunity, while other groups are protected. One cannot justify these policies with the dictum "*better to be safe than sorry*" either: indeed, the large cost inflicted on youngsters are "*safe*", it is hard to see how one can say "*sorry*" for that.

Economic theory, in particular behavioural economics provides two clues as to why the public discussion has been so one-sided. First, Kahneman and Tversky (1980) have shown that humans tend to overestimate small probabilities. That is our motivation for buying lottery tickets: we really think we can win. The same applies to covid-19: for people aged below 65, the probabilities of dying from covid-19 is comparable to dying by a traffic accident. Making this observation tends to invoke just outrage among the audience, not contemplation. This overestimation of small probabilities is reinforced by the daily attention on the television news and talkshows, which have spent half of their time budget on the pandemic in past four months.

Second, mankind does not satisfy the standard economic model of the *homo economicus*, who cares about himself only. Mankind isn't a *homo kantiensis* either, who cares only about the group, not about himself. Real-life humans are a mixture of both types, a *homo moralis*, see Alger and Weibull (2019). Our moral stance helps us as a group to provide public without strict government enforcement. We rally behind the flag. There is a danger, however. The "war" against covid-19 has got defined as a public cause, which we can win only by a joint effort, as the billboards along the highway tell: *Samen tegen corona* (together we beat corona). The danger of this moral definition of the effort to contain the pandemic is that it may invoke tunnel vision: serious weighing of cost and benefits is disqualified, almost as form of high treason.

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