Influence of Possible Natural and Artificial Collective Immunity on New COVID-19 Pandemic Waves in Ukraine and Israel

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Abstract

Background and objectives: The percentage of vaccinated people in Ukraine and Israel extensively varies. Based on this large difference, the influence of possible collective immunity on the COVID-19 pandemic dynamics in summer 2021 was evaluated.

Methods: To clarify the presence of a natural collective immunity, the visible and actual characteristics the COVID-19 epidemic in Ukraine were estimated based on the number of laboratory-confirmed cases (accumulated in May and June 2021), using a generalized SIR-model and parameter identification procedure, and considering the difference between registered and real number of cases.

Results: The calculated optimal value of the visibility coefficient shows that most Ukrainians have already been infected with coronavirus, some of whom have been infected more than once. This suggests that Ukrainians have probably achieved a natural collective immunity. Despite the large percentage of fully vaccinated people in Israel (approximately 60%), the emergence of a new epidemic wave after June 15, 2021 was not prevented, and the number of deaths increased after July 5, 2021. A new wave of the pandemic in Ukraine after July 10, 2021 is characterized by a smaller daily number of new COVID-19 cases per capita and new deaths per capita, despite having a much lower number of vaccinated people than in Israel. This can be explained by a much lower level of testing (many cases in Ukraine remain undetected) and possibly by the probable natural immunity of Ukrainians.

Conclusions: High levels of vaccination and natural collective immunity are unlikely to prevent new waves of the COVID-19 pandemic caused by mutated coronavirus strains.

Introduction

The dynamics of the COVID-19 pandemic in Israel and Ukraine have been extensively investigated in previous reports, particularly focusing on the influence of vaccinations and possible natural immunity. In Ukraine, the early stages of the COVID-19 pandemic outbreak and pandemic dynamics were investigated using the classical SIR model, and the statistics-based method of its parameter identification proposed in 2017. Results have shown that this approach is able to predict only the first epidemic wave and when the number of registered cases reflects the real figures (first predictions based on the data-sets corresponding to the initial stages of the epidemic were two optimistic). As quarantine restrictions were reduced, changes in social behavior and subsequent coronavirus mutations impacted the epidemic dynamics and corresponding parameters of models. To detect these new epidemic waves, a simple method was proposed based on the numerical differentiations of the smoothed number
Generalized SIR model and parameter identification procedure

The description of the generalized SIR model and exact solution of the set of non-linear differential equations relating the number of susceptible S, infectious I, and removed persons R (who are or were infected, but not spread the infection at fixed moment of time t) can be found in previous reports.\textsuperscript{18,20} This solution uses the function:

\[
V(t) = I(t) + R(t)
\]

where \(V(t)\) corresponds to the number of victims or the cumulative confirmed number of cases, and its derivative is:

\[
\frac{dV}{dt} = \alpha SI
\]

which yields the estimation of the average daily number of new cases. When the registered number of victims \(V_i\) is a random realization of its theoretical dependence (1), the exact solution\textsuperscript{18,20} depends on five parameters (including \(\alpha\)). The details of the optimization procedure for identifying these parameters can be found in a previous report.\textsuperscript{21}

If we assume that data set \(V_i\) is incomplete and there is a constant coefficient \(\beta_i \geq 1\), then the registered and real number of cases during the \(i\)-th epidemic wave can be related as:

\[
V(t) \approx \beta_i V_j
\]

It means that the number of unknown parameters increases by one. The procedure to identify the unknown parameters was presented previously.\textsuperscript{10} The values \(V_j\) corresponding to the moments of time \(t_j\) during March 11–24, 2021 were used\textsuperscript{10} to find the optimal values of these parameters corresponding to the 10\textsuperscript{th} epidemic wave in Ukraine. In particular, the optimal value of the visibility coefficient was determined to be \(\beta_{10} = 3.7\).

Monitoring changes in epidemic parameters and selection of epidemic waves

Changes in the epidemic conditions (in particular, the peculiarities and violations of quarantine, situations with testing and isolation of patients, vaccinations, and emergence of new pathogen strains) affect the dynamics or, in other words, lead to new epidemic waves. To control these changes, we can use daily or weekly numbers of new cases and their derivatives.\textsuperscript{7,8,11,19} Since these values are random, smoothing is needed, especially for daily amounts, which are also characterized by some weekly periodicity. For example, we can determine the smoothed daily number of accumulated cases by:

\[
\bar{V}_i = \frac{1}{7} \sum_{j=3}^{i+3} V_j
\]

The first and second derivatives can be estimated with the following formulas:

\[
\frac{d\bar{V}}{dt}|_{t=t_i} \approx \frac{1}{2}(\bar{V}_{i+1} - \bar{V}_{i-1})
\]

\[
\frac{d^2\bar{V}}{dt^2}|_{t=t_i} \approx \bar{V}_{i+1} - 2\bar{V}_i + \bar{V}_{i-1}
\]
In this work, SIR simulations of the 11th pandemic wave in Ukraine were performed based on the number of laboratory-confirmed cases (in the period $T_{c11}$: May 23 to June 5, 2021, presented in Table 1), supposing $\beta_i = 1$ for $i = 11$. The optimal values of parameters and other characteristics of this wave were calculated and are listed in Table 3 (middle column). Comparison with the corresponding values for the 10th epidemic wave in Ukraine indicate a large difference between the optimal values of SIR parameters for the 11th and 10th pandemic waves.\textsuperscript{10} In particular, the estimated average time of spreading the infection in the 10th wave, $1/\rho_{10} = 22.3$ days, is much less than $1/\rho_{11} = 4.1$ days, and the duration of the 11th epidemic wave (ended on August 25, 2021, corresponding to the moment when the number of infectious persons becomes less than one) was optimistic compared to the 10th wave (ended on March 29, 2022).

The difference in saturation levels (final sizes) was found to be rather small ($V_{11\infty} = 2,226,797$ and $V_{10\infty} = 1,783,175$). As of July 18, 2021, the registered number of COVID-19 cases in Ukraine
Table 2. The daily number of new COVID-19 cases per capita (DCC), new deaths per capita (DDC), daily number of tests per capita (DTC), and the percentage of fully vaccinated people (VC) in Israel and Ukraine in the period of June 1 to September 3, 2021.

| Day in 2021 | Israel | Ukraine |
|-------------|--------|---------|
|             | New cases per million DCC | New deaths per million DDC | New tests per thousand DTC | People fully vaccinated, %, VC | New cases per million DCC | New deaths per million DDC | New tests per thousand DTC | People fully vaccinated, %, VC |
| June        |        |         |                     |                           |                      |                     |                           |                             |
| 1           | 4.096  | 0.114   | 2.474               | 58.47                     | 52.178               | 3.888               | 0.609                     | 0.3                          |
| 2           | 0.683  | 0.228   | 1.962               | 58.48                     | 53.719               | 3.796               | 0.643                     | 0.32                         |
| 3           | 1.707  | 0.114   | 1.798               | 58.5                      | 62.277               | 2.485               | 0.609                     | 0.33                         |
| 4           | 0.796  | 0.114   | 2.047               | 58.5                      | 55.053               | 2.347               | 0.66                      | 0.34                         |
| 5           | 3.072  | 0.114   | 0.834               | 58.5                      | 46.725               | 2.163               | 0.669                     | 0.34                         |
| 6           | 0.569  | 0       | 1.824               | 58.51                     | 24.732               | 1.081               | 0.385                     | 0.34                         |
| 7           | 1.593  | 0       | 2.618               | 58.52                     | 15.345               | 0.851               | 0.247                     | 0.35                         |
| 8           | 0      | 0       | 2.417               | 58.53                     | 39.939               | 2.876               | 0.767                     | 0.37                         |
| 9           | 0      | 0       | 1.927               | 58.55                     | 34.992               | 1.91                | 0.583                     | 0.42                         |
| 10          | 5.12   | 1.138   | 2.011               | 58.56                     | 44.264               | 2.393               | 0.667                     | 0.47                         |
| 11          | 2.617  | 0       | 1.988               | 58.56                     | 40.192               | 1.748               | 0.594                     | 0.53                         |
| 12          | 0.91   | 0       | 1.187               | 58.56                     | 32.761               | 1.725               | 0.621                     | 0.55                         |
| 13          | 0.569  | 0.228   | 2.11                | 58.58                     | 23.443               | 0.851               | 0.394                     | 0.55                         |
| 14          | 2.73   | −0.228  | 2.996               | 58.59                     | 13.597               | 0.391               | 0.268                     | 0.6                          |
| 15          | 1.251  | 0       | 2.56                | 58.61                     | 27.538               | 1.886               | 0.743                     | 0.66                         |
| 16          | 2.162  | 0       | 2.093               | 58.62                     | 28.366               | 1.979               | 0.652                     | 0.72                         |
| 17          | 3.072  | −0.114  | 1.887               | 58.63                     | 31.932               | 1.403               | 0.622                     | 0.78                         |
| 18          | 2.503  | 0       | 2.309               | 58.63                     | 27.101               | 1.288               | 0.596                     |                             |
| 19          | 6.94   | 0       | 1.44                | 58.63                     | 24.824               | 1.035               | 0.609                     | 0.83                         |
| 20          | 4.209  | 0       | 2.805               | 58.65                     | 16.633               | 0.667               | 0.319                     | 0.83                         |
| 21          | 13.994 | 0       | 3.688               | 58.66                     | 13.505               | 0.483               | 0.206                     | 0.83                         |
| 22          | 10.125 | 0.114   | 3.517               | 58.67                     | 13.182               | 0.644               | 0.273                     | 0.91                         |
| 23          | 16.61  | 0       | 3.374               | 58.68                     | 25.905               | 1.817               | 0.605                     | 1                            |
| 24          | 24.915 | 0.114   | 3.4                 | 58.7                      | 28.712               | 1.541               | 0.518                     | 1.13                         |
| 25          | 22.071 | 0       | 4.524               | 58.71                     | 27.699               | 1.449               | 0.448                     | 1.27                         |
| 26          | 21.047 | 0       | 2.487               | 58.71                     | 25.514               | 1.012               | 0.5                        | 1.32                         |
| 27          | 7.395  | 0       | 3.457               | 58.75                     | 18.842               | 0.575               | 0.32                      | 1.33                         |
| 28          | 35.041 | 0       | 5.423               | 58.79                     | 15.575               | 0.437               | 0.278                     | 1.36                         |
| 29          | 32.993 | 0       | 5.331               | 58.83                     | 13.367               | 0.322               | 0.251                     | 1.49                         |
| 30          | 33.107 | 0       | 4.965               | 58.86                     | 23.972               | 1.15                | 0.518                     |                             |
| July        |        |         |                     |                           |                      |                     |                           |                             |
| 1           | 32.993 | 0       | 5.074               | 58.9                      | 25.767               | 1.449               | 0.481                     | 1.76                         |
| 2           | 34.586 | 0       | 5.654               | 58.92                     | 25.836               | 0.989               | 0.455                     |                             |
| 3           | 31.514 | 0       | 3.089               | 58.92                     | 26.25                | 1.104               | 0.459                     | 1.94                         |
| 4           | 36.52  | −0.114  | 4.153               | 58.95                     | 19.003               | 0.529               | 0.327                     | 1.96                         |
| 5           | 56.429 | 0.114   | 6.12                | 58.99                     | 16.15                | 0.598               | 0.228                     | 2.07                         |
| 6           | 48.579 | 0       | 6.904               | 59.02                     | 22.845               | 0.713               | 0.464                     | 2.2                          |

(continued)
## Table 2. (continued)

| Day in 2021 | New cases per million DCC | New deaths per million DDC | New tests per thousand DTC | People fully vacci-nated, %, VC | New cases per million DCC | New deaths per million DDC | New tests per thousand DTC | People fully vacci-nated, %, VC |
|-------------|---------------------------|---------------------------|---------------------------|-------------------------------|---------------------------|---------------------------|---------------------------|-------------------------------|
| Israel      | Ukraine                   | Israel                    | Ukraine                   | Israel                        | Ukraine                   | Israel                    | Ukraine                   | Israel                        | Ukraine                   |
| 7           | 55.292                    | 0                         | 6.24                      | 59.05                         | 24.432                    | 1.035                     | 0.466                     | 2.34                          |
| 8           | 69.513                    | 0.341                     | 5.929                     | 59.08                         | 24.709                    | 0.782                     | 0.413                     | 2.49                          |
| 9           | 49.148                    | 0.114                     | 3.933                     | 59.1                          | 22.592                    | 0.736                     | 0.426                     | 2.68                          |
| 10          | 36.747                    | 0.341                     | 4.832                     | 59.13                         | 17.922                    | 0.345                     | 0.296                     | 2.71                          |
| 11          | 21.957                    | 0                         | 7.069                     | 59.17                         | 15.299                    | 0.391                     | 0.221                     | 2.8                           |
| 12          | 145.055                   | 0.228                     | 7.076                     | 59.23                         | 22.362                    | 1.127                     | 0.481                     | 2.9                           |
| 13          | 81.913                    | 0.114                     | 7.177                     | 59.32                         | 23.995                    | 0.828                     | 0.427                     | 3                             |
| 14          | 108.308                   | 0.228                     | 7.464                     | 59.42                         | 25.836                    | 0.713                     | 0.449                     | 3.13                          |
| 15          | 94.428                    | 0.114                     | 9.315                     | 59.49                         | 28.827                    | 0.621                     | 0.42                       | 3.24                          |
| 16          | 98.296                    | 0.228                     | 3.754                     | 59.5                          | 25.698                    | 0.621                     | 0.414                     | 3.27                          |
| 17          | 85.895                    | 0.341                     | 6.451                     | 59.61                         | 19.256                    | 0.437                     | 0.309                     | 3.29                          |
| 18          | 138.798                   | 0.114                     | 9.582                     | 59.74                         | 16.495                    | 0.299                     | 3.36                       |                               |
| 19          | 169.629                   | 0.228                     | 10.307                    | 59.87                         | 26.089                    | 0.874                     | 3.45                       |                               |
| 20          | 127.193                   | 0.228                     | 9.77                      | 60                            | 27.492                    | 0.552                     | 3.58                       |                               |
| 21          | 163.144                   | 0.341                     | 8.967                     | 60.15                         | 28.965                    | 0.782                     | 3.72                       |                               |
| 22          | 112.745                   | 0                         | 11.178                    | 60.24                         | 29.862                    | 0.736                     | 3.87                       |                               |
| 23          | 161.665                   | 0.114                     | 6.908                     | 60.26                         | 29.839                    | 0.828                     | 3.92                       |                               |
| 24          | 142.666                   | 0.228                     | 8.763                     | 60.43                         | 19.348                    | 0.506                     | 3.94                       |                               |
| 25          | 234.932                   | 0.114                     | 11.693                    | 60.59                         | 17.807                    | 0.276                     | 4.05                       |                               |
| 26          | 249.722                   | 0                         | 12.063                    | 60.74                         | 28.228                    | 0.897                     | 4.18                       |                               |
| 27          | 264.853                   | 0.114                     | 11.701                    | 60.88                         | 29.149                    | 0.667                     | 4.31                       |                               |
| 28          | 207.4                     | 0.455                     | 11.611                    | 61.04                         | 32.116                    | 0.92                      | 4.46                       |                               |
| 29          | 259.392                   | 0.341                     | 12.643                    | 61.16                         | 34.739                    | 0.736                     | 4.6                        |                               |
| 30          | 304.331                   | 0.455                     | 8.4                       | 61.2                          | 33.566                    | 0.805                     | 4.65                       |                               |
| August      |                           |                           |                           |                               |                           |                           |                           |                               |
| 1           | 202.849                   | 0.455                     | 9.176                     | 61.23                         | 23.558                    | 0.483                     | 4.68                       |                               |
| 2           | 437.895                   | 1.138                     | 12.947                    | 61.27                         | 18.497                    | 0.437                     | 4.8                        |                               |
| 3           | 358.143                   | 0.91                      | 12.59                     | 61.3                          | 31.426                    | 1.081                     | 4.95                       |                               |
| 4           | 337.665                   | 0.91                      | 13.344                    | 61.34                         | 34.969                    | 1.472                     | 5.1                        |                               |
| 5           | 504.563                   | 0.683                     | 13.21                     | 61.38                         | 36.994                    | 1.104                     | 5.25                       |                               |
| 6           | 330.384                   | 0.796                     | 13.198                    | 61.4                          | 38.374                    | 0.851                     | 5.41                       |                               |
| 7           | 480.217                   | 2.162                     | 9.542                     | 61.41                         | 37.891                    | 1.012                     | 5.48                       |                               |
| 8           | 359.054                   | 0.796                     | 10.565                    | 61.44                         | 27.929                    | 0.713                     | 5.53                       |                               |
| 9           | 673.851                   | 1.934                     | 16.164                    | 61.47                         | 20.843                    | 0.529                     | 5.65                       |                               |
| 10          | 473.732                   | 1.365                     | 15.112                    | 61.51                         | 32.07                     | 1.081                     | 5.8                        |                               |
| 11          | 872.377                   | 1.82                      | 15.894                    | 61.54                         | 39.916                    | 0.92                      | 5.94                       |                               |
| 12          | 742.34                    | 1.934                     | 14.768                    | 61.58                         | 42.975                    | 1.012                     | 6.06                       |                               |

(continued)
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(2,244,677) had already exceeded the saturation level of the 11th epidemic wave. Since the difference recorded on day 43 after the last day of the period, \( T_{c11} \), was only 0.8%, we can confirm the suitability of the generalized SIR model for forecasting pandemic dynamics. The corresponding SIR curves (black lines), registered number of cases, and the derivatives (5) and (6) (red markers) are shown in Figure 1.

The rapid increase in values of the second derivative (6) (red dots in Fig. 1) illustrates the changes in the epidemic dynamics in the first half of May 2021 (most likely due to the holidays). The values of the first derivative (5) (represented by red crosses in Fig. 1) are in good agreement with the theoretical estimation (2) (black dotted line) for the period \( T_{c11} \) but deviate for the previous moments of time, indicating significant changes in the epidemic dynamics. We can see also higher values of the first derivative (5) in comparison with the estimation (2) (see black dotted line) after the period \( T_{c11} \). In particular, as of July 15, 2021, the estimation (2) yielded a value of 13, but the average registered daily number of new cases (5) was 503. This finding and the second derivative values close to zero (eq. (6), red “dots”) indicate the beginning of a new epidemic wave.

The last column of Table 3 presents the results of SIR simulations with the non-prescribed value of \( \beta_i \). The maximum of the correlation coefficient \( r_{11} \) was achieved at \( \beta_{11} = 20.376 \), which suggests that the vast majority of COVID-19 cases in Ukraine are undocumented (the real number of cases is probably approximately 20 times higher than the registered number). The real final size of the 11th epidemic wave, \( V_{11\infty} \), is expected to be around 45.4 million persons, which exceeds the population of Ukraine. If we multiply the number of registered cases (2,244,677 as of July 18, 2021) by the visibility coefficient \( \beta_{11} = 20.376 \), the result of 45.7 million persons is even higher. It is likely that millions of Ukrainians have already been re-infected and that the nation has achieved natural collective immunity (as of July 18, 2021, the percentage of fully vaccinated persons was only 3.5%).

If the calculated value of the visibility coefficient \( \beta_{11} \) is correct, the mortality rate in Ukraine is not high. To estimate the actual value of the deaths per case ratio, we considered the registered number of deaths (52,726 as of July 17, 2021). While all deaths caused by coronavirus have not likely been reported, the visibility rate of mortalities is less than 20.376 due to the fact that critically ill patients usually go to hospitals and the corresponding deaths are properly recorded. Thus, the most optimistic estimation of the mortality rate is 52,726*100%/(2,244,495*20.376) = 0.12%.

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Table 2. (continued)

| Day in 2021 | New cases per million DCC | New deaths per million DCC | New tests per thousand DTC | People fully vacci-nated, %, VC | New cases per million DCC | New deaths per million DCC | New tests per thousand DTC | People fully vacci-nated, %, VC |
|------------|--------------------------|---------------------------|---------------------------|-----------------------------|--------------------------|---------------------------|---------------------------|-----------------------------|
| Israel     | Ukraine                  |                           |                           |                             | Israel       | Ukraine                  |                           |                             |
| 13         | 513.324                  | 0.796                     | 14.911                    | 61.6                        | 43.228       | 1.472                    | 0.513                     | 6.19                        |
| 14         | 639.607                  | 1.251                     | 9.46                      | 61.61                       | 45.23        | 0.943                    | 0.574                     | 6.25                        |
| 15         | 507.863                  | 5.233                     | 10.546                    | 61.66                       | 30.115       | 0.759                    | 6.3                        |
| 16         | 989.559                  | 2.162                     | 17.379                    | 61.71                       | 23.65        | 0.713                    | 6.42                       |
| 17         | 938.818                  | 1.934                     | 16.989                    | 61.77                       | 34.486       | 1.081                    | 6.56                       |
| 18         | 669.3                    | 2.162                     | 17.277                    | 61.82                       | 47.139       | 1.38                     | 6.69                       |
| 19         | 957.135                  | 3.299                     | 16.666                    | 61.87                       | 49.67        | 1.265                    | 6.86                       |
| 20         | 865.324                  | 0.796                     | 17.135                    | 61.91                       | 50.383       | 1.081                    | 0.54                      | 7.05                        |
| 21         | 827.894                  | 1.82                      | 11.656                    | 61.92                       | 53.328       | 1.334                    | 0.631                     | 7.15                        |
| 22         | 572.825                  | 6.257                     | 12.624                    | 61.98                       | 36.58        | 0.943                    | 7.22                       |
| 23         | 976.817                  | 2.958                     | 18.03                     | 62.03                       | 27.354       | 0.644                    | 7.32                       |
| 24         | 1,378.078                | 2.73                      | 17.703                    | 62.08                       | 29.103       | 1.081                    | 7.34                       |
| 25         | 751.1                    | 3.186                     | 16.907                    | 62.13                       | 29.701       | 0.989                    | 7.62                       |
| 26         | 1,188.426                | 3.299                     | 16.991                    | 62.18                       | 48.704       | 1.518                    | 0.532                     | 7.89                       |
| 27         | 722.658                  | 1.138                     | 15.938                    | 62.21                       | 58.872       | 2.002                    | 0.53                      | 8.14                       |
| 28         | 1,271.591                | 0.341                     | 12.222                    | 62.23                       | 59.54        | 1.794                    | 0.635                     | 8.27                       |
| 29         | 660.881                  | 4.437                     | 10.385                    | 62.3                        | 55.076       | 1.219                    | 0.422                     | 8.33                       |
| 30         | 1,123.919                | 6.144                     | 17.296                    | 62.38                       | 27.975       | 0.782                    | 0.218                     | 8.56                       |
| 31         | 553.37                  | 0                        | 18.467                    | 62.45                       | 41.296       | 1.61                     | 0.491                     | 8.8                        |

| September  |                           |                           |                           |                             |                           |                           |                           |                             |
| 1          | 1,891.857                | 4.892                     | 17                        | 62.51                       | 57.239       | 1.426                    | 0.647                     | 8.99                       |
| 2          | 1,581.383                | 4.096                     | 16.038                    | 62.59                       | 66.05        | 1.449                    | 0.541                     | 9.23                       |
| 3          | 920.388                  | 0.796                     | 62.63                     | 70.836                      | 0.422        | 1.449                    | 0.542                     | 9.5                        |
As in the case of $\beta_i = 1$, there is a large difference between the optimal values of SIR model parameters of the 10th and 11th epidemic waves (comparing last column of Table 3 with a table from a previous report\(^{16}\)). In particular, this difference is correlated with the much higher value of the visibility coefficient for the 11th wave ($\beta_{11} = 20.376$ in comparison with $\beta_{10} = 3.7$). The optimistic prediction that the 11th epidemic wave ended on September 20, 2021 is most likely not reliable since the beginning of a new epidemic wave was already visible in Figure 1. In addition, there is no guarantee that the emergence or import of new coronavirus strains, which could cause new epidemic waves, can be prevented in Ukraine.

Using the optimal values of parameters in the last column of Table 3, SIR curves corresponding to the real epidemic dynamics with the use of the exact solution\(^{18,20}\) were calculated. These results are represented by blue lines in Figure 2, in which the solid line indicates complete accumulated number of cases (visible and invisible); the dashed line refers to the complete number of infectious persons multiplied by 100, i.e. $I(t)x100$; and the dotted black lines represent the derivative $dV/dt$ (which is an estimation of the real daily number of new cases) calculated with the use of (2) and multiplied by 100.

The estimated real average number of new daily cases for the 11th wave (red crosses in Fig. 2) were determined by multiplying the derivative (5) by $100\beta_i$. These values are in good agreement with the theoretical estimation (2) for the period $T_{ci}$ (May 23 to June 5, 2021) but deviate for the moments of time before and after this period (similar to the visible dynamics in Fig. 1). The red line in Figure 2 represents the smoothed accumulated number of laboratory-confirmed cases (eq. (4)) multiplied by the optimal value of the visibility coefficient $\nu_{11} = 20.376$, which is in very good agreement with the theoretical blue solid line before a new epidemic wave that started in July 2021.

In Figure 3, crosses correspond to the cases in Israel, and triangles represent cases in Ukraine. The smoothed DCC, DDC, DTC, and VC values are indicated by blue, black, magenta, and red colors, respectively. It can be seen that the large percentage of vaccinated persons in Israel (approximately 60%, red “crosses”) did not prevent the emergence of a new epidemic wave after June 15, 2021 (blue “crosses”), and an increase in the number of deaths (see black “crosses”) occurred after July 5, 2021. In Ukraine, a new wave of the pandemic beginning after July 10, 2021 is characterized by lower DCC (blue “triangles”) and DDC (black “triangles”) values, despite having a much lower level of vaccinated people (VC) than in Israel (compare red markers in Fig. 3).

A possible reason for such a paradoxical situation may be due to the much smaller number of tests and, thus, higher number of undetected COVID-19 cases in Ukraine. Comparatively, the daily number of tests per capita in Israel was approximately 30 times higher (compare magenta markers). In addition, the corresponding visibility coefficients in Ukraine varied from 3.7 to 20.4 for different epidemic waves in the time period December 2020 – June 2021, but were most likely much smaller for Israel.

### Discussion

It is pertinent to know the real characteristics of the COVID-19 pandemic in order to evaluate the effectiveness of vaccinations and natural immunity. From which, we can also estimate the probability of meeting an infected person with the use of simple formula:\(^{7,8}\)

$$p(t) = \frac{I(t)}{N_{pop}}$$

where $N_{pop}$ is the population volume. As of July 19, 2021, the theoretical estimations (using the parameters presented in the last column of Table 3) yielded the value $I = 1,656$ (blue dashed line in Fig. 2), and the probability $p$ was estimated to be 0.00004, which is much lower than the corresponding estimation of 0.015 for the end of March 2021.\(^{16}\) This indicates that Ukrainians could be welcome guests in many countries in July 2021, but probably not in September 2021 during the new epidemic wave.

To clarify the influence of vaccinations in Israel, we calculated the smoothed DCC, DDC, DTC, and VC values for the period of June 1, 2020 to June 1, 2021 using datasets from JHU.\(^{32}\) According to the results in Figure 4, the maximal averaged number of daily new cases corresponding to previous pandemic waves in Israel (September 2020 and January 2021, i.e., before vaccinations) were lower than the DCC values in August 2021 (compare

### Table 3. Visible and real characteristics of the eleventh COVID-19 pandemic wave in Ukraine; results are the calculated optimal values of SIR parameters and other characteristics

| Characteristics | $1^{10}$th epidemic wave, $i = 11$, $\beta_{11} = 1$ | $1^{10}$th epidemic wave, $i = 11$, $\beta_{11} = 20.376$ |
|-----------------|--------------------------------|--------------------------------|
| Time period taken for calculations $T_{ci}$ | May 23 to June 5, 2021 | May 23 to June 5, 2021 |
| $I_i$ | 10,190.8327995721 | 207,648.409124103 |
| $R_i$ | 2,180,167.16720043 | 44,423,086.1988759 |
| $N_i$ | 2,258,464 | 46,018,462.464 |
| $\nu_i$ | 60,891.3982283695 | 1,240,723.13030139 |
| $\alpha_i$ | 3.98540619731056e−06 | 1.95593158486001e−07 |
| $\rho_i$ | 0.242676955862249 | 0.242676955862287 |
| $1/\rho_i$ | 4.12070440082342 | 4.12070440082277 |
| $r_i$ | 0.996838194153353 | 0.996838194153390 |
| $S_{pop}$ | 31,667 | 645,251 |
| $V_{pop}$ | 2,226,797 | 45,373,211 |
| Final day of the epidemic wave | August 25, 2021 | September 20, 2021 |
blue “crosses” in Figs. 3 and 4). However, this difference cannot be explained by testing levels, since DTC values in January and August 2021 were similar (compare magenta “crosses” in Figs. 3 and 4). Unfortunately, the mortality rates in August 2021 were close to their maximum values in October 2020 and January-February 2021 (compare black “crosses” in Figs. 3 and 4). It must be noted that some quarantine restrictions were reinstated in Israel in the summer of 2021 (including the mandatory wearing of mask indoors on June 25, 2021 and the green pass requirement for indoor events with more than 100 participants on July 29, 2021). We can conclude that even a high vaccination rate of 60% does not allow refusing quarantine and does not reduce overall mortality. While high vaccination rates are likely to reduce mortality in the elderly, this requires specialized study. Probably, higher levels of vaccination will be able to reduce the mortality. Nevertheless, further research on these issues is still needed, for which reports on the pandemic dynamics in Qatar may be useful.

In Qatar, the vaccination rate exceeded 74.4% as of September 6, 2021, and an almost monotonous decline in DCC values was observed in summer 2021 (after a small increase at the end of August 2021, we again see smaller values in September). The averaged registered DCC values are consistent with the forecast for the real dynamics in this country, considering the calculated visibility coefficient of 5.3. According to this forecast, the end of the epidemic in Qatar is not expected to occur before January 16, 2022.

**Future directions**

Further monitoring of the COVID-19 pandemic is necessary to compare its dynamics in Ukraine and Israel. The visibility coefficients for these countries must be calculated with the use of datasets of laboratory-confirmed numbers of cases for same period of time in order to estimate the actual numbers of cases, including asymptomatic patients who were not tested or registered. It is highly important to clarify the effect of DTC values and the number of tests per case (DTC/DCC) on the visibility coefficients. This knowledge will allow us to clarify the effect of vaccinations and natural immunity on DCC and DDC. Based on the preliminary results of this study, we hypothesize that high levels of vaccinations and natural collective immunity are unlikely to prevent new waves of the COVID-19 pandemic predominantly caused by new mutated strains.

**Conclusions**

The high value of the visibility coefficient (20.4) calculated for the previous epidemic wave in Ukraine leads us to conclude that Ukrain-
Fig. 2. Real COVID-19 epidemic dynamics in Ukraine in the summer of 2021. The results of SIR simulations of the eleventh wave at the optimal value $\beta_{11} = 20.376$ are represented by blue lines. Numbers of victims $V(t) = I(t) + R(t)$ – solid lines; numbers of infected and spreading $I(t)$ multiplied by 100 – dashed line; derivatives $dV/dt$ (eq. (2)) multiplied by 100 – dotted line. The red solid line shows smoothed accumulated number of laboratory-confirmed cases (eq. (4)) multiplied by the optimal value $\beta_{11} = 20.376$. The red “crosses” indicate the first derivative (5) multiplied by $100\beta_{11}$.

Fig. 3. COVID-19 pandemic dynamics in Ukraine and Israel in the summer of 2021. Averaged numbers of new cases per capita (DCC, blue), new deaths per capita (DDC, black), daily number of tests per capita (DTC, magenta) and the percentage of fully vaccinated people (VC, red) registered in Israel (“crosses”) and Ukraine (“triangles”) in the summer of 2021.
ians have probably achieved collective immunity against coronavirus. Nevertheless, in the wake of the new epidemic wave that started in July 2021, we do not predict that the number of new cases and mortality rate in this country will not considerably increase. Similar dynamics occurred in Israel with a rather high level of vaccinations (more than 60%). Our study suggests that high levels of vaccination and natural collective immunity are unlikely to prevent new waves of the COVID-19 pandemic caused by mutated coronavirus strains.

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Conflict of interest

The author states no conflict of interests.

Ethical statement

No human or animal subjects were involved in this study.

Data sharing statement

The data used to support the findings of this study are available from the corresponding author upon request.

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