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Forecast of omicron wave time evolution

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Abstract: Adopting an early doubling time of three days for the rate of new infections with the omicron mutant the temporal evolution of the omicron wave in different countries is predicted. The predictions are based on the susceptible-infectious-recovered/removed (SIR) epidemic compartment model with a constant stationary ratio $k = \mu(t)/a(t)$ between the infection ($a(t)$) and recovery ($\mu(t)$) rate. The fixed early doubling time then uniquely relates the initial infection rate a_0 to the ratio k , which therefore determines the full temporal evolution of the omicron waves. For each country three scenarios (optimistic, pessimistic, intermediate) are considered and the resulting pandemic parameters are calculated. These include the total number of infected persons, the maximum rate of new infections, the peak time and the maximum 7-day incidence per 100000 persons. Among the considered European countries Denmark has the smallest omicron peak time and the recently observed saturation of the 7-day incidence value at 2478 is in excellent agreement with the prediction in the optimistic scenario. For Germany we predict peak times of the omicron wave ranging from 32 to 38 and 45 days after the start of the omicron wave in the optimistic, intermediate and pessimistic scenario, respectively, with corresponding maximum SDI values of 7090, 13263 and 28911, respectively. Adopting Jan 1st, 2022 as the starting date our predictions implies that the maximum of the omicron wave is reached between Feb 1 and Feb 15, 2022. Rather similar values are predicted for Switzerland. Due to an order of magnitude smaller omicron hospitalization rate, due to the high percentage of vaccinated and boosted population, the German health system can cope with maximum omicron SDI value of 2800 which is about a factor 2.5 smaller than the maximum omicron SDI value 7090 in the optimistic case. By either reducing the duration of intensive care during this period of maximum, and/or by making use of the nonuniform spread of the omicron wave across Germany, it seems that the German health system can barely cope with the omicron wave avoiding triage decisions. The reduced omicron hospitalization rate also causes significantly smaller mortality rates compared to the earlier mutants in Germany. In the optimistic scenario one obtains for the total number of fatalities 7445 and for the maximum death rate 418 per day which are about one order of magnitude smaller than the beta fatality rate and total number.

Keywords: coronavirus; extrapolation; omicron mutant; Covid-19

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1. Introduction

After being exposed to several Covid-19 outbreaks the recently identified omicron mutant threatens many societies worldwide [1,2]. Not many details are known so far about its infection characteristics [3,4] apart from alarming hints (1) that it is spreading at least four times quicker than the beta mutant with a short doubling time of $t_2 = 3$ days, and (2) that the existing vaccines, tailored to prevent infections from the earlier alpha, beta, gamma and delta mutants, are less efficient against the action of the omicron mutant especially without the current booster campaigns [5–8]. The alpha (α), beta (β), gamma (γ) and delta (δ) mutants have caused the first four Covid-19 waves, respectively. Positively, the omicron

mutant seems to lead to on average milder symptoms and thus to smaller hospitalization fractions compared to the earlier mutants.

Even with so little details known today it is of high interest to explore quantitatively the future time evolution of the omicron mutant under realistic scenarios of currently taken non-pharmaceutical interventions (NPIs). Of particular interest are reliable estimates of the maximum and total percentage of infected persons from this mutant in order to compare with the available medical capacities in different countries. In the following we provide these estimates by modeling the time evolution of the omicron wave with the susceptible-infectious-recovered/removed (SIR) epidemic compartment model [9].

As in our earlier analysis [10,11] – hereafter referred to as KSSIR-model – we adopt a constant stationary ratio $k = \mu(t)/a(t) = \text{const.}$ between the infection ($a(t)$) and recovery ($\mu(t)$) rate regulating the transition from susceptible to infected persons and infected to recovered/removed persons in the semi-time case, respectively. As it is so far unclear whether earlier vaccinated persons are not infected by the omicron mutant, we adopt the worst case scenario here and treat the vaccinated persons as fully susceptible to the omicron mutant. However, when calculating hospitalization and mortality rates below we will account for the influence of boosted (with vaccines) persons.

As proven by Table 1 and Figs. 1 and 2 of ref. [10] the KSSIR-model predicted the temporal evolution of the second wave in several countries convincingly good including the maximum rate $\dot{J}_{\text{max}}$ of new infections and the total cumulative number (J_{∞}) of infections as well as the initial and final second wave time dependence and the time of maximum. For the considered countries the maximum deviation in the total number of infected persons is at most 13 percent off from the later recorded values. An outstanding property of the KSSIR-model is that basically only one parameter, the ratio k of recovery and infection rates, fully determines the wave evolution in reduced time τ , whereas the influence of the initial fraction η of infected people at the onset of the modeled mutant at time t_0 is only minor especially for values of η much smaller than unity. Here the reduced time

$$\tau = \int_{t_0}^t a(\xi) d\xi \quad (1)$$

can be calculated for any arbitrary but given real time dependence of the infection rate $a(t)$.

Adopting a constant infection rate $a(t) = a_0$ is a good approximation for rapidly evolving mutant waves and not only for its initial phases, so that in this case the simple relation $\tau = a_0(t - t_0)$ holds between the reduced and the real time. Moreover, by determining the then two decisive parameters k and a_0 from the early monitored real time evolution then allows us the accurate determination of all relevant quantities of the considered outburst. The two parameters k and a_0 differ among different societies depending besides specific virus mutant properties also on the NPIs taken, the quality and ability of the health care system, and the discipline of the people in keeping distances, wearing masks and following quarantine measures. As the latter are mainly unchanged during different mutant actions it makes sense to relate the k and a_0 parameters of the omicron mutant to those of the earlier beta mutant as we will adopt below.

2. Results from the SIR-model

In terms of the reduced time (1) the KSSIR model equations read

$$\frac{dS}{d\tau} = -SI, \quad \frac{dI}{d\tau} = SI - kI, \quad \frac{dR}{d\tau} = kI \quad (2)$$

obeying the sum constraint

$$S + I + R = 1 \quad (3)$$

at all times. In Eqs. (2)-(3) S , I and R denote the fractions of susceptible, infected and recovered/removed persons in a population, respectively, subject to the semi-time initial conditions

$$\begin{aligned} I(t_0) &= I(\tau = 0) = \eta, \\ S(t_0) &= S(\tau = 0) = 1 - \eta, \\ R(t_0) &= R(\tau = 0) = 0. \end{aligned} \quad (4)$$

The rate of new infections and its corresponding cumulative number are given by $j(\tau) = S(\tau)I(\tau)$ and $J(\tau) = \int_0^\tau d\xi j(\xi)$, respectively, whereas $\dot{J}(t) = a(t)j(\tau)$ and $J(t) = J(\tau)$.

2.1. Exact results

In terms of J the exact solution of the KSSIR model in the semi-time case is given by [11]

$$\tau = \int_\eta^J \frac{dy}{n(y)}, \quad n(y) = (1 - y)[y + k\epsilon + k \ln(1 - y)] \quad (5)$$

with $\epsilon = -\ln(1 - \eta)$. The remaining SIR quantities are given by $J(\tau)$ as $S(\tau) = 1 - J(\tau)$, $I(\tau) = J(\tau) + k\epsilon + k \ln[1 - J(\tau)]$ and $R(\tau) = -k[\epsilon + \ln(1 - J(\tau))]$. Differentiating Eq. (5) with respect to τ readily yields for the rate of new cases

$$j(\tau) = \frac{dJ}{d\tau} = (1 - J)[J + k\epsilon + k \ln(1 - J)] \quad (6)$$

As shown before [11] without the explicit inversion of the solution (5) to $J(\tau)$ one obtains for the final cumulative fraction of infected persons

$$J_\infty = \lim_{\tau \rightarrow \infty} J(\tau) = 1 + kW_0(\alpha), \quad (7)$$

with $\alpha = -(1 - \eta)k^{-1}e^{-1/k}$, and for the maximum rate of new infections

$$j_{\max} = (1 - J_0)(1 - J_0 - k) = \frac{k^2}{4}([1 + W_{-1}(\alpha_0)]^2 - 1), \quad (8)$$

occurring at

$$J_0 = 1 + \frac{k}{2}W_{-1}(\alpha_0), \quad \alpha_0 = \frac{2\alpha}{e} \quad (9)$$

in terms of the principal (W_0) and non-principal (W_{-1}) solution of Lambert's equation [12], the well-known and documented Lambert functions. We emphasize that for small values of $\eta \ll 1$ the results (7) and (9) are basically independent of the value of η and only determined by the parameter k . The first Eq. (8) implies

$$J_0(k) = 1 - \frac{k}{2} - \sqrt{\left(\frac{k}{2}\right)^2 + j_{\max}} \quad (10)$$

2.2. Approximate results

Very accurate approximations have been obtained [12] for

$$\begin{aligned} j_{\max}(k) &\simeq \frac{(1 - k)^2(7 + 8k)}{14(2 - k)(1 + k)}, \\ J_\infty(k) &\simeq \frac{7 + k - 8k^2}{7}, \end{aligned} \quad (11)$$

so that Eq. (10) provides the approximation

$$J_0(k) \simeq 1 - \frac{k}{2} - \sqrt{\left(\frac{k}{2}\right)^2 + \frac{(1-k)^2(7+8k)}{14(2-k)(1+k)}} \quad (12)$$

Note that for small $k < 1/8$ the exact expressions (7), (9), and (10) are still useful as the approximation gives values slightly larger than unity for J_∞ . 85
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The occurrence of the maximum rate of new infections (8) at positive values of the reduced peak time $\tau_{\max} > 0$ requires values of $k < 1 - 2\eta$. In this case [11] the reduced peak time is well approximated by

$$\tau_{\max} \simeq \frac{1}{c_3} \operatorname{artanh} \frac{2c_3}{c_1 + \frac{2c_0}{J_0 - \eta}}, \quad (13)$$

with $c_0 = \eta(1 - \eta)$ and $c_1 = 1 - k - 2\eta$, 87

$$\begin{aligned} c_2 &= \frac{j_{\max} - c_0 - c_1(J_0 - \eta)}{(J_0 - \eta)^2}, \\ c_3 &= \sqrt{\left(\frac{c_1}{2}\right)^2 - c_0 c_2}. \end{aligned} \quad (14)$$

The reduced time dependence of the rate of new infections is well approximated as

$$\frac{j(\tau)}{j_{\max}} = \begin{cases} \left(\frac{\sinh(c_3 \tau_m)}{\sinh(c_3 \tau) + \sqrt{\frac{j_{\max}}{c_0}} \sinh[c_3(\tau_m - \tau)]} \right)^2 & \text{for } \tau \leq \tau_m \\ \frac{e^{d_1(\tau - \tau_m)}}{\left(1 + \frac{j_{\max}}{d_1(J_\infty - J_0)} [e^{d_1(\tau - \tau_m)} - 1]\right)^2} & \text{for } \tau \geq \tau_m \end{cases} \quad (15)$$

with $d_1 = J_\infty - (1 - k)$. 88

For a stationary infection rate a_0 the corresponding real peak time is given by

$$t_{\text{peak}} = t_0 + \frac{\tau_{\max}}{a_0} \quad (16)$$

Likewise, the early asymptotic reduced time behavior is well approximated [12] by

$$j_{\text{early}}(\tau \ll \tau_{\max}) \simeq A e^{(1-k)\tau}, \quad (17)$$

corresponding to the early asymptotic real time behavior

$$\dot{J}_{\text{early}}(t) = a(t) j_{\text{early}}(\tau(t)) \quad (18)$$

In the considered case of a stationary infection rate Eq. (18) reduces to

$$\dot{J}_{\text{early}}(t) = a_0 j(\tau = a_0(t - t_0)) = A a_0 e^{(1-k)a_0(t - t_0)}, \quad (19)$$

implying for the early doubling time defined by $\dot{J}_{\text{early}}(t + t_2) = 2\dot{J}_{\text{early}}(t)$ that

$$t_2 = \frac{\ln 2}{a_0(1-k)} = \frac{\ln 2}{a_0 - \mu_0}, \quad (20)$$

where we inserted $k = \mu_0/a_0$ in the case of stationary infection and recovery rates. Equation (20) will be used in the following two sections in two different ways. 89
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The maximum 7-day incidence value per 10^5 persons is calculated by integrating

$$\text{SDI} = 7 \times 10^5 \int_{t_{\max}-3.5}^{t_{\max}+3.5} dt j(t) \quad (21)$$

It is only slightly smaller than the estimate $\text{SDI} \simeq 7 \times 10^5 \dot{j}_{\max}$ from the maximum rate. At late times after the maximum half-decay time is given by

$$t_{1/2} \simeq \frac{\ln 2}{a_0 d_1} = \frac{0.693}{a_0 [J_{\infty} - (1 - k)]} \quad (22)$$

3. Consequences of early 2-day doubling time

For the omicron mutant the early doubling time of $t_{2,\text{omicron}} = 3$ days has been reported [3,4] in South Africa, Great Britain and Denmark. Adopting this value for all countries considered then provides according to Eq. (20) for the omicron mutant the relation

$$a_0^{\text{omicron}} = \frac{\ln 2}{3(1 - k_{\text{omicron}})} = \frac{0.231}{1 - k_{\text{omicron}}} \text{ days}^{-1} \quad (23)$$

throughout. Using this relation in all results of the last section to eliminate a_0 we find that all quantities of interest are solely determined by the parameter k . Particularly for the peak time (16) we obtain

$$t_{\text{peak,omicron}} = t_0 + 4.328 \tau_{\max}(1 - k_{\text{omicron}}), \quad (24)$$

whereas the maximum rate of new infections

$$\begin{aligned} \dot{j}_{\max,\text{omicron}}(k) &= a_0^{\text{omicron}} \dot{j}_{\max}(k) = \frac{0.231 \dot{j}_{\max}(k)}{1 - k_{\text{omicron}}} \\ &\simeq \frac{0.0165 (1 - k_{\text{omicron}})(7 + 8k)}{(2 - k_{\text{omicron}})(1 + k_{\text{omicron}})}. \end{aligned} \quad (25)$$

Likewise the real time dependence of the rate of new infections with Eq. (14) is given by

$$\dot{j}_{\text{omicron}} = \frac{0.231 j\left(\frac{0.231(t-t_0)}{1-k_{\text{omicron}}}\right)}{1 - k_{\text{omicron}}} \quad (26)$$

In Fig. 1 we display the resulting dependence of J_{∞} , $t_{\max} - t_0 = \tau_{\max}/a_0^{\text{omicron}}$ and $\dot{j}_{\max} = a_0^{\text{omicron}} \dot{j}_{\max}$ as a function of the parameter $k_{\text{omicron}} \in [0, 1]$. It can be seen that J_{∞} and $\dot{j}_{\max}$ decrease with increasing values of k almost independent of the initial fraction η of infected persons, except at very large values of k_{omicron} close to unity. Obviously, for comparatively small values of the total number of infected persons J_{∞} and the maximum rate of newly infected persons $\dot{j}_{\max}$ large values of the ratio k are required. Alternatively, the reduced time of maximum $\tau_{\max}$ decreases with increasing values of k as long as k is much smaller than $1 - 2\eta$.

4. Omicron forecast in individual countries

With the earlier inferred parameter values [10] a_0^{β} and k_{β} for the second wave caused by the β -mutant we calculate the second wave doubling time t_2^{β} for the countries listed in Table 1. Adopting for all countries the short omicron doubling time $t_2^{\text{omicron}} = 3$ days we obtain the ratio of the doubling times also listed in the last column of Table 1. With Eq. (20) we then infer for this ratio

$$r = t_2^{\beta}/t_2^{\text{omicron}} = \frac{a_0^{\text{omicron}}(1 - k_{\text{omicron}})}{a_0^{\beta}(1 - k_{\beta})}, \quad (27)$$

Figure 1. (a) J_{∞} , (b) $t_{\text{max}} - t_0$, and (c) $\dot{J}_{\text{max}}$ as a function of the only parameter k for different values of the initial fraction of infected persons η in the case of an early 3-day doubling time.

Table 1. Second wave parameters a_0^β in days⁻¹, k_β , initial fraction η_β , and the inferred second doubling time t_2^β in days. For the omicron mutant in all countries we adopt t_2^{omicron} to calculate the ratio of the the two doubling times $r = t_2^\beta / t_2^{\text{omicron}}$.

country	a_0^β	k_β	η_β	t_2^β	t_2^{omicron}	$r = t_2^\beta / t_2^{\text{omicron}}$
ITA	0.13	0.823	1.1×10^{-4}	30.1	3.0	10.03
AUT	0.43	0.898	1.8×10^{-5}	15.8	3.0	5.27
DNK	2.48	0.972	3.6×10^{-5}	10.0	3.0	3.33
DEU	0.45	0.907	1.1×10^{-5}	16.6	3.0	5.53
CHE	0.44	0.892	2.2×10^{-5}	14.6	3.0	4.87
GBR	0.44	0.874	4.6×10^{-5}	12.5	3.0	4.17
FRA	0.17	0.868	1.0×10^{-4}	30.9	3.0	10.30
BEL	0.53	0.893	1.8×10^{-4}	12.2	3.0	4.07
NLD	0.37	0.926	3.4×10^{-5}	25.3	3.0	8.43
RUS	0.03	0.801	6.9×10^{-3}	116.1	3.0	38.70
SWE	0.58	0.919	8.0×10^{-9}	14.8	3.0	4.93
USA	0.22	0.868	9.5×10^{-4}	23.9	3.0	7.97

yielding readily the relation

$$a_0^{\text{omicron}}(1 - k_{\text{omicron}}) = r a_0^\beta(1 - k_\beta). \quad (28)$$

For each country we then consider 3 possible omicron scenarios:

(1) the *optimistic* case with $k_{\text{omicron}} = k_\beta$ so that the increase in the ratio r is solely due to the increase in the stationary infection rate

$$a_0^{\text{omicron}} = r a_0^\beta \quad (29)$$

As noted earlier the larger the value of k_{omicron} the smaller the total cumulative number of infections J_∞ and the maximum rate of new infections j_{max} will be. This justifies the classification of this case as optimistic.

(2) the *pessimistic* scenario with $a_0^{\text{omicron,pess}} = a_0^\beta$ so that the increase in the ratio r is solely due to the decrease in the ratio k

$$k_{\text{omicron,pess}} = 1 - r(1 - k_\beta) \quad (30)$$

Clearly, with these small values of k_{omicron} the resulting total cumulative number of infections J_∞ and the maximum rate of new infections j_{max} will be highest, justifying the classification of this case as pessimistic. In four countries (ITA, FRA, RUS, USA) the resulting $k_{\text{omicron,pess}}$ is negative which cannot be. In these cases we use $k_{\text{omicron,pess}} = 0$ and $a_0^{\text{omicron,pess}} = 0.231$.

(3) the *intermediate* case with

$$a_0^{\text{omicron,interm}} = \frac{r}{2} a_0^\beta, \quad (31)$$

where half of the increase in the ratio r stems from the increase in the stationary infection rate. Then as a consequence

$$k_{\text{omicron,interm}} = 2k_\beta - 1 \quad (32)$$

In Tables 2, 3 and 4 we calculate the forecast for the omicron mutant for these three scenarios, respectively. Figure 2 visualizes the relationship between a_0 and k and the location of the three regimes for the 12 countries, and Fig. 3 shows the time dependence of $j(t)$ and cumulative fraction $J(t)$ of infected persons for all 12 countries.

It is obvious from these three tables that in European countries, apart from Russia with limited data reliability, Denmark has the shortest peak time of the omicron wave

Table 2. Forecast of the omicron mutant for the optimistic case, i.e., $a_0 = a_0^{\text{omicron, opti}}$, $k = k_{\text{omicron, opti}}$, and initial fraction $\eta = \eta_\beta$ from Tab. 1 for this table. Columns list the final cumulative fraction J_∞ of infected persons, the maximum (dimensionless) rate $j_{\max}$ of new infections, the cumulative fraction J_0 of infected persons at peak time, the reduced peak time $\tau_{\max}$, the peak time $t_{\max} - t_0$ in days, and the SDI, the maximum 7-day incidence per 10^5 persons. Country names are abbreviated by their α_3 codes.

optimistic scenario									
α_3	a_0	k	J_∞	$j_{\max}$	$\dot{J}_{\max}$	J_0	$\tau_{\max}$	$t_{\max} - t_0$	SDI
ITA	1.304	0.823	0.33	0.0139	0.018	0.160	35.6	27 days	12725
AUT	2.265	0.898	0.20	0.0049	0.011	0.097	68.9	30 days	7716
DNK	8.267	0.972	0.06	0.0004	0.004	0.028	130.1	16 days	2424
DEU	2.490	0.907	0.18	0.0041	0.010	0.089	79.0	32 days	7090
CHE	2.141	0.892	0.21	0.0054	0.012	0.102	64.0	30 days	8148
GBR	1.833	0.874	0.24	0.0073	0.013	0.118	51.3	28 days	9392
FRA	1.751	0.868	0.25	0.0080	0.014	0.123	43.5	25 days	9853
BEL	2.155	0.893	0.21	0.0055	0.012	0.101	44.3	21 days	8250
NLD	3.120	0.926	0.14	0.0026	0.008	0.071	77.4	25 days	5751
RUS	1.161	0.801	0.39	0.0219	0.025	0.173	10.7	9 days	17773
SWE	2.861	0.919	0.16	0.0031	0.009	0.078	175.6	61 days	6216
USA	1.753	0.868	0.26	0.0087	0.015	0.122	26.0	15 days	10650

Table 3. Forecast of the omicron mutant for the pessimistic case, i.e., $a_0 = a_0^{\text{omicron, pess}}$ and $k = k_{\text{omicron, pess}}$.

pessimistic scenario									
α_3	a_0	k	J_∞	$j_{\max}$	$\dot{J}_{\max}$	J_0	$\tau_{\max}$	$t_{\max} - t_0$	SDI
ITA	0.231	0.000	1.000	0.2500	0.058	0.500	9.2	40 days	40414
AUT	0.430	0.463	0.836	0.0984	0.042	0.379	18.8	44 days	29621
DNK	2.480	0.907	0.181	0.0041	0.010	0.089	65.6	27 days	7148
DEU	0.450	0.485	0.812	0.0918	0.041	0.369	20.4	45 days	28911
CHE	0.440	0.474	0.824	0.0950	0.042	0.374	18.7	42 days	29259
GBR	0.440	0.475	0.823	0.0949	0.042	0.374	17.3	39 days	29208
FRA	0.231	0.000	1.000	0.2500	0.058	0.500	9.2	40 days	40414
BEL	0.530	0.565	0.721	0.0696	0.037	0.331	17.0	32 days	25819
NLD	0.370	0.376	0.911	0.1249	0.046	0.412	15.5	42 days	32336
RUS	0.231	0.000	1.000	0.2500	0.058	0.500	5.0	22 days	40422
SWE	0.580	0.600	0.675	0.0602	0.035	0.312	43.1	74 days	24408
USA	0.231	0.000	1.000	0.2500	0.058	0.500	7.0	30 days	40419

Table 4. Forecast of the omicron mutant for the intermediate case, i.e., $a_0 = a_0^{\text{omicron, inter}}$ and $k = k_{\text{omicron, inter}}$.

intermediate scenario									
α_3	a_0	k	J_∞	$j_{\max}$	$\dot{J}_{\max}$	J_0	$\tau_{\max}$	$t_{\max} - t_0$	SDI
ITA	0.652	0.646	0.613	0.0489	0.032	0.286	21.4	33 days	22307
AUT	1.132	0.796	0.378	0.0181	0.021	0.182	41.0	36 days	14328
DNK	4.133	0.944	0.110	0.0015	0.006	0.054	90.9	22 days	4462
DEU	1.245	0.814	0.347	0.0152	0.019	0.168	46.7	38 days	13263
CHE	1.071	0.784	0.398	0.0201	0.022	0.191	38.2	36 days	15060
GBR	0.917	0.748	0.458	0.0267	0.024	0.218	31.0	34 days	17109
FRA	0.876	0.736	0.477	0.0290	0.025	0.226	26.8	31 days	17797
BEL	1.078	0.786	0.396	0.0199	0.021	0.189	28.6	27 days	14979
NLD	1.560	0.852	0.281	0.0099	0.016	0.137	48.0	31 days	10832
RUS	0.580	0.602	0.678	0.0627	0.036	0.307	8.8	15 days	25466
SWE	1.431	0.838	0.305	0.0117	0.017	0.148	96.2	67 days	11748
USA	0.876	0.736	0.479	0.0295	0.026	0.226	18.3	21 days	18110

Figure 2. Location of the considered values of a_0 and k for the omicron mutant in the investigated 12 countries with the adopted 3-day early doubling times. The symbols β represent the values for the earlier beta mutant. The solid black line is Eq. (23).

ranging from 16 to 22 and 27 days after the start of the omicron wave in the optimistic, intermediate and pessimistic scenario, respectively. The corresponding predicted maximum 7-day incidence values per 10^5 persons (SDI) are 2424, 4462 and 7148, respectively. Presently on January 10, 2022 the well-monitored data of Denmark [13] indicate that the SDI has saturated at its maximum value at 2478 which is in excellent agreement with our predicted value in the optimistic case. Although preliminary this outstanding agreement is definitely encouraging and argues in favour of the optimistic scenario

Regarding Germany we predict peak times of the omicron wave ranging from 32 to 38 and 45 days after the start of the omicron wave in the optimistic, intermediate and pessimistic scenario, respectively, with corresponding maximum SDI values of 7090, 13263 and 28911, respectively. Adopting Jan 1st, 2022 as the starting date our predictions implies that the maximum of the omicron wave is reached between Feb 1 and Feb 15, 2022. In the optimistic case the total cumulative number of omicron infections will be 0.180 but can go up high to 0.812 in the pessimistic case. The late half decay times are 3.2 to 3.5 and 5.2 days in the optimistic, intermediate and pessimistic case, respectively.

Rather similar values are predicted for Switzerland. Here the peak times of the omicron wave range from 30 to 36 and 42 days after the start and the corresponding maximum SDI values are 8148, 15060 and 29259, respectively. Here with the same starting date the maximum of the omicron wave is reached between Jan 31 and Feb 13, 2022. Here, in the optimistic case the total cumulative number of omicron infections will be 0.208 but can go up high to 0.824 in the pessimistic case. The late half decay times are 3.2 to 3.6 and 5.3 days in the optimistic, intermediate and pessimistic case, respectively.

5. Medical consequences for Germany

5.1. Tolerable maximum 7-day incidence value

We have argued earlier [14] that the German health system can cope with maximum SDI values of $280/(hm)$ without any triage decisions, where m in months denotes the average duration of intensive care with access to breathing apparati for seriously infected persons, and h in units of percent indicates the percentage of people seriously infected needing access to breathing apparati in hospitals. For the earlier α and β mutants the value of $h = 1$ has been reasonable. Fortunately, for the omicron variant from studies in South Africa [15] and Great Britain [16] substantial 70–90 percent reductions as compared to earlier mutants in Covid-19 hospitalization have been reported. This strong reduction is predominantly caused by the high percentage of persons with boosted vaccination.

We therefore adopt here the value of $h_{\text{omicron}} = 0.1$, i.e. only one out of 1000 new infections with the omicron mutant needs to be hospitalised. Consequently, the German health system can cope with maximum omicron SDI value of $2800/m$ which is about a

Figure 3. Time dependence of the daily rate of newly infected persons, $\dot{J}(t)$, as well as the cumulative fraction of infected persons, $J(t)$, for all 12 countries.

factor 2.5 smaller than the maximum omicron SDI value 7090 in the optimistic case. By either (1) reducing the duration of intensive care during this period of maximum to $m = 0.5$, and/or (2) by making use of the nonuniform spread of the omicron wave across Germany, appearing first in the northern states and considerably later in the southern and eastern states, combined with mutual help in hospital capacities, it seems that the German health system can cope with the omicron wave avoiding triage decisions.

5.2. Fatality rates and total number of fatalities

As before [10,14] we assume that every second hospitalised person eventually dies from the omicron virus so that the omicron mortality rate is $f_{\text{omicron}} = 0.5h_{\text{omicron}} = 5 \times 10^{-4}$ which is one order of magnitude smaller than the mortality rates of the earlier mutants. Consequently, the total fatality rate is given by $D_{\infty} = f_{\text{omicron}} \int_{\infty} N$, where $N = 82.7$ million denotes the German population. Likewise the maximum death rate is $d_{\text{max}} = f_{\text{omicron}} N \dot{J}_{\text{max}}$. In the optimistic scenario one obtains $D_{\infty} = 7445$ and $d_{\text{max}} = 418$ per day which are about one order of magnitude smaller than the beta fatality rate and total number of fatalities of the second wave [10]. The main reason for these comparatively small numbers is the order of magnitude smaller hospitalization rate of the omicron mutant compared to the earlier more deadly mutants.

However, in the less likely pessimistic scenario the fatality numbers increase by a factor 4.5 to to $D_{\infty} = 33576$ and $d_{\text{max}} = 1708$ which are about half of the fatality values of the second wave.

6. Summary and conclusions

Adopting an early doubling time of three days for the rate of new infections with the omicron mutant the temporal evolution of the omicron wave in different countries is predicted. The predictions are based on the susceptible-infectious-recovered/removed (SIR) epidemic compartment model with a constant stationary ratio $k = \mu(t)/a(t)$ between the infection ($a(t)$) and recovery ($\mu(t)$) rate. The fixed early doubling time then uniquely relates the initial infection rate a_0 to the ratio k , which therefore determines the full temporal evolution of the omicron waves.

As all considered countries have been exposed to earlier waves of the Covid-19 virus we relate the parameters a_0 and k to those of the well-studied second wave. In the optimistic case we assume that the decrease in the early doubling time of the omicron mutant as compared to the beta mutant is solely due to a corresponding increase in the initial infection rate a_0 whereas the ratio k is the same as for the beta mutant. In the pessimistic case we assume that the decrease in the early doubling times is fully caused by a corresponding decrease in the ratio k whereas the initial infection rate is the same as for the beta mutant. In the intermediate scenario half of the decrease in the early doubling time is assigned to a corresponding increase of the initial infection rate and a corresponding decrease of the ratio k . For 12 countries these three scenarios (optimistic, pessimistic, intermediate) are considered and the resulting pandemic parameters are calculated. These include the total number of infected persons, the maximum rate of new infections, the peak time and the maximum 7-day incidence per 100000 persons.

Among the considered European countries Denmark has the smallest omicron peak time and the recently observed saturation of the 7-day incidence value at 2478 is in excellent agreement with our prediction in the optimistic case. For Germany we predict peak times of the omicron wave ranging from 32 to 38 and 45 days after the start of the omicron wave in the optimistic, intermediate and pessimistic scenario, respectively, with corresponding maximum SDI values of 7090, 13263 and 28911, respectively. Adopting Jan 1st, 2022 as the starting date our predictions implies that the maximum of the omicron wave is reached between Feb 1 and Feb 15, 2022. In the optimistic case the total cumulative number of omicron infections will be 0.180 but can go up high to 0.812 in the pessimistic case. The late half decay times are 3.2 to 3.5 and 5.2 days in the optimistic, intermediate and pessimistic case, respectively.

Rather similar values are predicted for Switzerland. Here the peak times of the omicron wave range from 30 to 36 and 42 days after the start and the corresponding maximum SDI values are 8148, 15060 and 29259, respectively. Here with the same starting date the maximum of the omicron wave is reached between Jan 31 and Feb 13, 2022. Here, in the optimistic case the total cumulative number of omicron infections will be 0.208 but can go up high to 0.824 in the pessimistic case. The late half decay times are 3.2 to 3.6 and 5.3 days in the optimistic, intermediate and pessimistic case, respectively.

Adopting an order of magnitude smaller omicron hospitalization rate thanks to the high percentage of vaccinated and boosted population we conclude that the German health system can cope with maximum omicron SDI value of 2800 which is about a factor 2.5 smaller than the maximum omicron SDI value 7090 in the optimistic case. By either reducing the duration of intensive care during this period of maximum, and/or by making use of the nonuniform spread of the omicron wave across Germany, it seems that the German health system can barely cope with the omicron wave avoiding triage decisions.

The reduced omicron hospitalization rate also causes significantly smaller mortality rates compared to the earlier mutants in Germany. In the optimistic scenario one obtains for the total number of fatalities $D_{\infty} = 7445$ and for the maximum death rate $d_{\max} = 418$ per day which are about one order of magnitude smaller than the beta fatality rate and total number. In the less likely pessimistic scenario these numbers increase by a factor 4.5.

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7. Deutsche Zusammenfassung: Maximum der Omikron-Welle zwischen 1. Februar und 15. Februar 2022 mit maximaler 7-Tage Inzidenz von mindestens 7090 in Deutschland vorhergesagt am 11. Januar 2022

Ausgehend von einer frühen Verdopplungszeit von 3 Tagen für die Rate der Neuinfektionen wird der zeitliche Verlauf der Omikron-Welle in 12 Ländern prognostiziert. Die Prognosen beruhen auf dem SIR-Schubladen-Modell (susceptible-infected-removed model) der mathematischen Epidemiologie mit einem zeitlich konstanten Verhältnis $k = \mu(t)/a(t)$ zwischen der Infektions- ($a(t)$) und der Genesungs- und Sterbe- ($\mu(t)$) Raten. Die festgelegte frühe Verdopplungszeit bestimmt dann die anfängliche Infektionsrate a_0 als Funktion des Ratenverhältnisses k , das dann die gesamte zeitliche Entwicklung der Omikron-Welle festlegt. Für jedes Land werden mit den analytischen Lösungen des SIR-Modells für drei Verlaufsszenarien (optimistisch, pessimistisch, mittelwertig) die totale Zahl der mit Omikron infizierten Personen, die maximale Rate der Neuinfektionen, der Tag des Maximums an Neu-Infizierten und die maximale 7-Tage Inzidenz pro 100000 Einwohner bestimmt. Unter den betrachteten europäischen Ländern hat Dänemark die kürzeste Omikron Maximalzeit und die kürzlich beobachtete Saturierung der 7-Tage Inzidenz bei Werten von 2478 ist in exzellenter Übereinstimmung mit der Prognose für das optimistische Verlaufsszenario. Für Deutschland wird das Maximum der Omikron-Welle zwischen dem 1. Februar und 15. Februar 2022 auftreten mit maximaler 7-Tage Inzidenz von mindestens 7090. Sehr ähnliche Werte werden für die Schweiz vorhergesagt. Aufgrund der um einen Faktor 10 kleineren Omikron-Hospitalisierungsrate im Vergleich zu früheren Covid-Mutanten, die durch die hohe Anzahl von geboosterten Personen zustandekommt, erscheint es beim optimistischen Verlaufsszenario, dass das deutsche Gesundheitssystem die maximale 7-Tage Inzidenz von 7090 ohne Triage-Entscheidungen gerade so bewältigen kann. Dazu muss aber die typische Beatmungszeit von Intensivpatienten während der Zeit des Maximums halbiert werden. Ebenso muss die regional unterschiedliche Ausbreitung der Omikron-Mutante in den nördlichen und südlichen Bundesländern bei gegenseitiger Krankenhaushilfe genutzt werden. Die niedrigere Hospitalisierungsrate sorgt auch für signifikant kleinere Sterberaten und Gesamttodesfälle durch die Omikron-Mutante. Im Vergleich zu der früheren zweiten Welle prognostizieren wir mit 7445 Gesamttodesfällen und einer maximalen Sterberate von 418 pro Tag im optimistischen Verlaufsszenario um einen Faktor 10 kleinere Raten als bei der vergangenen zweiten Welle. Bei einem pessimistischen Verlaufsszenario würden sich die Omikron-Sterberaten und Todesfälle um den Faktor 4.5 erhöhen.