Agent-Based SARS-CoV-2 Simulation Model

Parametrisation and Calibration *Feb2023*

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Abstract

With the official end of the COVID-19 crisis in Austria, the Agent-Based SARS-CoV-2 Simulation Model was freshly calibrated to real Austrian data one list time in February 2023. This parametrisation and calibration process, henceforth called *Feb2023*, was intended to provide a precise virtual representation of the time-frame between Jan 2020 and Dec 2022 using the most recently available data, causal information, parameter information and model version to run retrospective what-if (rather what-would-have-been) scenarios.

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1 Introduction

With the official end of the COVID-19 crisis in Austria, the Agent-Based SARS-CoV-2 Simulation Model was freshly calibrated to real Austrian data one list time in February 2023. This parametrisation and calibration process, henceforth called *Feb2023*, was intended to provide a precise virtual representation of the time-frame between Jan 2020 and Dec 2022 using the

- most recently available data, including epidemics, vaccination, population and variant data,
- most recent causal system information, such as immunity waning and cross-immunity,
- most recent parameter estimates, in particular duration for specific disease phases, and
- most recent model version,

to run retrospective what-if (rather what-would-have-been) scenarios.

This gave us the opportunity to reflect on previously applied parametrisation and calibration strategies and improve the processes. In this work we describe the *Feb2023* parameter setup and how precisely it was found using the algorithms defined in sections 1.3.3 and 1.3.4 https://www.dwh.at/projects/covid-19/Covid19_Model-20230322.pdf.

2 Parametrisation Goal and Metric

Goal of the calibration process is to fit the simulated daily new confirmed SARS-CoV-2 cases in the simulation model with the corresponding cases in the Epidemiologischem Meldesystem EMS [5], as of state 2023-02-01, in the time-frame between t_0=2020-01-01 to t_{end} = 2022-12-31. With decreasing priority, the numbers must fit

1. in total,
2. per federal-state,
3. per variant,
4. per age,
5. per variant and federal-state,
6. per age and federal-state, and
7. per age, federal-state and variant.

Only the for the first two we will actually implement a validation metric. Let $X(t,r)$ stand for the new confirmed cases in the reporting system for date t and federalstate r, and $\hat{X}(t,r)$ be the simulated counterpart, then

$$E(r) = \sqrt{\frac{1}{t_{end}-t_0}\sum_{t=t_0}^{t_{end}}\Big(SMA_7(\hat{X})(t,r) - SMA_7(X)(t,r)\Big)^2}. \tag{1}$$

Hereby, SMA_7 stands for the simple-moving-average with 7-day horizon. For targets 3. - 7. we do not consider a fixed metric but perform calibration visually. This is feasible since the importance of the fit regards any of these factors is differently relevant in different situations. For example, fit of variant specific cases is highly

Table 1: Variant introduction and takeover in Austria collected from national sequencing information and GISAID data [6].

variant	5% of cases ($t_i^{0.05}$)	50% of cases ($t_i^{0.5}$)
Alpha	2020-12-20	2021-02-03
Delta	2021-06-01	2021-06-23
BA.1	2021-12-16	2022-01-02
BA.2	2022-02-08	2022-02-27
BA.5	2022-06-04	2022-06-18
BQ1	2022-10-06	2023-01-01
XBB15	2022-12-25	2023-02-19

important whenever a new variant takes over, but is rather irrelevant in between. Age specific fits are heavily important for the system dynamics at the start of pandemic waves, but are less relevant in between waves.

For the variants we consider the main eight variants of concern (VoC) which shaped the epidemic landscape of Austria: Wildtype (all variants before VoC), Alpha, Delta, and the Omicron lineages BA.1, BA.2, BA.5, BQ1, and XBB15. Since variant information in the EMS system is highly incomplete, a time-dependent 8-dimensional ratio-vector $\vec{r}(t)$ with $\sum \vec{r}(t) = 1$ is multiplied with the daily reported cases (per federalstate, per age) to get the cases per variant.

Since officially reported time-series are fuzzy and heavily biased, the vector time-series is generated from meta information related to relevenat points in time: We define t_i^c as the first point in time at which the ratio of cases with the variant related to index i is equal or greater than $100c\%$. Values for $t_i^{0.05}$ and $t_i^{0.5}$ are collected from national sequencing information and GISAID data [6], see Table 1. All further values are calculated via logistic takeover curves:

$$f_i : \mathbb{R} \to [0,1] : t \mapsto \frac{1}{1 + \exp\left(\log\left(\frac{0.05}{1-0.05}\right) \frac{t - t_i^{0.5}}{t_i^{0.5} - t_i^{0.05}}\right)}, \tag{2}$$

and

$$\vec{R}_i(t) := f_i(t) - f_{i+1}(t), \quad \vec{r}(t) = \vec{R}^0(t). \tag{3}$$

This idea is taken from [4] in which variant takeover curves are fitted with logistic regression. A visualisation of variant curves and corresponding calculated confirmed cases per variant are displayed in Figure 1.

3 Calibration Result

The result of the process is displayed in Figures x-xx. Note that the time-line of the parametrisation of *Feb2023* (see Section 4) does not contain any events changing the value of β_{ex}. That means, the fit can be interpreted as rough and could be further fine tuned by adding these events systematically.

4 Parameters

We furthermore state all model parameters and parameter values used for *Feb2023*. We hereby differentiate between static parameters, i.e. parameters which do not change with time, and time-dependent parameters, i.e. parameters which are specific for a certain time-interval. Note that we do not distinguish between a changing parameter value or an introduced policy, since both are considered to be time-dependent and, technically, both would be part of the event-timeline of the model.

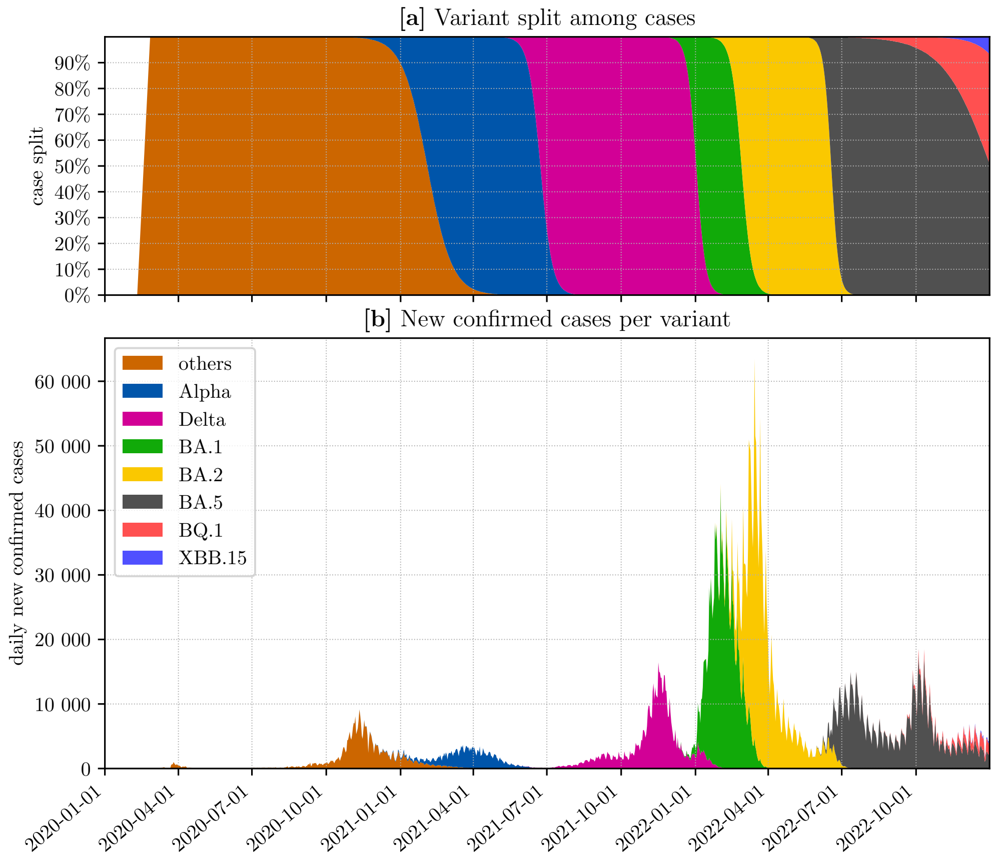

Figure 1: Variant split [a] and corresponding case numbers [b] between Jan 2020 and Dec 2023

4.1 Static Parameters

The static parameters and their values are already fully documented in https://www.dwh.at/projects/covid-19/Covid19_Model-20230322.pdf. Therefore we refer to the parameter tables 3 to 9 in Section 1.3.3.

4.2 Time-Dependent Parameters (Event Timeline)

All parameters changing with time are included into the model's time-line. Calibration of it poses the fundamental task of the calibration *Feb2023*. We furthermore present te calibrated values in a list format. This list includes all events which occur in the course of one simulation between 2023-01-01 and 2023-12-31 including their parametrisation. The colours indicate the event type. Blue events change the import model meaning that either number or strain (distribution) of imported cases is changed. White events target the TTI system meaning that either number of screening tests, detection rates w.r. to symptomatic tests, or quarantine settings are changed. Red events lead to closure or opening of locations such as schools or workplaces. Finally, green events indicate a change of transmissibility or contacts.
A small d (direct) or c (calibrated) in rectangular brackets after a parameter or date indicates that the value was either set directly (a-priori) or was calibrated using a Bisection strategy. The latter primarily but not exclusively refers to the parameter values of the "setLeisureTimeContactReduction" and the dates of the "changeImportModel" events. Directly set parameters are either computed from related data sources (see Section 5) or are directly taken from print- and television media collected over the course of the three years.

2020-02-10 [c], changeImportModel

importFactor := 9e-05 [c] strains := (before VoC) [d] ageSpan := (20,40) [d]	Start regularly introducing cases from Feb 02 results in the measured upswing of detected cases. Factor of 9e-05 provides a stable situation over Summer 2020 on the observed case level.

2020-02-10 [c], changeTestModel

detectionProbabilities/10 := 0.0555555555555556 [d] detectionProbabilities/20 := 0.0555555555555556 [d] detectionProbabilities/30 := 0.222222222222222 [d] detectionProbabilities/40 := 0.222222222222222 [d] detectionProbabilities/50 := 0.222222222222222 [d] detectionProbabilities/60 := 0.333333333333333 [d] detectionProbabilities/70 := 0.444444444444445 [d] detectionProbabilities/80 := 0.555555555555556 [d] detectionProbabilities/90 := 0.666666666666667 [d] detectionProbabilities/200 := 0.777777777777778 [d] positiveTestQuarantineDuration := 14	Initialised for detection rate of 19.5%, see Section 5.1

2020-03-01 [d], changeImportModel

importFactor := 0.00018 [d]	Numbers in the tourism file all come from the first half of march. So we double the original import scaling-factor (0.00009) for the first half and set to zero afterwards.

2020-03-14 [d], setClosed

location := SCHOOL [d] above14 := 1.0 [d] below14 := 1.0 [d]	1st Lockdown: all schools closed

2020-03-15 [d], changeImportModel

importFactor := 0.0 [d]	Tourism zero due to lockdown

2020-03-16 [d], setClosed

location := WORKPLACE [d] fraction := 0.68 [d]	1st Lockdown; Ratio for closed workplaces (0.68) from data.

2020-03-16 [d], setBetaLoc

values/WORKPLACE := 0.3 [d] values/CAREHOME := 0.3 [d] values/SCHOOL := 0.4 [d] values/LEISURETIME := 0.6 [d]	β_{loc}-level: hardest lockdown

2020-03-16 [d], setLeisuretimeContactReduction

reduction := (0.75,0.75,0.75,0.75,0.75) [c]	1st lockdown. Values calibrated to curve.

2020-04-14 [d], setPreventiveQuarantine

location := HOUSEHOLD [d] quarantineDuration := 14 [d] delay := 2 [d]	Household members need to go into quarantine too. Date is estimated.

2020-04-16 [d], setClosed

location := WORKPLACE [d] fraction := 0.5 [d]	Tailor shops and small stores reopen. Ratio estimated from worekplace distribution.

2020-05-01 [d], setClosed

location := WORKPLACE [d] fraction := 0.2 [d]	All stores open, home-office remains. Ratio estimated from workplace distribution.

2020-05-01 [d], setPreventiveQuarantine

active := True [d] quarantineDuration := 14 [d] delay := 2 [d] location := TRACING [d] trackedDays := 7 [d] rate := 0.85 [d]	First useful contact tracing established. Initialisation date is estimated.

2020-05-01 [d], changeImportModel

importFactor := 9e-05 [d]	Back to normal import rate.

2020-05-04 [d], setClosed

location := SCHOOL [d] above14 := 0.75 [d] below14 := 1.0 [d]	Matura classes (about 1/4th of all classes) reopen

2020-05-04 [d], setBetaLoc

values/WORKPLACE := 0.75 [d] values/CAREHOME := 0.65 [d] values/SCHOOL := 0.85 [d] values/LEISURETIME := 0.85 [d]	β_{loc}-level: general increased awareness. See Section 4.3

2020-05-04 [d], setLeisuretimeContactReduction

reduction := (0.27,0.27,0.27,0.32,0.32) [d]	End of 1st lockdown

2020-05-15 [d], setClosed

above14 := 0.75 [d] below14 := 0.0 [d] location := SCHOOL [d]	Schools below 14 reopen

2020-05-29 [d], setClosed

above14 := 0.0 [d] below14 := 0.0 [d] location := SCHOOL [d]	All school classes reopen

2020-06-01 [d], setReactiontimeDistribution

value := (1.3,2.9) [d]	Increased awareness, see Section 5.2.

2020-07-01 [d], setBetaLoc

values/LEISURETIME := 0.95 [d]	β_{loc}-level: general increased awareness + summer holidays. See Section 4.3

2020-07-01 [d], setLeisuretimeContactReduction

reduction := (0.16,0.16,0.16,0.26,0.26) [c]	Increased contacts over holidays

2020-08-01 [d], changeTestModel

positiveTestQuarantineDuration := 10 [d]	Quarantine length reduced to ten days.

2020-09-01 [d], changeTestModel

detectionProbabilities/10 := 0.0868421052631579 [d] detectionProbabilities/20 := 0.260526315789474 [d] detectionProbabilities/30 := 0.347368421052632 [d] detectionProbabilities/40 := 0.347368421052632 [d] detectionProbabilities/50 := 0.347368421052632 [d] detectionProbabilities/60 := 0.521052631578947 [d] detectionProbabilities/70 := 0.694736842105263 [d] detectionProbabilities/80 := 0.868421052631579 [d] detectionProbabilities/90 := 1.0 [d] detectionProbabilities/200 := 1.0 [d]	Detection rate increases to 35% due to higher availability of tests among pupils. See Section 5.1.

2020-09-07 [d], setBetaLoc

values/WORKPLACE := 0.8 [d] values/CAREHOME := 0.7 [d] values/SCHOOL := 0.9 [d] values/LEISURETIME := 0.9 [d]	β_{loc}-level: general awareness. See Section 4.3

2020-09-07 [d], setLeisuretimeContactReduction

reduction := (0.1,0.1,0.1,0.2,0.2) [c]	Many leisure time activities restart with school.

2020-09-17 [c], changeImportModel

strains := (Alpha) [d]	Date for changed import strain is calibrated to match the takeover process.

2020-10-10 [c], setPreventiveQuarantine

active := True [d] quarantineDuration := 14 [d] delay := 4 [d] location := TRACING [d] trackedDays := 7 [d] rate := 0.3 [d]	Contact tracing cannot keep up due to resource limits. Date is calibrated.

2020-11-02 [d], setLeisuretimeContactReduction

reduction := (0.55,0.55,0.55,0.6,0.6) [c]	Soft-lockdown

2020-11-02 [d], setBetaLoc

values/WORKPLACE := 0.6 [d] values/CAREHOME := 0.5 [d] values/SCHOOL := 0.75 [d] values/LEISURETIME := 0.8 [d]	β_{loc}-level: soft lockdown + face mask indoor. See Section 4.3

2020-11-17 [d], setClosed

location := SCHOOL [d] above14 := 1.0 [d] below14 := 1.0 [d]	2nd hard Lockdown, all schools closed

2020-11-17 [d], setBetaLoc

values/WORKPLACE := 0.5 [d]
values/CAREHOME := 0.4 [d]
values/SCHOOL := 0.65 [d]
values/LEISURETIME := 0.7 [d]

β_{loc}-level: hard lockdown + face mask indoor. See Section 4.3

2020-11-17 [d], setClosed

location := WORKPLACE [d]
fraction := 0.68 [d]

2nd hard Lockdown. Ratio for closed workplaces (0.68) from data.

2020-12-07 [d], setClosed

location := SCHOOL [d]
above14 := 0.25 [d]
below14 := 0.0 [d]

End of 2nd hard Lockdown. Matura-classes remain closed.

2020-12-07 [d], setClosed

location := WORKPLACE [d]
fraction := 0.14 [d]

End of 2nd hard Lockdown. All stores open, home-office remains. Ratio estimated from workplace distribution.

2020-12-12 [d], changeTestModel

ALL/testsPerDay/AT-1 := 36870 [d]
ALL/testsPerDay/AT-2 := 70088 [d]
ALL/testsPerDay/AT-3 := 211072 [d]
ALL/testsPerDay/AT-4 := 186768 [d]
ALL/testsPerDay/AT-5 := 69946 [d]
ALL/testsPerDay/AT-6 := 155945 [d]
ALL/testsPerDay/AT-7 := 95030 [d]
ALL/testsPerDay/AT-8 := 49850 [d]
ALL/testsPerDay/AT-9 := 241016 [d]
ALL/sensitivity := 0.2 [d]
ALL/interval := 1 [d]

Two days december mass-tests. Parameters so that 1/8 of pop is tested per day (fitted from EMS data)

2020-12-15 [d], changeTestModel

ALL/testsPerDay/AT-1 := 0 [d]
ALL/testsPerDay/AT-2 := 0 [d]
ALL/testsPerDay/AT-3 := 0 [d]
ALL/testsPerDay/AT-4 := 0 [d]
ALL/testsPerDay/AT-5 := 0 [d]
ALL/testsPerDay/AT-6 := 0 [d]
ALL/testsPerDay/AT-7 := 0 [d]
ALL/testsPerDay/AT-8 := 0 [d]
ALL/testsPerDay/AT-9 := 0 [d]
ALL/sensitivity := 0.2 [d]
ALL/interval := 1 [d]

End of mass tests

2020-12-23 [d], setBetaLoc

values/LEISURETIME := 0.8 [c]

Christmas

2020-12-23 [d], setLeisuretimeContactReduction

reduction := (0.4,0.4,0.4,0.4,0.4) [c] — Christmas

2020-12-23 [d], setBetaLoc

values/WORKPLACE := 0.65 [d]
values/CAREHOME := 0.55 [d]
values/SCHOOL := 0.8 [d]
values/LEISURETIME := 0.95 [d]

β_{loc}-level: general increased awareness + face mask indoor + holidays. See Section 4.3

2020-12-27 [d], setClosed

location := SCHOOL [d]
below14 := 1.0 [d]
above14 := 1.0 [d]

Return to hard lockdown

2020-12-27 [d], setBetaLoc

values/WORKPLACE := 0.5 [d]
values/CAREHOME := 0.4 [d]
values/SCHOOL := 0.65 [d]
values/LEISURETIME := 0.8 [d]

β_{loc}-level: hard lockdown + face mask indoor + holidays. See Section 4.3

2020-12-27 [d], setClosed

location := WORKPLACE [d]
fraction := 0.68 [d]

Return to hard lockdown

2021-01-02 [d], setLeisuretimeContactReduction

reduction := (0.45,0.45,0.45,0.45,0.45) [c] — Christmas and newyears-eve over

2021-01-02 [d], setBetaLoc

values/WORKPLACE := 0.5 [d]
values/CAREHOME := 0.4 [d]
values/SCHOOL := 0.65 [d]
values/LEISURETIME := 0.7 [d]

β_{loc}-level: hard lockdown + face mask indoor. See Section 4.3

2021-02-01 [d], setClosed

location := SCHOOL [d]
below14 := 0.0 [d]
above14 := 0.0 [d]

End of hard lockdown

2021-02-08 [d], setBetaLoc

values/WORKPLACE := 0.65 [d]
values/CAREHOME := 0.55 [d]
values/SCHOOL := 0.6 [d]
values/LEISURETIME := 0.85 [d]

β_{loc}-level: general increased awareness + face mask indoor + additional safety measures in schools. See Section 4.3

2021-02-08 [d], setClosed

location := WORKPLACE [d]
fraction := 0.28 [d]

End of hard lockdown. Restaurants still closed.

2021-02-08 [d], setLeisuretimeContactReduction

reduction := (0.35,0.35,0.35,0.35,0.35) [c]

End of hard lockdown

2021-02-16 [d], changeTestModel

SCHOOL/testsPerDay/AT-1 := 4992 [d]
SCHOOL/testsPerDay/AT-2 := 9975 [d]
SCHOOL/testsPerDay/AT-3 := 28973 [d]
SCHOOL/testsPerDay/AT-4 := 24417 [d]
SCHOOL/testsPerDay/AT-5 := 10969 [d]
SCHOOL/testsPerDay/AT-6 := 21431 [d]
SCHOOL/testsPerDay/AT-7 := 14123 [d]
SCHOOL/testsPerDay/AT-8 := 7884 [d]
SCHOOL/testsPerDay/AT-9 := 35463 [d]
SCHOOL/sensitivity := 0.19 [d]
SCHOOL/interval := 7 [d]

Start testing all pupils once a week. 19% sensitivity estimated from prior work.

2021-03-15 [c], changeImportModel

strains := (Delta) [d]

Date for changed import strain is calibrated to match the takeover process.

2021-04-01 [d], setClosed

location := WORKPLACE [d]
fraction := 0.68 [d]
regions := (AT-1,AT-3,AT-9) [d]

'Osterruhe' in some regions of Austria

2021-04-01 [d], setClosed

location := SCHOOL [d]
above14 := 1.0 [d]
below14 := 1.0 [d]
regions := (AT-1,AT-3,AT-9) [d]

'Osterruhe' in some regions of Austria

2021-04-01 [d], setLeisuretimeContactReduction

reduction := (0.7,0.7,0.7,0.7,0.7) [c]

Osterruhe implicitly/cognitively affects all federal states

2021-04-01 [d], setBetaLoc

values/WORKPLACE := 0.5 [d]
values/CAREHOME := 0.4 [d]
values/SCHOOL := 0.45 [d]
values/LEISURETIME := 0.7 [d]

β_{loc}-level: hard lockdown + face mask indoor + additional safety measures in schools. See Section 4.3

2021-04-26 [d], setClosed

location := SCHOOL [d]
above14 := 0.0 [d]
below14 := 0.0 [d]
regions := (AT-1,AT-3,AT-9) [d]

Osterruhe ends for schools

2021-04-26 [d], setBetaLoc

values/WORKPLACE := 0.65 [d]
values/CAREHOME := 0.55 [d]
values/SCHOOL := 0.6 [d]
values/LEISURETIME := 0.8 [d]

β_{loc}-level: general increased awareness + face mask indoor + 3G + additional safety measures in schools. See Section 4.3

2021-05-03 [d], setClosed

location := WORKPLACE [d]
fraction := 0.28 [d]
regions := (AT-1,AT-3,AT-9) [d]

Osterruhe ends, restaurants still closed.

2021-05-19 [d], setClosed

location := WORKPLACE [d]
fraction := 0.1 [d]

Restaurants reopen

2021-05-19 [d], setLeisuretimeContactReduction

reduction := (0.55,0.55,0.55,0.55,0.55) [c]

Restaurants reopen leads increased contacts in leisure time.

2021-05-19 [d], changeTestModel

ALL/testsPerDay/AT-1 := 5267 [d]
ALL/testsPerDay/AT-2 := 10013 [d]
ALL/testsPerDay/AT-3 := 30153 [d]
ALL/testsPerDay/AT-4 := 26681 [d]
ALL/testsPerDay/AT-5 := 9992 [d]
ALL/testsPerDay/AT-6 := 22278 [d]
ALL/testsPerDay/AT-7 := 13576 [d]
ALL/testsPerDay/AT-8 := 7121 [d]
ALL/testsPerDay/AT-9 := 68862 [d]
ALL/sensitivity := 0.25 [d]
ALL/interval := 1 [d]

Start testing persons due to 3G in restaurants. Parameters so that 1/8 of pop in AT-1 to AT-8, 1/4 of pop in AT-9 per week

2021-05-19 [d], setBetaLoc

values/WORKPLACE := 0.7 [d]
values/CAREHOME := 0.6 [d]
values/SCHOOL := 0.65 [d]
values/LEISURETIME := 0.85 [d]

β_{loc}-level: general awareness + face mask indoor + 3G + additional safety measures in schools. See Section 4.3

2021-07-01 [d], setLeisuretimeContactReduction

reduction := (0.1,0.1,0.1,0.2,0.2) [c]

Summer holidays

2021-07-01 [d], setBetaLoc

values/WORKPLACE := 0.8 [d]
values/CAREHOME := 0.7 [d]
values/SCHOOL := 0.95 [d]
values/LEISURETIME := 0.95 [d]

β_{loc}-level: reduced awareness + face mask indoor + holidays +3G

2021-07-22 [d], setLeisuretimeContactReduction

reduction := (0.05,0.05,0.05,0.15,0.15) [c]

Bars etc. reopen.

2021-08-01 [d], changeTestModel

detectionProbabilities/10 := 0.118421052631579 [d]
detectionProbabilities/20 := 0.355263157894737 [c]
detectionProbabilities/30 := 0.592105263157895 [c]
detectionProbabilities/40 := 0.592105263157895 [d]
detectionProbabilities/50 := 0.592105263157895 [c]
detectionProbabilities/60 := 0.710526315789474 [c]
detectionProbabilities/70 := 0.710526315789474 [d]
detectionProbabilities/80 := 0.828947368421053 [c]
detectionProbabilities/90 := 0.947368421052632 [c]
detectionProbabilities/200 := 0.947368421052632 [c]

Higher availability of tests leads to increased detection rate. An overall value of 45% was found useful to fit the Delta wave in a manual calibration round.

2021-09-01 [d], setReactiontimeDistribution

value := (1.43,2.59) [d]

Changed awareness, see Section 5.2

2021-09-01 [d], setBetaLoc

values/WORKPLACE := 0.7 [d]
values/CAREHOME := 0.6 [d]
values/SCHOOL := 0.8 [c]
values/LEISURETIME := 0.8 [c]

β_{loc}-level: general awareness + face mask indoor + 3G. See Section 4.3. Calibrated reduction (-0.05) for SCHOOL and LEISURETIME.

2021-09-13 [d], changeTestModel

SCHOOL/testsPerDay/AT-1 := 9984 [d]
SCHOOL/testsPerDay/AT-2 := 19949 [d]
SCHOOL/testsPerDay/AT-3 := 57947 [d]
SCHOOL/testsPerDay/AT-4 := 48834 [d]
SCHOOL/testsPerDay/AT-5 := 21937 [d]
SCHOOL/testsPerDay/AT-6 := 42862 [d]
SCHOOL/testsPerDay/AT-7 := 28246 [d]
SCHOOL/testsPerDay/AT-8 := 15769 [d]
SCHOOL/testsPerDay/AT-9 := 70926 [d]
SCHOOL/sensitivity := 0.19 [d]
SCHOOL/interval := 1 [d]

Start testing all pupils twice a week. Assumed 19% sensitivity, as before.

2021-10-29 [c], changeImportModel

strains := (BA.1) [d]	Date for changed import strain is calibrated to match the takeover process.

2021-11-01 [d], setReactiontimeDistribution

value := (1.53,1.99) [d]	Changed awareness, see Section 5.2

2021-11-22 [d], setClosed

location := WORKPLACE [d] fraction := 0.68 [d]	Delta lockdown. Fraction for closed workplaces estimated from distribution data.

2021-11-22 [d], setLeisuretimeContactReduction

reduction := (0.3,0.3,0.3,0.3,0.3) [c]	Delta lockdown.

2021-11-22 [d], setBetaLoc

values/WORKPLACE := 0.5 [d] values/CAREHOME := 0.4 [d] values/SCHOOL := 0.45 [d] values/LEISURETIME := 0.7 [d]	β_{loc}-level: hard lockdown + face mask indoor + additional safety measures in schools. See Section 4.3

2021-12-12 [d], setClosed

location := WORKPLACE [d] fraction := 0.1 [d]	Delta lockdown.

2021-12-12 [d], setLeisuretimeContactReduction

reduction := (0.2,0.2,0.2,0.2,0.2) [c]	Delta lockdown over.

2021-12-12 [d], setBetaLoc

values/WORKPLACE := 0.8 [d] values/CAREHOME := 0.7 [d] values/SCHOOL := 0.95 [d] values/LEISURETIME := 0.95 [d]	β_{loc}-level: reduced awareness + face mask indoor + 3G. See Section 4.3

2021-12-24 [d], setBetaLoc

values/WORKPLACE := 0.8 [d] values/CAREHOME := 0.7 [d] values/SCHOOL := 0.95 [d] values/LEISURETIME := 1.0 [d]	β_{loc}-level: reduced awareness + face mask indoor + 3G + holidays. See Section 4.3

2021-12-24 [d], setLeisuretimeContactReduction

reduction := (0.1,0.1,0.1,0.1,0.1) [c]	More contacts due to Christmas and Newyear

2021-12-29 [c], changeImportModel

strains := (BA.2) [d]

Date for changed import strain is calibrated to match the takeover process.

2022-01-01 [d], changeTestModel

detectionProbabilities/10 := 0.118421052631579 [d]
detectionProbabilities/20 := 0.355263157894737 [d]
detectionProbabilities/30 := 0.592105263157895 [d]
detectionProbabilities/40 := 0.592105263157895 [d]
detectionProbabilities/50 := 0.592105263157895 [d]
detectionProbabilities/60 := 0.710526315789474 [d]
detectionProbabilities/70 := 0.497368421052632 [c]
detectionProbabilities/80 := 0.497368421052632 [d]
detectionProbabilities/90 := 0.473684210526316 [D]
detectionProbabilities/200 := 0.378947368421053 [d]

Reduce detection rates for elderly. Still 45% detection rate in total. See Section 5.1.

2022-01-03 [d], setBetaLoc

values/WORKPLACE := 0.8 [d]
values/CAREHOME := 0.7 [d]
values/SCHOOL := 0.95 [d]
values/LEISURETIME := 0.95 [d]

β_{loc}-level: reduced awareness + face mask indoor + 3G. See Section 4.3

2022-01-03 [d], setLeisuretimeContactReduction

reduction := (0.2,0.2,0.2,0.3,0.3) [c]

Christmas and Newyear over

2022-01-08 [d], changeTestModel

positiveTestQuarantineDuration := 8 [d]

Quarantine length now 10 days with options to freitesten after day 5. Assume average of 8 days.

2022-01-18 [c], changeImportModel

strains := (BA.5) [d]

Date for changed import strain is calibrated to match the takeover process.

2022-02-15 [d], setLeisuretimeContactReduction

reduction := (0.1,0.1,0.1,0.2,0.2) [c]

Peak is reached, awareness reduced

2022-03-05 [d], setLeisuretimeContactReduction

reduction := (0.05,0.05,0.05,0.15,0.15) [c]

Lift many policies

2022-03-05 [d], setBetaLoc

values/WORKPLACE := 0.9 [d]
values/CAREHOME := 0.9 [d]
values/SCHOOL := 0.95 [d]
values/LEISURETIME := 1.0 [d]

β_{loc}-level: no awareness + face mask indoor. See Section 4.3

2022-03-25 [d], changeTestModel

positiveTestQuarantineDuration := 5 [d]	Quarantine length reduced to 5 for all persons (no freitesten anymore, neglect different policy in Vienna)

2022-04-01 [d], changeTestModel

ALL/testsPerDay/AT-1 := 2634 [d] ALL/testsPerDay/AT-2 := 5006 [d] ALL/testsPerDay/AT-3 := 15077 [d] ALL/testsPerDay/AT-4 := 13341 [d] ALL/testsPerDay/AT-5 := 4996 [d] ALL/testsPerDay/AT-6 := 11139 [d] ALL/testsPerDay/AT-7 := 6788 [d] ALL/testsPerDay/AT-8 := 3561 [d] ALL/testsPerDay/AT-9 := 17215 [d] ALL/sensitivity := 0.25 [d] ALL/interval := 1 [d]	Reduced tests per day. 1/16 of pop per week, 1/8 in AT-9

2022-04-01 [d], changeTestModel

detectionProbabilities/10 := 0.0855263157894737 [d] detectionProbabilities/20 := 0.256578947368421 [d] detectionProbabilities/30 := 0.427631578947368 [d] detectionProbabilities/40 := 0.427631578947368 [d] detectionProbabilities/50 := 0.427631578947368 [d] detectionProbabilities/60 := 0.513157894736842 [d] detectionProbabilities/70 := 0.359210526315789 [d] detectionProbabilities/80 := 0.359210526315789 [d] detectionProbabilities/90 := 0.342105263157895 [d] detectionProbabilities/200 := 0.273684210526316 [d]	Awareness decreases and detection rate drops to 32.5%. See Section 5.1

2022-04-15 [c], changeImportModel

strains := (BQ.1) [d]	Date for changed import strain is calibrated to match the takeover process.

2022-04-19 [d], changeTestModel

SCHOOL/testsPerDay/AT-1 := 4992 [d] SCHOOL/testsPerDay/AT-2 := 9975 [d] SCHOOL/testsPerDay/AT-3 := 28973 [d] SCHOOL/testsPerDay/AT-4 := 24417 [d] SCHOOL/testsPerDay/AT-5 := 10969 [d] SCHOOL/testsPerDay/AT-6 := 21431 [d] SCHOOL/testsPerDay/AT-7 := 14123 [d] SCHOOL/testsPerDay/AT-8 := 7884 [d] SCHOOL/testsPerDay/AT-9 := 35463 [d] SCHOOL/sensitivity := 0.19 [d] SCHOOL/interval := 1 [d]	Reduced tests at schools (1x per week). Based on a report from AT-5 after easter holidays

2022-05-01 [d], changeTestModel

detectionProbabilities/10 := 0.0576315789473684 [d] detectionProbabilities/20 := 0.172894736842105 [d] detectionProbabilities/30 := 0.288157894736842 [d] detectionProbabilities/40 := 0.288157894736842 [d] detectionProbabilities/50 := 0.288157894736842 [d] detectionProbabilities/60 := 0.34578947368421 [d] detectionProbabilities/70 := 0.242052631578947 [d] detectionProbabilities/80 := 0.242052631578947 [d] detectionProbabilities/90 := 0.230526315789474 [d] detectionProbabilities/200 := 0.184421052631579 [d]	Announced to lift mandatory registration. Awareness decreases and detection rate drops to 21.9%. See Section 5.1

2022-06-01 [d], changeTestModel

SCHOOL/testsPerDay/AT-1 := 0 [d] SCHOOL/testsPerDay/AT-2 := 0 [d] SCHOOL/testsPerDay/AT-3 := 0 [d] SCHOOL/testsPerDay/AT-4 := 0 [d] SCHOOL/testsPerDay/AT-5 := 0 [d] SCHOOL/testsPerDay/AT-6 := 0 [d] SCHOOL/testsPerDay/AT-7 := 0 [d] SCHOOL/testsPerDay/AT-8 := 0 [d] SCHOOL/testsPerDay/AT-9 := 0 [d] SCHOOL/sensitivity := 0.19 [d] SCHOOL/interval := 1 [d]	School testing over

2022-06-01 [d], setLeisuretimeContactReduction

reduction := (0.0,0.0,0.0,0.05,0.05) [c]	Basically all activities back to normal

2022-07-01 [d], setBetaLoc

values/WORKPLACE := 0.9 [d] values/CAREHOME := 0.9 [d] values/SCHOOL := 0.95 [d] values/LEISURETIME := 1.0 [d]	β_{loc}-level: no awareness + face mask indoor + 3G + holiday. See Section 4.3

2022-08-01 [d], changeTestModel

positiveTestQuarantineDuration := 2 [d]	No mandatory quarantine anymore. Leave 2 days since people tested are usually feeling sick

2022-08-15 [c], changeImportModel

strains := (XBB.15) [d]	Date for changed import strain is calibrated to match the takeover process.

2022-09-01 [d], setBetaLoc

values/WORKPLACE := 0.9 [d] values/CAREHOME := 0.9 [d] values/SCHOOL := 0.95 [d] values/LEISURETIME := 1.0 [d]	β_{loc}-level: no awareness + face mask indoor + 3G. See Section 4.3

2022-11-10 [d], changeTestModel

detectionProbabilities/10 := 0.0247368421052632 [d] detectionProbabilities/20 := 0.0742105263157895 [d] detectionProbabilities/30 := 0.123684210526316 [d] detectionProbabilities/40 := 0.123684210526316 [d] detectionProbabilities/50 := 0.123684210526316 [d] detectionProbabilities/60 := 0.148421052631579 [d] detectionProbabilities/70 := 0.103894736842105 [d] detectionProbabilities/80 := 0.103894736842105 [d] detectionProbabilities/90 := 0.0989473684210526 [d] detectionProbabilities/200 := 0.0791578947368421 [d]	Further reduced test awareness. Detection rate drops to 9.4%. See Section 5.1

2022-11-10 [d], changeTestModel

ALL/testsPerDay/AT-1 := 658 [d] ALL/testsPerDay/AT-2 := 1252 [d] ALL/testsPerDay/AT-3 := 3769 [d] ALL/testsPerDay/AT-4 := 3335 [d] ALL/testsPerDay/AT-5 := 1249 [d] ALL/testsPerDay/AT-6 := 2785 [d] ALL/testsPerDay/AT-7 := 1697 [d] ALL/testsPerDay/AT-8 := 890 [d] ALL/testsPerDay/AT-9 := 4304 [d] ALL/sensitivity := 0.25 [d] ALL/interval := 1 [d]	Reduced screening tests per day. 1/64 of pop per week

Table 2: Conventional parametrisation of events which change the β_{loc} variable corresponding to the introduced policy.

β_{loc}-level	workplace	care-home	school	leisure-time
hardest lockdown	0.3	0.3	0.4	0.6
hard lockdown	0.6	0.5	0.7	0.7
soft lockdown	0.7	0.6	0.8	0.8
general increased awareness	0.75	0.65	0.85	0.85
general awareness	0.8	0.7	0.9	0.9
reduced awareness	0.9	0.8	1	1
no awareness	1	1	1	1
optional modifiers on top				
holidays				+0.1
face mask indoor	-0.1	-0.1	-0.05	
3g in restaurants				-0.05
additional safety measures in schools			-0.2	

4.3 Contact Reduction

To reduce the degrees of freedom, we specified conventions for specified the assumed impact of specific policies on the β_{loc} variable in Table 2.

5 Time-Dependent Parameters – Details

While following the methodological concept of sections 1.3.3 and 1.3.4 https://www.dwh.at/projects/covid-19/Covid19_Model-20230322.pdf, a series of computations have been hinted loosely which indicate how certain time-dependent parameters have been found, e.g the reaction-time or detection rate dynamics. In this section we will show corresponding details.

5.1 Detection Rate

The detection rate is defined as the probability that a new infected case will be found by the symptomatic-testing regime. It depends on three factors: test availability, population adherence and asymptomatic rate of the virus strain. Since all three changed heavily in the course of the thee observed years, it is necessary to adjust this rate from time to time.

We distinguish between the overall and the age-dependent detection rate:

$$d(t) = P(\text{infected agent will be found}|\text{time} = t)$$

$$d(t, a) = P(\text{infected agent will be found}|\text{time} = t, \text{agent's age} = a)$$

Since age is an important factor for the model, it is parametrised with the latter. So a-prior parametrisation of the detection rate involves two challenges:

- Estimate the overall detection rate as a function of time (we will use a step-function).
- Estimate age-dependent detection rates from the overall detection rates.

The overall detection probability for the first months of the pandemic was estimated to 19.5%. This value was originally taken from a Spanish antibody study [7]. In Autumn 2020 increased test availability lead to a higher detection rate. An Austrian antibody study by Statistics Austria (November 12-14, 2020, [2]) indicatedc a higher detection rate which can be computed to 35%. The detection rate in Austria reached its highest level in autumn 2021. Test kits were available very easily and quickly, especially in the eastern provinces, thanks to programmes such as "Alles Gurgelt". In addition, the capacity of mobile testers was already well developed due to the autumn wave in the previous year. Unfortunately, quantification of the detection rate in this time was difficult, since antibody studies are biased by the vaccination program. Attempts to calibrate the Delta wave with different levels between 40% and 70% suggested that 45% produced the most native parametrisation.

In January 2022, nationwide wastewater surveillance [3] became a reliable second source for observing the current infection level next to the EMS system. Most importantly, the observed viral load in the wastewater are unbiased with respect to two of the three mentioned factors above: test availability and adherence. Since these are important variables for the difference between cases reported in the official testing system, the reference for the model calibration, and the actual infections. Therefore the dynamics of the detection rate, starting with 45% in January 2022, can be investigated by the ratio of the viral load in the wastewater and the reported cases in the EMS system.

In this process we identified four phases with decreasing detection levels: A reduction from 45 to 32.5% after the peak of the BA.2 wave in April, further reduction to 21.9% by May, likely due to rumours about lifting mandatory registration of COVID-19. By be the second week of November, another clear reduction to 9.4% could be investigated, but currently lacks an interpretation.

In the model, the overall detection rate was implemented as step-function using the aforementioned values. For the dates of the steps we chose points at which the disease dynamics is rather low to cause as little artefacts as possible due to the unsteady change:

$$d(t) = \begin{cases} 19.5\%, & t \in [2020-01-01, 2020-09-01) \\ 35.0\%, & t \in [2020-09-01, 2021-08-01) \\ 45.0\%, & t \in [2021-08-01, 2022-04-01) \\ 32.5\%, & t \in [2022-04-01, 2022-05-01) \\ 21.9\%, & t \in [2022-05-01, 2022-11-10) \\ 9.4\%, & t \in [2022-11-10, 2022-12-31) \end{cases} \tag{4}$$

The corresponding curve can be seen in part [a] of Figure 2. Part [b] of the figure displays, how the estimated detection rates shape the connection between the new detected cases and the new infections. The black curve displays the officially reported cases, the red curve corresponds to the black curve divided by the detection rate. It hereby becomes a estimate for the daily new infections. Note, that this estimate is very rough since it neglects e.g. the time difference between infection and detection of cases. For more information we refer to [8].

Furthermore, age-dependent detection-rates were computed. Hereby the method displayed in [8] was used essentially leading to the values found in the time-line in Section 4. For 2022-01-01 the age-distribution was changed even though the overall detection rate was left constant. This was due to a significant under-representation of elderly cases in the simulations (compare, calibration-target 4 in Section 2).

5.2 Reaction Time

The Austrian Agency for Health and Food Safety (AGES, [1]) has been operating the Epidemiological Reporting System EMS for many years. During the COVID-19 crisis, this was used as a national surveillance and reporting system. During this time, however, AGES was not only responsible for registering cases, but also for further activities in contact with people who tested positive, such as contact tracing. In this way, in a large number of cases during the course of the pandemic, not only the date of notification was recorded in the EMS, but also the estimated date of symptom onset. The percentage of cases for which the date of illness is available or is estimated lied around 60-80% (see Figure 3, section [a]). Even if these records do not claim to be bias-free or

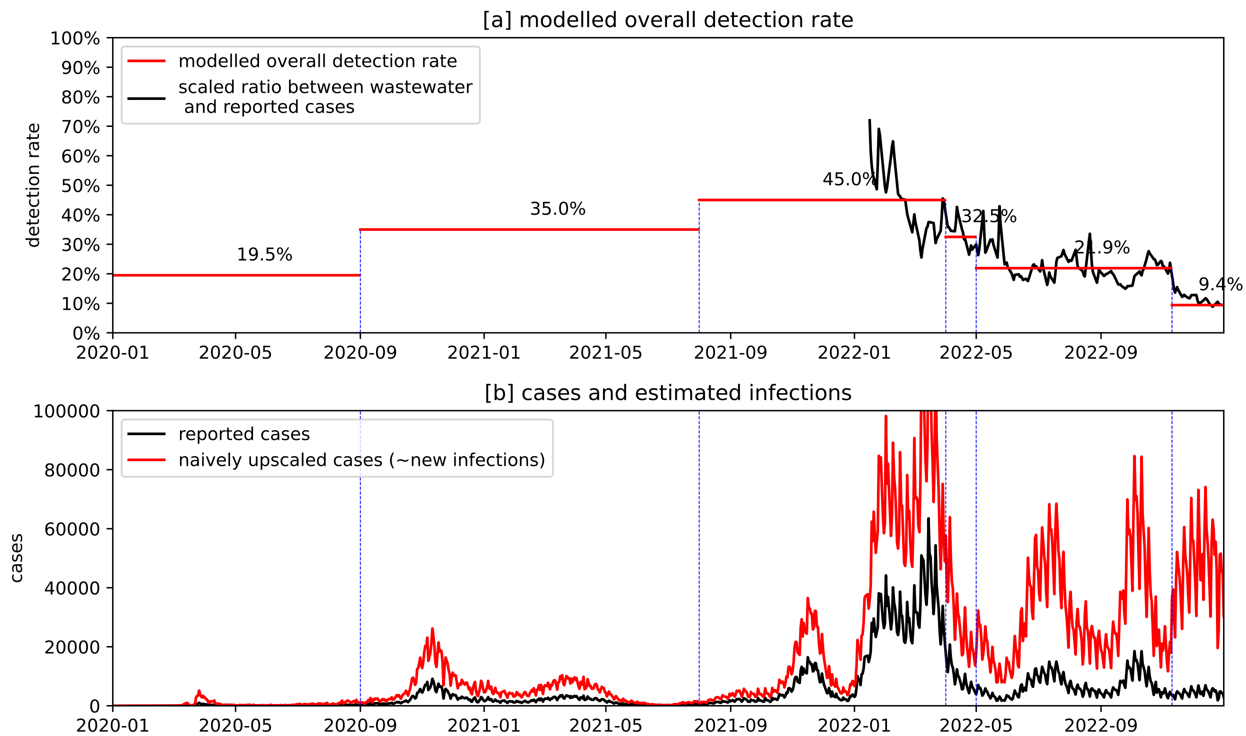

Figure 2: Plot [a] shows the modelled curve $d(t)$ including the scaled ratio between confirmed cases and wastewater signal in 2022. Plot [b] gives and idea on the impact of the estimated detection rate on the overall infection count by naively up-scaling the reported cases.

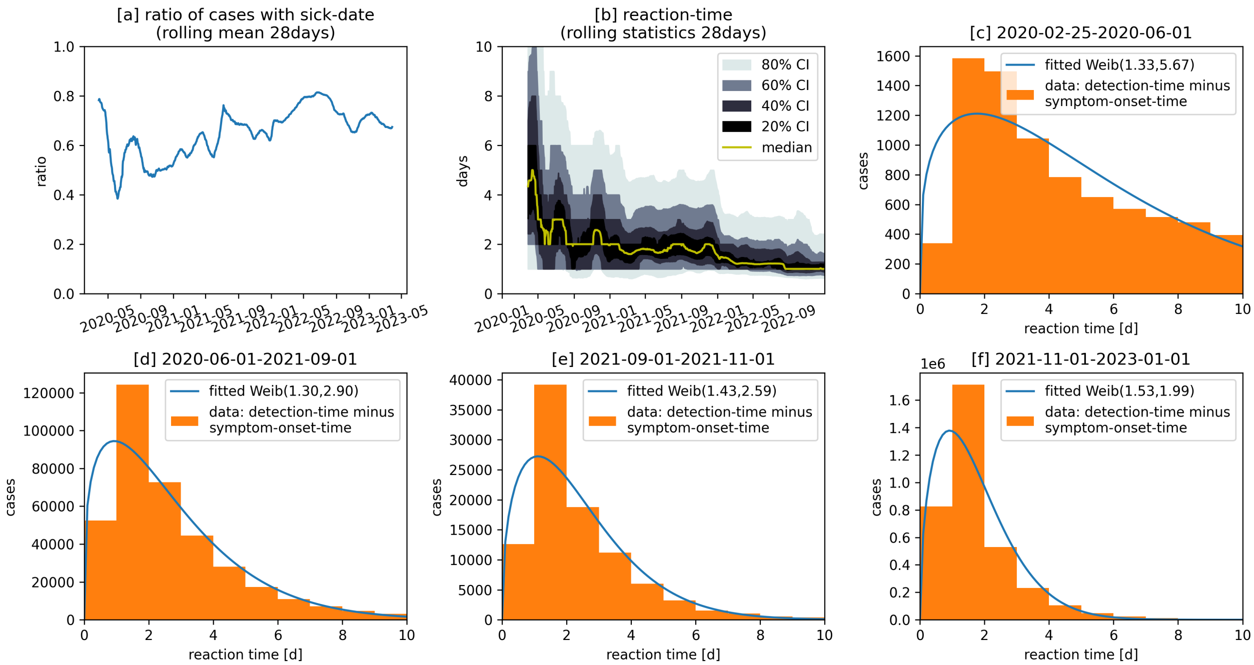

Figure 3: Part [a] shows the ratio of cases in the EMS system with estimated symptom-onset time. The time dynamics of the difference between confirmation time and symptom-onset time is displayed in part [b]. Finally, parts [c] to [f] show data and a fitted Weibull distribution for different time-frames.

of good data quality, the available sample is undoubtedly large enough to make statements about the reaction time, i.e. the time between symptom onset and positive test result.

In order to compute reaction time distributions we analysed the data and fitted Weibull distributions using a standard maximum-likelihood approach. Considering the dynamics in the measured reaction time distribution, see section [b] in Figure 3, and knowledge about specific events in the history of the pandemic (e.g. start of additional testing programs) we found it useful to split the simulation time-frame into four sections with individually fitted reaction time setup. Data and corresponding fits are displayed in parts [c-f] in Figure 3.

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