

Replication Package for: Optimal Age-based Policies for Pandemics: An Economic Analysis of Covid-19 and Beyond

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Notes

This package corresponds to the version of the paper published in the Review of Economic Studies.

All tables and figures in the manuscript can be replicated using this package.

The root folder contains MATLAB scripts used to generate the tables and figures in the paper. The folder “functions” contains auxiliary scripts called by the main routines.

All outputs are saved in the folder “out.” Figures are saved as `pdf` files, while tables are saved as `xlsx` files.

The code was replicated using MATLAB 2024b.

The only required MATLAB toolbox is the Optimization Toolbox. MATLAB version R2019a or later is required due to the use of the `readcell` function.

How to run the replication

1. Open MATLAB and set the root folder as the working directory
2. Run the script `master.m`
3. This will generate all tables and figures in sequence

The script `master.m` takes less than 10 minutes on a standard machine.

This replication package includes the optimal policy solutions used in the paper. The scripts therefore generate the published tables and figures directly from the stored policy paths. Researchers interested in reproducing the optimization procedure itself can use the

routines described in the section “Notes on optimal policies” below, which solve the policy problems from scratch.

Individual tables/figures can be generated by running the corresponding scripts:

Script	Table(s) and/or Figure(s)
Figure_1_2_3_4.m	Figures 1, 2, 3, 4
Figure_5a.m	Figure 5(a)
Figure_5b_6b.m	Figures 5(b), 6(b)
Figure_6a.m	Figure 6(a)
Table_1_2.m	Tables 1, 2
Table_3.m	Table 3
Table_4.m	Table 4
Table_5.m	Table 5
Table_6.m	Table 6
Table_7.m	Table 7
Table_8_B11_Figure_7.m	Table 8, Table B11, Figure 7
Table_9.m	Table 9
Table_10.m	Table 10
Table_11.m	Table 11
Table_12_13_Part_A.m	Tables 12 and 13 (Part A)
Table_12_13_Part_B_Table_14.m	Tables 12 and 13 (Part B), Table 14
Table_15.m	Table 15
Table_16.m	Table 16
Table_B1.m	Table B1
Table_B2.m	Table B2
Table_B3.m	Table B3
Table_B4.m	Table B4
Table_B5.m	Table B5
Table_B6.m	Table B6
Table_B7.m	Table B7
Table_B8.m	Table B8
Table_B9.m	Table B9
Table_B10.m	Table B10
Table_C12.m	Table C12
Table_C13.m	Table C13
Table_D14.m	Table D14
Table_F15.m	Table F15

Excel files

The MATLAB code uses Excel files as inputs for certain data, such as model parameters and time series used in the simulations.

`data_in.xlsx`: contains data used in the simulations, including weekly Covid-19 testing data used in the general equilibrium model and statistics used to compare the model to the data.

`parameters.xlsx`: contains alternative model calibrations, including those for Covid-19, the Spanish flu, and synthetic diseases.

`taus.xlsx`: contains lockdown tax vectors used as inputs in the simulations. Rows store a time path of taxes for young and old agents. These taxes are the policy instruments denoted by τ in the paper and should be interpreted as wedges that reduce outside/social activity. Values are bounded between 0 and 1, with higher values corresponding to stricter lockdowns. The file includes both optimal and non-optimal policy paths. For example, "covid_optimal_lowtol" corresponds to the optimal policy under the benchmark Covid-19 calibration, "covid_benchmark_lowtol" corresponds to the calibrated U.S. lockdown policy used as the benchmark comparison.

Data Availability Statement

Data used in this project are included in the replication package in `data_in.xlsx`. The file contains the processed series used by the MATLAB code; the sheet "sources" documents the source associated with each variable. The original public sources are listed below so that readers can obtain the underlying data directly. The sources are publicly available online without monetary cost. No confidential, proprietary, or restricted-use data are required to replicate the tables and figures.

The variables in `parameters.xlsx` and the policy paths in `taus.xlsx` are model inputs and computed policy vectors used by the simulations. They are included in the replication package and do not require access to additional external datasets.

The list below reports variable names in `data_in.xlsx`, together with a brief description of each variable and the corresponding data sources used in their construction.

- **young_death_rate and old_death_rate.** Provisional COVID-19 deaths by week, sex, and age. Public data are available from the CDC data portal at <https://data.cdc.gov/NCHS/Provisional-COVID-19-Deaths-by-Week-Sex-and-Age/vsak-wrfu>. In-text citation: National Center for Health Statistics (2026).
- **stringencyindexSTATE_TOTAL.** COVID-19 Stringency Index description and data documentation from Our World in Data. Public information is available at <http://ourworldindata.org/covid-stringency-index>. In-text citation: Roser (2021).

- **residential_percent_change_from_**. Google COVID-19 Community Mobility Reports. Public archived reports are available at <https://www.google.com/covid19/mobility/>. In-text citation: Google LLC (2022).
- **emp**. Track the Recovery employment series. Public data and documentation are available at <https://tracktherecovery.org/>. In-text citation: Opportunity Insights (2026).
- **emp_bls**. Employment-Population Ratio, series LNS12300000, retrieved through FRED, Federal Reserve Bank of St. Louis. Public data are available at <https://fred.stlouisfed.org/series/EMRATIO>. In-text citation: U.S. Bureau of Labor Statistics (2026a).
- **tests_frac_pop**. Daily tests per thousand people, 7-day smoothed. Public data and documentation are available at <http://ourworldindata.org/coronavirus-testing>. In-text citation: Our World in Data (2022).
- **positive_rate**. Positive test rate from WHO COVID-19 Dashboard and Our World in Data COVID-19 testing data. Public data and documentation are available at <http://ourworldindata.org/coronavirus-testing>. In-text citation: World Health Organization (2026) and Our World in Data (2022).
- **life_expectancy**. Social Security Actuarial Life Table, combined with U.S. Census population age groups. Public data are available at <https://www.ssa.gov/oact/STATS/table4c6.html> and <https://www2.census.gov/programs-surveys/popest/tables/2010-2018/national/asrh/PEPAGESEX.pdf>. In-text citation: Social Security Administration (2019) and U.S. Census Bureau (2018).
- **time_outside**. American Time Use Survey table A-1 for 2018, with retrieval through the BLS data portal. Public data are available at <https://www.bls.gov/tus/tables/a1-2018.pdf> and <https://data.bls.gov/cgi-bin/srgate>. In-text citation: U.S. Bureau of Labor Statistics (2018).
- **consumption_outside**. Consumer Expenditure Survey table 1300 for 2018. Public data are available at <https://www.bls.gov/cex/tables/calendar-year/mean-item-share-average-standard-error/reference-person-age-ranges-2018.pdf>. In-text citation: U.S. Bureau of Labor Statistics (2020).
- **CFR_covid**. CDC COVID-19 Pandemic Planning Scenarios, combined with U.S. Census population age groups. Public data are available at <https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html> and

[2018/national/asrh/PEPAGESEX.pdf](#). In-text citation: Centers for Disease Control and Prevention (2021) and U.S. Census Bureau (2018).

- **icu_time.** Published article estimating health care worker time with ICU patients. The article is available at <https://doi.org/10.1016/j.amjmed.2018.03.015>. In-text citation: Butler et al. (2018).
- **atus_2020.** American Time Use Survey data for 2019 and 2020. Public data and documentation are available at <https://www.bls.gov/tus/>. In-text citation: U.S. Bureau of Labor Statistics (2021).

In addition to the data sources listed above, the following sources are used for specific calibration exercises and auxiliary inputs:

- **Maddison Project Database 2020.** These data are used to calibrate historical U.S. income in the Spanish flu counterfactual. Specifically, the U.S. per capita GDP in 1917 relative to 2018 is used to set the wage parameter in that calibration. In-text citation: Groningen Growth and Development Centre (2020).
- **Oxford COVID-19 Government Response Tracker.** These data are used in the testing-capacity calibration. Daily tests performed in the United States in 2020 are aggregated to weekly frequency and used to discipline the build-up of testing capacity. In-text citation: Oxford COVID-19 Government Response Tracker (2020).
- **U.S. Department of Health and Human Services COVID-19 testing expenditures.** These data are used to discipline the investment cost of expanding testing capacity. The calibration uses the reported 2020 HHS spending on COVID-19 testing capacity and related testing expenses. In-text citation: U.S. Department of Health and Human Services (2020).
- **Health System Tracker COVID-19 testing prices.** These data are used to discipline the marginal cost of administering a COVID-19 test. The calibration uses the lower part of the reported price distribution, specifically a value around the 25th percentile. In-text citation: Health System Tracker (2020).

Rights

I/We certify that the author(s) of the manuscript have legitimate access to and permission to use the data used in this manuscript.

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Notes on optimal policies

The optimization problem is highly non-linear and may converge to different local optima depending on the starting values. For this reason, the procedure uses multiple starting points and alternating optimization steps.

We describe below the procedure used to obtain optimal lockdown policies, which may vary by age but does not depend on agents' health status. For simplicity, we present the algorithm for computing the optimal lockdown policy while holding testing-related variables fixed. Most of the optimal policies analyzed in the paper are of this type. However, the paper also considers policies that jointly optimize over testing variables, as well as policies in which lockdown taxation can depend not only on age but also on agents' health status.

The objective function in this optimization problem is the expected utility of young and old agents in the initial period. At $t=0$, there are susceptible and infected agents, but no hospitalized or recovered individuals.

The optimization is carried out using the `fmincon` algorithm.

Step	G.e. tolerance	Initial guess	Choice variables
1	High (1e-4)	Flat optimal	Young and old
2	High (1e-4)	Solution from step 1	Old
3	High (1e-4)	Solution from step 2	Young and old
4	High (1e-4)	Optimal benchmark Covid-19 lockdown policy	Young and old
5	High (1e-4)	Solution from step 4	Old
6	High (1e-4)	Solution from step 5	Young and old
7	Low (1e-6)	Best of {Step 3 solution, Step 6 solution}	Young and old
8	Low (1e-6)	Solution from step 7	Old
9	Low (1e-6)	Solution from step 8	Young and old

The procedure for computing the optimal policy can be divided into three main blocks (steps 1–3, 4–6, and 7–9).

In steps 1–3, the optimization algorithm starts from an initial guess that we refer to as the “flat optimal” policy (described below) and chooses time-varying lockdown taxes for both young and old agents. Once the algorithm converges to a candidate optimal policy, we restart the optimization from that candidate but restrict the choice to the tax vector for old agents only (step 2). This is motivated by the fact that the fraction of old agents in the economy is small, so changes in their tax vector have only a limited numerical impact on the objective function (relative to changes in the taxes of young agents). The purpose of step 2 (and, more generally, steps 2, 5, and 8) is therefore to make the objective function more responsive to variations in the tax vector of old agents. Finally, after convergence, the algorithm is restarted from the policy obtained in step 2, allowing for the joint choice of lockdown taxes for both young and old agents.

Steps 4–6 replicate steps 1–3, with the only difference being the initial guess. In steps 4–6, the initial guess is the optimal policy computed under the benchmark Covid-19 calibration. Naturally, the optimal policy for the benchmark Covid-19 calibration does not involve steps 4–6, since these steps rely on using the benchmark optimal policy itself as the starting point.

Finally, steps 7–9 use a tighter convergence tolerance for the general equilibrium and take as the initial guess the best policy obtained from steps 1–3 and 4–6.

The “flat optimal” initial guess is obtained by maximizing the objective function while allowing lockdown taxes to differ across young and old agents, but remain constant over time. That is, this problem involves choosing only two values (one tax for young agents and one for old agents, both fixed over time) to maximize the objective. The initial guess is [0.5, 0.5].

The objective function is the same across all steps, regardless of whether the choice variables are restricted to old agents or not.

Lockdown taxes are allowed to vary over time. To reduce computational costs, we allow taxes to vary weekly over half of the time horizon plus two additional months. After this period, taxes can adjust every two weeks.

For agents who test positive, the applicable tax is the maximum between the calibrated isolation parameter (denoted by $\bar{\tau}_i$ in the paper) and the lockdown tax chosen by the optimization algorithm.

The file `optimal_lockdown.m` contains an example of an optimal policy search that generates the benchmark optimal lockdown policy (plotted in Figure 5(a)) starting from step 7. This script takes between one and two days to converge.

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