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IMPLEMENTATION OF HIDDEN INFECTIONS IN THE SEIR MODEL ANALYSIS OF THE OMICRON VARIANT SPREAD IN BULGARIA

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Abstract

In this paper we study the impact of the hidden cases of Covid-19 spread in Bulgaria by means of the SEIR model, in the period December 15, 2021 – until March 2022. In particular, the numerical experiments based on the hidden cases till mid-January, provide a forecast of the peak of the infectious curve about February 8, 2022, and reaching the maximum of about 90 000 cases. The forecast shows that end of the epidemics (in Bulgaria) would be in mid-May, 2022. This forecast is compared to the previous forecasts based on the same data excluding hidden cases; they have shown that the peak will be about February 28, reaching about 75 000 cases and will vanish until end of May. As seen in Fig. 3, our forecast of the end of the particular wave of epidemics shows just two weeks difference with what happened in real life – the wave ended in the first week of June. It is curious, that though the peak of the curve in the hidden cases approach has shifted to February 8, the cumulative number of cases in both approaches is nearly the same. More details on the methods used in the present paper and the non-hidden cases study, are provided as well.

Key words: mathematical modelling in epidemiology, prediction, Covid-19, Omicron variant

2020 Mathematics Subject Classification: 37N25, 49J15, 92D30

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1. Introduction. Accurate study of spread of all Covid-19 variants in Bulgaria faces a significant obstacle – the relatively small number of performed PCR tests. Many people, especially in small communities, prefer to not be tested and eventually put into quarantine. Most of the people that had none or light symptoms did not test in order to avoid quarantine as well. It is common that patients call for medical help when they have already mild to serious symptoms. That is why the number of hidden cases in Bulgaria is significant. The authors estimated that only one of five (or even ten in the case of Omicron) infectious cases have been reported officially. More details on the methods of the estimation of non-reported cases will be provided in a future paper.

In this paper authors provide numerical experiments taking into account the hidden cases, unlike the previous research where only the officially reported cases have been used, see [1]. Comparing the output of the two pairs of experiments – with and without taking into account hidden cases, one may see that the forecast peak of the fifth Omicron wave comes few weeks earlier if hidden cases are counted – about February 08. Nevertheless the cumulative number of cases does not differ essentially in both approaches – it is about 4 million cases (if hidden cases are taken into account) vs. 3 and a half millions (without hidden cases taken into account). One reasonable explanation of this fact is that the population of Bulgaria is a little more than 6 million and the number of herd immunity people is in the range 3.4–4.3 million (in case of partial application of measures). Here we take into account that Omicron variant evades antibody-mediated immunity that comes from vaccination or infection with earlier variants – it is due to accumulation of numerous spike mutations.

In this paper we give a more detailed description of the methods used. In particular, description of SEIR models follows.

2. Methods used. In this research we use the classical epidemic SEIR model to describe the spread of the Covid-19 disease which on the eve of 2022 was dominated by the Delta and the Omicron variants. SEIR is a representative of the so-called **Compartmental models**. In these models the population is assigned to four compartments – **S**usceptible (S), **E**xposed (E), **I**nfectious (I), and **R**ecovered (R). People may switch between compartments in a strict order. When a susceptible (from compartment S) and an infectious individual come into "infectious contact", the susceptible individual contracts the disease and transitions to the exposed compartment E. As many other infections, for Covid-19 there is a significant **latency** (**incubation**) period during which individuals have been infected but are not yet infectious themselves. That is why during this period the individual is in compartment E. After the latency period people transfer to the **i**nfectious compartment I. These are individuals who have been infected and are capable of infecting susceptible individuals. After individual differences in recovery time, the individuals transfer to compartment R of **r**emoved by recovery from the disease or by death. It is assumed that the number of deaths is negligible with respect to the total population. This compartment may also be called "**r**ecovered" or "**r**esistant". SEIR model can be illustrated by the following sequence:

$$\textbf{S}\text{usceptible} \longrightarrow \textbf{E}\text{xposed} \longrightarrow \textbf{I}\text{nfectious} \longrightarrow \textbf{R}\text{emoved}$$

For more details we refer to some classical monographs in the area [2,3].

In this study we use a deterministic rather than a stochastic approach to the modelling. Let $S(t)$ be the number of susceptible individuals, $E(t)$ be the number of exposed ones, $I(t)$ be the number of infected people and $R(t)$ be the number of **r**ecovered or deceased individuals. Then the dynamics of the disease spread is described by the following system of ordinary differential equations (ODEs), cf. [3].

If N is the total number of the population, $N = S(t) + E(t) + I(t) + R(t)$, and the latency period σ is medically determined, for instance and it is widely accepted that the average is about **six** days for Delta variant and about **three** days for Omicron.

Here, the parameters are defined as follows: β is the transmission coefficient which may vary in time t; γ is the removal coefficient, may vary in time; σ is a constant which is the reciprocal of the latency (incubation) period (the time which passes from the infection to becoming sick – getting first symptoms). In the case of the Delta variant the incubation period has been found to have the average value **five**; in the case of the Omicron variant it is **three** days; hence $1/5$ and $1/3$ are the corresponding values of σ. The mortality rate μ is considered to be equal to the birth rate. This assumption does not play essential role for the short periods of time like a couple of months, as is the case of the present application. Hence we put $\mu = 0$.

The advantage of SEIR models is that they give the opportunity to predict how a disease spreads, the total number of infected people, the duration of an epidemic, to estimate various epidemiological parameters such as the basic reproductive number $\mathcal{R}_0$, etc. Furthermore, such models can show the effects of different public health interventions on the epidemic dynamics, for instance vaccination, restrictions on social contacts, etc. One of the most amazing features of the SIR/SEIR models is that they provide a simple direct approximation of the Basic Reproduction Number, [3], namely:

$$\mathcal{R}_0 = \frac{\beta}{\gamma}. \tag{1}$$

For more details about the description of the SEIR model, its discretization and numerical treatment we refer to [3–8] and to more recent references [9,10], devoted to the spread of the Omicron variant.

In the present study we model the fifth wave of the spread of Covid-19 disease in Bulgaria which is mainly due to the Omicron variant, for relatively short intervals of time, in particular we give an estimate of the **Basic Reproduction Number** (BRN) which is usually denoted by $\mathcal{R}_0$, and may be approximately calculated by formula (1). We use British databases for the Omicron statistics instead of Bulgarian ones due to lack of significant research by sequencing of positive Covid-19 samples in Bulgaria and the databases. The main reason for using the datasets of UK is that they are most reliable due to the huge amount of sequencing of the samples of the positive cases. The main remarkable source is Report 49 of December 16, by Imperial College; it reports about data of sequencing of all positive cases in the period 29.11.2021–11.12.2021 which are more than 400 000 samples, [12,13]. For this period we see that in UK there was a huge number of positive cases equal to 630 158, if one adheres to the data available in [14]. Hence, their conclusions have a very solid background, compared to other studies, in particular in Germany or Bulgaria, where the number of sequencing is much lower, see the usual source of Omicron data in the link provided in [15].

A comparison between BRN $\mathcal{R}_0$ of Omicron and Delta variants was provided by Nishiura et al. [16] in their study based on the data from South Africa. Another interesting study, modelling the consequences of the Omicron variant, and based on the data for UK (especially for England), is given in Barnard et al. [9].

3. Numerical experiments and forecasts, using hidden infectious cases in Bulgaria. Here we extend the experiments provided in a previous research, by considering the hidden infectious cases. We consider what is the forecast curve of the SEIR model if one takes into account the hidden infectious cases. Hidden cases are those persons who have met the disease but have not been officially registered. Practically, this number includes persons with no symptoms but also people with mild symptoms. It has been highly disputed how to obtain the number of hidden cases, which are sometimes called in Germany *dark numbers.* For Bulgarian data, it seems to be a reasonable approach (based on discussions with medical doctors and other people from the medical circles) to multiply the official infected cases by a factor of five (or even by ten), i.e. only about 20% (or 10%) of the cases are officially registered.[1] On the other hand, some researchers in Germany determine this factor to take values between two and three.

In the experiments below we see the resulting SEIR forecast curves based on the above-mentioned approach. In Fig. 1 we see that the forecast curve attains a maximum in early February with almost 90 000 cases, unlike results of previous research, where the peak was about 70 000 cases but is reached about a month later.

In a similar way, in Fig. 2 we see that the forecast cumulative curve of infected cases will reach the maximum of about 4 million infected cases at the end of March

[1]For the previous strains the factor for hidden cases in Bulgaria has been considered from 3 to 5. Important argument for the choice of a factor 5 and even more for the Omicron variant, is also the lesser severity of the sickness compared to the previous variants, which brings a lot more unreported cases.

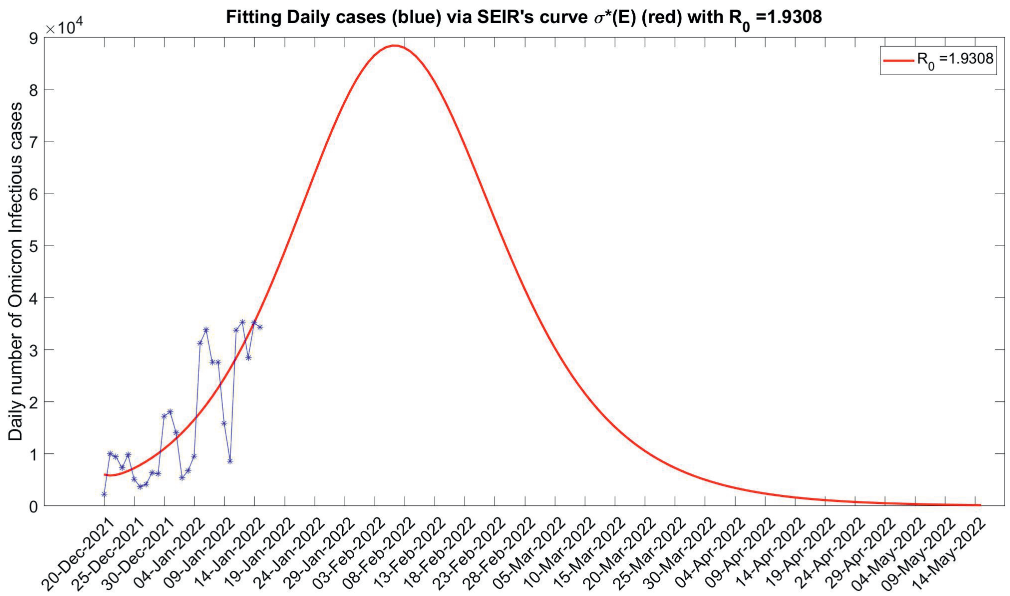

Fig. 1. Hidden data of infected cases for Bulgaria (escalation factor 5) plus fitted SEIR model (black) to the data before January 15, 2022. The forecast includes hidden cases

2022. The overall view shows that the total number of infected in both scenarios (with and without accounting for the hidden cases) is very close (3.8 and 4 millions, resp.), however, the duration of the epidemics and its peak differ by one month.

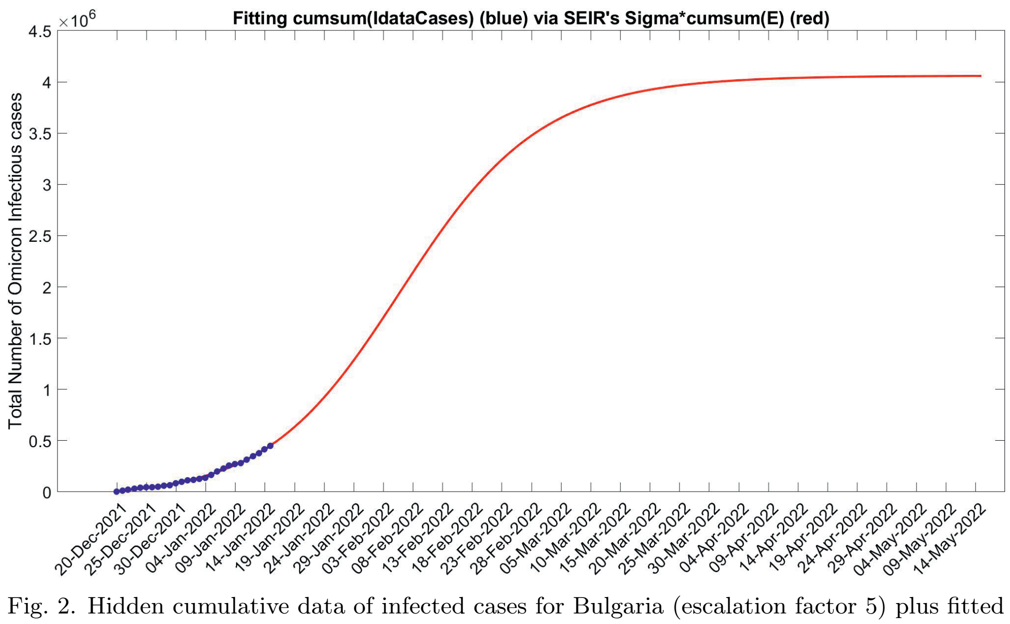

Fig. 2. Hidden cumulative data of infected cases for Bulgaria (escalation factor 5) plus fitted cumulative SEIR model (black) to the data before January 15, 2022

Remark 1. An interesting conclusion of the above experiments in Fig. 1, and those carried out in a previous research where only officially reported cases were taken into account, is that although we multiply the daily infected cases by a factor 5, the forecast curve of the daily infected cases in Fig. 1 has a maximum of about 90 000 cases which is somewhat higher than the 70 000 cases of the previous research where no hidden cases were considered. Hence, the main effect of using the hidden infected cases is not the forecast number of infected cases but the shift of the peak of the forecast infected cases curve.

3.1. Forecast of the end of the Omicron wave in March 2022. In the present section we analyze the data for Bulgaria during the period February–March 2022, when the Omicron wave has gradually decayed. As we have seen above in Fig. 1 the peak of the Omicron wave has been reached at the end of January due to the strong social restriction measures. These measures have been followed for quite a long period of time, even after mid-March. On the other hand the government has announced that since March 20 the measures will be completely released in case no critical number of ICU (intensive care units) will be occupied (about 50 ICUs), and the number of the daily infectious cases decreases essentially.

3.2. Estimation of the overall number of infectious cases. If we want to be able to predict the global behaviour of the infectious curve, we need to have a rough estimate of the total number of infections until the end of March 2022. Let us indicate a plausible approach to its calculation. First of all, we assume that after January 15, 2022 more than 90% of all infectious cases are due to Omicron variant [[17]]. As we mentioned in the introduction, the studies of the European Centre for Prevention and Disease Control (ECDC), in [[15]], have shown that the percentage of lethality in the Omicron infected cases is about 0.06%. We may assume that in Bulgaria this percentage is 0.12%, or even 0.2%, a point which will be justified in a follow-up study. To make the final calculation, we check the official number of lethalities due to Omicron in the period after February 1, 2022 till March 18 (see [[18]]), it is 3088. As said, this is approximately 0.12% of the cases infected say after January 15, 2022. Using a simple proportion we obtain that the last figure is about 2.6 million people. Let us see that this number is rather close to the collective immunity of the population. Indeed, the official population of Bulgaria is 6.5 millions; according to the official figures, about 400 000 have got a third doze of vaccination (booster). By the results of the report in [[12]] almost 80% of the population (vaccinated and those with natural immunity due to previous variants of Coronavirus) is susceptible to Omicron variant. This makes about 4.8 million people. The herd immunity for Omicron is about 90% of the susceptible population without any restrictions and about 70% of the susceptible population in case restrictions are imposed (online teaching, digital certificates, etc.). As a result we obtain $70\% * 80\% * 6$ which is approximately 3.4 million people. Also, if all restrictions are lifted, then we have to consider 90% herd immunity which results in 4.3 million people.

Hence, we see that if the restrictions will be lifted after 20 March 2022, there may emerge a new peak based on minimum 0.8 and maximum of 1.7 million people who have not yet met the Omicron variant. Needless to say, the above figures change if we assume that the Omicron lethality rate in Bulgaria is 0.2% instead of 0.12%.

3.3. Forecast starting March 20, 2022. In Fig. 3 we provide the forecast infectious cases curve fitted to Bulgarian data in the interval January 1 – March 18, 2022. We forecast a steep decline at the end of March and even steeper in April. We would comment on the interpretation of our results: As has become clear already in March 2022, being sick and then recovering from one variant of Omicron does not guarantee immunity against the other variants. For example, this was the case with the wave of the Omicron sub-variant BA5 which has started in Bulgaria at the end of June 2022. (The same happened with the Delta variant which started in Bulgaria in August 2021.) Our forecast in the present paper is related to certain subvariants (21K and 21L) of Omicron (they started in Bulgaria, resp. 21K at the end of December 2021, and 21L in February 2022); see the dynamics of variants and subvariants at the site `https://covariants.org/per-country?region=World&country=Bulgaria`. The appearance of new subvariants (as e.g. the Omicron sub-variant BA5) which do not respect the immunity (achieved after recovery and/or after vaccination with vaccines designed for the previous variants) is beyond our models. The "controlled peak" of the infectious curve has appeared a week or so after the massive introduction by the authorities of

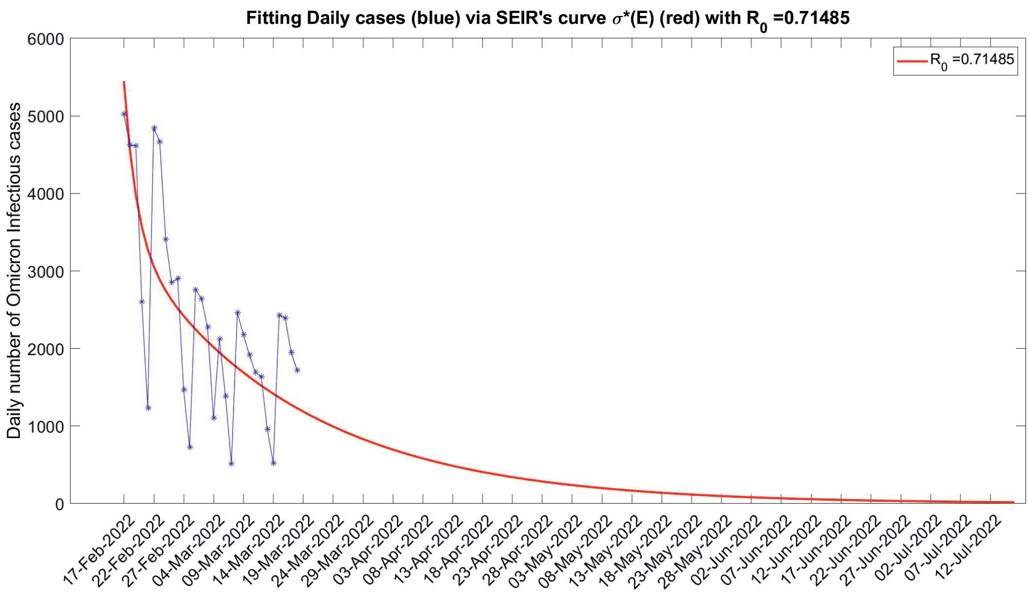

Fig. 3. Data of infected cases for Bulgaria (blue) fitted by SEIR model (red) to the data before March 18, 2022

containment measures about January 23, 2022; the reader may consult the official Bulgarian data at the Worldometers' website `https://www.worldometers.info/coronavirus/country/bulgaria/`. The health authorities' decision has been influenced to some extent by the results of our research group made available by us to the public in TV interviews in January 2022 (see the links `https://www.bgonair.bg/a/2-bulgaria/252564-do-60-000-zarazeni-dnevno-u-nas-v-pika-na-valnata-ochakvat-ya-prez-fevruari`; `https://n9.cl/kn8rb`; and `https://btvnovinite.bg/predavania/tazi-sutrin/matematik-pikat-prez-mart-shte-e-sas-70-000-zarazeni-na-den.html`, and others), and now presented in this paper and its preceding part [1], showing the large numbers of potentially infected people.

Remark 2. The processing of the data and all experiments above are based on a very natural hypothesis: we assume that the main parameters of the SEIR models do not change essentially during the months January–March. This hypothesis is reasonable and it is justified by the SEIR model analyses of the Influenza epidemics in Bulgaria for previous years – the β and γ parameters do not vary essentially.

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