Online Supplement for the analysis reported in:

“Quantifying COVID-19 Endgame: Is a New Normal within Reach?”

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All models and data are available at:
https://osf.io/t47eq/?view_only=6315e8a435054f08810c2659c717ed79

S1. Data Sources for Calibration

The primary data for calibration includes daily Infections and Deaths, which we match for each country in the sample, and excess deaths from the beginning of the pandemic until the calibration date. We also use daily test and vaccination data as an input into the model. The case, death, and test data are downloaded from Our World in Data platform’s portal for COVID-19: https://ourworldindata.org/coronavirus

The pre-processing conducted on the data is discussed in detail in the supplement to a previous paper (Rahmandad, Lim and Sterman 2021).

For the excess mortality data (and its uncertainty) we use estimates from The Economist Magazine, available through a github platform they created (Solstad 2022).

S2. A Note On Estimating Parameter Uncertainty

In principle, the use of a formal likelihood function enables the quantification of credible regions for the estimated parameters using Markov Chain Monte Carlo (MCMC) methods. However, two issues limited our ability to provide reliable credible intervals for the parameters. First, the large parameter space (with >2000 estimated parameters) and slow simulation time (a few seconds per simulation) make MCMC computationally challenging. Second, even if computationally feasible, we were not convinced of the reliability of the results. MCMC methods explore the parameter space and accept or reject different vectors of parameters based on the resulting value of the log-likelihood payoff function. If the log-likelihood for a given set of alternative parameter values falls notably, that parameter combination is more likely to be rejected; if the payoff improves, the parameter combination is accepted. However, we find that the resulting credible regions for the parameters that are shared across countries are unrealistically narrow. Specifically, even very small deviations in important parameters from the likelihood-maximizing value significantly lower the log likelihood. These parameters include those affecting the payoff across countries, such as the impact of Omicron on severity or transmission. The result is that MCMC rejects most alternative parameter settings even if they offer qualitatively reasonable fits to the data. Technically the problem may arise in part because the negative binomial likelihood function we use assumes that the error terms are uncorrelated, increasing the impact of each datapoint even if the error in matching that point is highly correlated with success in matching the next datapoint. With over a hundred thousand data points across nations, even small variations in parameters change the resulting likelihood function significantly. However, we are not aware of any simple workaround to address this problem with a negative binomial likelihood function. Based on both these considerations we do not report confidence intervals for the estimated parameters. This is a notable limitation of the reported results. Instead, we rely on the projection uncertainties accounted for by the state-resetting heuristic to inform other uncertainties in the results.
S3. Figure 3 panel A

Given the small size of the Panel A of Figure 3 in the main paper, we replicate that panel with higher resolution here for those interested to see country-level death projections more closely.

![Figure S3](image)

Figure S3-Cumulative deaths (and 90% confidence intervals) per million by the end of 2023, assuming historical responsiveness (base case; red dots) and full relaxation of all NPIs starting in mid 2022 (black dots).

S4. Replication Instructions

The analysis reported in the paper is conducted primarily using the Vensim™ model “CovidGlobal-Disaggregate-V76.mdl”. This file, and all the data and parameter input files needed for running simulations with it are available in the “Primary Model” folder. Also included with this supplement is the SDM-DOC documentation of the model (see “CovidGlobal-Disaggregate-V76_English.zip”). To conduct the baseline simulation you can run the model with the following settings:

- The following “.vdf” files should be loaded as data sources:
  - CovidModelInputs - TestData.vdf (Daily test rate data)
- CovidModelInputs - ConstantData.vdf (Various country-specific parameters such as population and hospital capacity, as well as excess mortality data)
- CovidModelInputs - CRW.vdf (Weather effects for different countries from (Xu, Rahmandad et al. 2021))
- CovidModelInputs - FlowData.vdf (Data on daily case, death, and vaccination rates)
- CovidModelInputs - FormattedData.vdf (cumulative data on cases and deaths)

The following “.out” files should be loaded to read the correct parameter settings for a baseline simulation:

- Optim-220419-4.out: This is the primary result of the calibration, and includes all the estimated parameters for the main model.
- Opt7.out: Sets the process noise parameters needed for generating noisy projections consistent with past state-resetting results
- VariantIntroOmicron.out: Sets the introduction time for the Omicron variant in different countries for which this data could be found, based on statistics reported on covariants.org website.
- V1-Optim.cin: This file includes maximum vaccination adoption rates estimated for different countries based on the generalized logistic fit to country level data.

Conducting the primary calibration would be feasible by using the following optimization command files:

- COVID-V76-Update.voc: The optimization control file that includes the estimated parameters and optimization settings. Note that starting this optimization from a random point in parameters space is inefficient and may not lead to the current results given the large parameter space and potential ruggedness in parts of that space. We have been using “.out” files from the previous calibration over time as the starting point.
- PayoffFlowV76-Policy.vpd: Optimization payoff needed for calibration

Besides the primary model, two additional models were used to generate the inputs utilized. Specifically, the model, data, and optimization files included in the “ProcessNoise” folder were used to generate the “Opt7.out”, which is then read into the primary model to generate process noise for projections consistent with historical process noise (which plays the primary role in state resetting as well; see the discussion in the manuscript). Replicate the analysis by using the optimization control and payoff files included in the “ProcessNoise” folder along with the “GenProcessNoise.mdl” (note that “V76-DataForProcessNoise.vdf” is the data file needed for conducting the calibration).

The second auxiliary analysis is required to estimate maximum vaccination rates in each country using a generalized logistic curve. The needed files are found in the “VaccineCurves” folder, where conducting an optimization using the “.voc” and “.vpd” files in the folder (along with the data in the .vdf files) will replicate the estimation of desired outputs (which will then be used as input in the primary analysis; that input is “V1-Optim.cin”).

Finally, conducting the complete analysis and replicating the graphs would require 17 simulations and 6 sensitivity analyses, followed by exporting of the Vensim data and creating various graphs and tables. These steps were automated and completed using a Matlab function, “MakeGraphsV76.m”, available under the folder “MatlabFiles”, along with various functions called within the script. You will need to set the correct directory for running the analysis, as well as where Vensim DSS is available on your computer, before you can conduct this analysis using the Matlab code. We also include two “.cmd” files that are generated in the process of automated analysis in the “ExampleCommandFiles” under the “Primary Model” folder.
**Estimated Parameters**

The parameter estimates for different countries are found in the file “Optim-220419-4.out”, under the Primary Model folder.

**References**

Rahmandad, H., T. Y. Lim and J. Sterman (2021). "Behavioral Dynamics of COVID-19: Estimating Under-Reporting, Multiple Waves, and Adherence Fatigue Across 92 Nations." System Dynamics Review 37(1): 5-31.

Solstad, S. U. (2022). "The Economist Global Excess Deaths Model." from https://github.com/TheEconomist/covid-19-the-economist-global-excess-deaths-model.

Xu, R., H. Rahmandad, M. Gupta, C. DiGennaro, N. GhaFFarZadegan, H. Amini and M. S. Jalali (2021). "Weather, air pollution, and SARS-CoV-2 transmission: a global analysis." The Lancet Planetary Health 5(10): e671-e680.