

Vaccines and Variants: A Comment on “Optimal Age-Based Vaccination and Economic Mitigation Policies for the Second Phase of the Covid-19 Pandemic”^{*}

Luiz Brotherhood[†] Cezar Santos[‡]

June 19, 2023

Abstract

This note discusses age-specific vaccination programs designed to curb the Covid-19 pandemic. We first provide some comments on the analysis by Glover et al. (2021*b*) and point directions where further research can be carried out. Additionally, we adapt the framework from Brotherhood et al. (2021) to assess the effects of different vaccination schemes when more infectious variants can emerge when more infections take place. We find that policy prescriptions crucially depend on taking individual behavioral responses into account and on whether variants can appear.

Keywords: Covid-19, vaccines, variants

JEL codes: E17, C63, D62, I10, I18

1 Introduction

The Covid-19 pandemic has been a huge health and economic shock that hit all economies in the world starting in 2020. This shock spurred a great effort among economists to study what types of policies could be used to diminish the

^{*}Financial support from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES)—Finance Code 001 and Faperj is gratefully acknowledged. This research received institutional support from the Spanish Science, Technology and Innovation System (project reference PID2020-114040RB-I00). The views expressed in this article are those of the authors and do not necessarily represent those of Banco de Portugal or the Eurosystem.

[†]Universitat de Barcelona, FGV EPGE & BEAT. Email: brotherhoodluiz@gmail.com

[‡]Banco de Portugal, FGV EPGE & CEPR. Email: cezarsantos.econ@gmail.com

effects of the pandemic. Already in April/May 2020 there were papers studying the positive and normative implications of different Nonpharmaceutical Interventions (NPIs). As 2020 came to a close, the rapid development of vaccines allowed people to start being inoculated. NPIs could then be complemented by vaccination programs. Thinking about policy now meant to study the use of these different instruments jointly.

The study of NPIs together with vaccination is the subject of Glover et al. (2021*b*). In a world with young and old agents in which older people are more at risk of dying from Covid, the authors ask which group should be vaccinated first and how lockdowns should respond to the specific vaccination program that is chosen. The quantitative model used in the analysis is based on their previous work (Glover et al., 2021*a*). The framework features heterogeneous agents. Old individuals do not work. The young work; some in the essential sector and others in the “luxury” sector. The difference is that, if a lockdown is in effect, it only affects those that work in the luxury sector since the essential sector must always be open. This rich heterogeneity creates important distributional effects when choosing which policy to implement.

The model in Glover et al. (2021*b*) is calibrated to US data from the beginning of the Covid-19 pandemic until the end of 2020. Then, from the beginning of 2021, the authors feed into the model a vaccination program aimed at mimicking the US experience, both regarding the number of vaccines and who received them. This benchmark scenario is then compared with two counterfactuals: vaccinating the young first and then the old, and vice versa. Together with each alternative vaccination scheme, a utilitarian social planner chooses the optimal strictness of a lockdown.

The results in Glover et al. (2021*b*) imply that the old are the most affected group by the alternative policies. Their welfare gains/losses are at least an order of magnitude greater than those experienced by the young. The utilitarian planner prefers to vaccinate the old first as this group is the most affected. Interestingly, the optimal lockdown acts to bring preferences closer. That is, if the young are vaccinated first, the planner chooses a stricter lockdown to curb the effects on the old. On the other hand, if the old are vaccinated first, the planner responds with a lighter lockdown, a policy preferred by the young since they must work.

This note contains two parts beyond this introduction. Section 2 comments

on some modeling choices made by Glover et al. (2021*b*) and provides some ideas for follow-up analyses. Section 3 uses the framework developed in Brotherhood et al. (2021) to analyze different vaccination schemes in the presence of mutating variants of the novel coronavirus. The results from this last section show that incorporating individual rational behavior and the possibility of variants can change policy prescriptions. In particular, as the old endogenously protect themselves, the planner prefers to vaccinate the young first since this larger group contributes to more social encounters. The young-first vaccination program leads to less deaths overall than the old-first alternative. However, the results change if more infectious variants can arise with the stock of infected individuals. More infectious variants are particularly dangerous to the old. Hence, in the presence of variants, a lower number of deaths is achieved with the old-first vaccination scheme.

2 Comments

Though the framework developed in Glover et al. (2021*b*) features substantial heterogeneity, it does not allow for individual behavioral changes in response to Covid-19. That is, though the epidemic renders outside activities such as work or shopping more risky, individuals are not allowed to respond. Economic models with endogenous behavior in the presence of infectious diseases already existed even before the Covid-19 pandemic. Seminal work by Kremer (1996) incorporates behavior into an epidemiological model of HIV/AIDS. Greenwood et al. (2019) show that behavioral responses and equilibrium effects are important for the quantitative evaluation of policies aimed at curbing the HIV/AIDS epidemic. After Covid-19, several economics papers have developed epidemiological models with endogenous behavior; e.g., Brotherhood et al. (2021), Eichenbaum, Rebelo and Trabandt (2021) and Farboodi, Jarosch and Shimer (2021). As we will see in the next section, endogenous behavior might change policy prescriptions.

The calibration in Glover et al. (2021*b*) uses data for the entire US. There is, however, substantial variation in the experiences across the different states in the country. For instance, the stringency of the policies adopted varied widely (Hallas et al., 2021). Vaccination rates also differed dramatically. As of Decem-

ber 2021, 109 doses were administered per 100 people in Alabama whereas this rate was 187 per 100 people in Vermont.¹ Exploiting such variation might be interesting to empirically tease out the effects of lockdowns and vaccination rates.

The importance of vaccination programs against Covid-19 is obvious. But most developed countries have already vaccinated a large share of their population. For instance, as of December 2021, Canada, France, Germany and the United Kingdom have more than 2/3 of the population fully vaccinated. Even latecomers like Australia and New Zealand have also crossed this threshold.² So, what is exactly the goal of the exercise in Glover et al. (2021*b*)? Provide a framework to think about future vaccination programs? Learn from a developed country's experience to help better inform developing countries that are further behind? As of December 2021, the share of the population that is fully vaccinated in countries like Kenya, Malawi, Uganda or Nigeria was all below 6%.³

There are, however, some issues related to vaccination programs that developed countries still have to deal with. For instance, whether or not to vaccinate children. Besides the medical need, infected children can transmit the virus to older, more at-risk adults in their households. Moreover, sick children may need to isolate at home and their parents must then provide extra child care. The framework in Glover et al. (2021*b*) seems particularly suited to explore these implications since it contains different age groups and both transmission outside and inside the home.

Another issue that all countries are having to deal with is the possibility of declining immunity and the need for booster shots.⁴ Most of the work in economics that tackle vaccines assume that, upon inoculation, individuals are fully protected forever. Though Glover et al. (2021*b*) are particularly interested in the second wave of Covid-19 infections, their framework could be easily extended to assess vaccination programs when shots are imperfect.

Finally, as it became clear with the emergence of variants such as Delta and

¹See <https://covid.cdc.gov/covid-data-tracker/>.

²Despite a fast start, the US has had an unusually slow rise in vaccination rates since around June 2021. This is widely perceived as due to vaccine hesitancy. Perhaps a question for future research is how to implement policies in the presence of such hesitancy.

³Vaccination data is available at ourworldindata.org.

⁴See <https://www.cdc.gov/coronavirus/2019-ncov/vaccines/booster-shot.html>.

Omicron, more infections can lead to these mutations. And these variants seem to be more infectious than previous ones.⁵ These variants can thus lead to a tilt on the cost-benefit analysis of whom to vaccinate first. On the one hand, more infectious variants can hurt the old even more. On the other, since the young are more active, form a larger group and hence account for a larger share of infections, it might be a good idea to vaccinate them first. And all this can interact with individual behavioral responses. We explore these issues in the next section.

3 Vaccines and Variants

To study the effects of Covid-19 variants and vaccination, we adapt the framework from Brotherhood et al. (2021). We briefly describe the model and calibration strategy here and refer the reader to the paper for a full description.

Time is discrete and each period corresponds to one week. The economy is populated by young and old individuals. People of both age groups decide on how to best allocate their time. Old people receive a fixed retirement income, do not work and decide whether to enjoy leisure at home or outside. Young people can divide their time into four activities: leisure at home, leisure outside, work outside and telework. The productivity of teleworking declines when more work is shifted to the home. In the presence of Covid-19, all outside activities are risky since individuals can get infected when they leave their homes. Hence, people that have not acquired immunity may rationally opt to spend more time at home to protect themselves against the virus. The likelihood of infection depends on the (endogenous) measure of infected people that venture outside and the aggregate prevalence is determined in equilibrium. Individuals can fall into four health categories: i) susceptible, when they have not been exposed to the virus yet; ii) infected, when they are infected with Covid, can transmit the disease and, due to altruism, partially refrain from engaging in social encounters; iii) hospitalized, when they need an ICU bed for treatment; and iv) recovered, when they are immune to future infections.

The parameters are calibrated such that the model is consistent with health and (pre-pandemic) economic data targets. For instance, moments such as the

⁵See <https://www.cdc.gov/coronavirus/2019-ncov/variants/delta-variant.html> and <https://www.cdc.gov/coronavirus/2019-ncov/variants/omicron-variant.html>.

Table 1: Baseline Scenario: No Variants

	No vaccines		With vaccines		
	Benchmark	Epidem.	Random	Old first	Young first
Wks to peak srsly ill (yng)	31.00	12.00	31.00	31.00	31.00
Wks to peak srsly ill (old)	29.00	12.00	28.00	28.00	28.00
Srsly ill p/ 1,000 @ peak (yng)	0.38	12.81	0.34	0.35	0.34
Srsly ill p/ 1,000 @ peak (old)	0.12	11.11	0.11	0.11	0.11
Dead p/ 1,000 1year (yng)	0.56	4.04	0.49	0.52	0.48
Dead p/ 1,000 1year (old)	2.26	31.40	2.00	1.88	2.02
Dead p/ 1,000 1year (all)	0.93	9.89	0.81	0.81	0.81
Dead p/ 1,000 LR (yng)	1.10	4.04	0.56	0.67	0.53
Dead p/ 1,000 LR (old)	4.65	31.40	2.25	2.00	2.27
Dead p/ 1,000 LR (all)	1.86	9.89	0.92	0.95	0.91
Immune in LR (yng), %	23.38	85.29	99.94	99.93	99.95
Immune in LR (old), %	6.84	43.86	86.64	86.67	86.64
Immune in LR (all), %	19.84	76.42	97.10	97.09	97.10
GDP at peak - rel to BM	1.00	1.05	1.00	1.00	1.00
GDP 1year - rel to BM	1.00	1.03	1.00	1.00	1.00
Hrs @ home (yng) - peak	67.41	57.97	67.71	67.64	67.72
Hrs @ home (old) - peak	99.31	88.99	98.99	99.13	98.96
Hrs @ home (yng) - 6m	67.33	57.97	67.64	67.57	67.66
Hrs @ home (old) - 6m	99.28	88.99	98.96	99.10	98.93
Value - healthy (yng)	9491.76	9463.48	9497.03	9495.95	9497.24
Value - healthy (old)	4349.97	4236.93	4361.69	4362.83	4361.59
Value - healthy (all)	8391.41	8345.00	8398.07	8397.46	8398.21

basic reproduction number (R_0), the age-specific probabilities of hospitalization, death and recovery, the value of statistical life, fraction of consumption expenditures on outside activities and time-use data are used in the calibration.

We adapt this framework by allowing for the possibility that the virus mutates and more infectious variants emerge as more infections take place. In particular, in the baseline scenario, the infectiousness of Covid is consistent with $R_0 = 2.5$. In the presence of variants, we allow the infectiousness to increase to a value consistent with an $R_0 = 8$ after 20% of the population has been infected. This higher infection rate mimics the evidence that the Delta and Omicron variants can be 2-3 times more infectious. After this threshold, we assume that the virus stops mutating.

As for vaccination rates, the US reached a peak volume of about 3 million vaccines a week in April 2021. This corresponds to around 1% of the population per week. We thus assume that this flow of weekly vaccines is available starting 9 months after the onset of the pandemic. Moreover, we assume for simplicity that, after 36 months, a perfect treatment appears and the pandemic is over.

Table 1 reports simulation results for the baseline scenario in which variants

do not emerge. The first column (Benchmark) provides results for a pandemic that evolves without any vaccination. In the end, around 20% of the population is exposed to the virus, but only 6.8% of the old. This is due to the extra precautions that the old take in response to the virus, which can be seen in the rise of hours this group spends at home. Despite this extra precaution, the death rate among the old is still four times higher than among the young. The overall death rate is 1.86 dead per 1,000 people. The number of infections and deaths in the benchmark is substantially lower than in a scenario in which individuals do not change their behavior in response to the virus (Epidem. column in Table 1). This behavioral response acts to flatten the infections curve, as can be seen from the longer time it takes for the disease to reach its peak.

What if vaccines are available? The last three columns in Table 1 provide the results. The Random column relates to a vaccination program that does not prioritize any particular age group and vaccinates all individuals randomly. The Old first column starts vaccinating the old. After 70% of this group is vaccinated, it moves to vaccinate the young. And, after 70% of the young are vaccinated, it reverts to a random allocation of vaccines. The Young first program flips the order between the two age groups. First, not surprisingly, any vaccination scheme increases the welfare of both groups and lowers the death toll. Moreover, a utilitarian planner actually prefers to vaccinate the young first (last row in the table). This is due to the fact that the young contribute to more infections and must work and the old can self protect. Additionally, the young-first program also leads to a lower overall death rate, though a higher death rate among the old materializes compared with the old-first scheme.

How do these results change in the presence of more infectious variants? Table 2 reports the simulations. First, the benchmark scenario is characterized by a higher exposure to the virus and, consequently, a much higher death rate. In response, individuals of both age groups respond by spending more time at home compared with the epidemiological world with no behavioral change. What about the different vaccination programs? A utilitarian planner still prefers the young-first scheme. However, the results for overall death rates flip. The old-first program now exhibits a lower aggregate death rate compared with the young-first scenario. Though vaccinating the larger group of the young first may prevent more infectious variants to emerge, this added infectiousness is particularly harmful to the old. So, if the objective is to decrease the overall

Table 2: Scenario With Variants

	No vaccines		With vaccines		
	Benchmark	Epidem.	Random	Old first	Young first
Wks to peak srsly ill (yng)	26.00	11.00	28.00	28.00	28.00
Wks to peak srsly ill (old)	25.00	11.00	28.00	27.00	29.00
Srsly ill p/ 1,000 @ peak (yng)	2.61	17.49	1.12	1.31	1.03
Srsly ill p/ 1,000 @ peak (old)	0.33	16.74	0.24	0.24	0.24
Dead p/ 1,000 1year (yng)	2.41	4.58	1.38	1.55	1.30
Dead p/ 1,000 1year (old)	5.27	42.71	4.13	3.69	4.22
Dead p/ 1,000 1year (all)	3.02	12.74	1.97	2.01	1.92
Dead p/ 1,000 LR (yng)	3.49	4.58	1.96	2.25	1.78
Dead p/ 1,000 LR (old)	11.65	42.71	6.35	4.32	7.21
Dead p/ 1,000 LR (all)	5.24	12.74	2.90	2.69	2.94
Immune in LR (yng), %	73.97	96.66	99.80	99.78	99.82
Immune in LR (old), %	17.19	59.62	86.27	86.45	86.19
Immune in LR (all), %	61.82	88.74	96.91	96.92	96.90
GDP at peak - rel to BM	1.00	1.26	1.03	1.02	1.02
GDP 1year - rel to BM	1.00	1.11	0.97	0.96	0.97
Hrs @ home (yng) - peak	88.93	57.97	85.19	86.19	86.22
Hrs @ home (old) - peak	109.95	88.99	107.40	108.34	107.13
Hrs @ home (yng) - 6m	93.75	57.97	88.03	89.11	87.47
Hrs @ home (old) - 6m	110.08	88.99	107.77	108.63	107.30
Value - healthy (yng)	9464.48	9458.21	9477.89	9474.36	9479.90
Value - healthy (old)	4289.49	4187.64	4326.23	4338.56	4322.03
Value - healthy (all)	8357.03	8330.31	8375.44	8375.30	8376.11

number of deaths, with variants, it is better to vaccinate and protect the old first.

References

- Brotherhood, Luiz, Philipp Kircher, Cezar Santos, and Michèle Tertilt.** 2021. "An economic model of the Covid-19 pandemic with young and old agents: Behavior, testing and policies." Working paper.
- Eichenbaum, Martin S, Sergio Rebelo, and Mathias Trabandt.** 2021. "The Macroeconomics of Epidemics." *The Review of Financial Studies*, 34(11): 5149–5187.
- Farboodi, Maryam, Gregor Jarosch, and Robert Shimer.** 2021. "Internal and external effects of social distancing in a pandemic." *Journal of Economic Theory*, 196: 105293.

- Glover, Andrew, Jonathan Heathcote, Dirk Krueger, and Jose-Victor Rios-Rull.** 2021a. "Health versus Wealth: On the Distributional Effects of Controlling a Pandemic." CEPR Discussion Paper DP14606.
- Glover, Andrew, Jonathan Heathcote, Dirk Krueger, and Jose-Victor Rios-Rull.** 2021b. "Optimal Age-Based Vaccination and Economic Mitigation Policies for the Second Phase of the Covid-19 Pandemic." *Journal of Economic Dynamics and Control*, this volume.
- Greenwood, Jeremy, Philipp Kircher, Cezar Santos, and Michèle Tertilt.** 2019. "An Equilibrium Model of the African HIV/AIDS Epidemic." *Econometrica*, 87(4): 1081–1113.
- Hallas, Laura, Ariq Hatibie, Rachelle Koch, Saptarshi Majumdar, Monika Pyarali, Andrew Wood, and Thomas Hale.** 2021. "Variation in US states' COVID-19 policy responses." Blavatnik School of Government, University of Oxford BSG-WP-2020/034, Version 3.0.
- Kremer, Michael.** 1996. "Integrating Behavioral Choice into Epidemiological Models of AIDS." *The Quarterly Journal of Economics*, 111(2): 549–573.