Determinants of COVID-19 Hospitalizations in Slovakia

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Abstract: Prediction of COVID-19 related hospital admissions, especially in the conditions where testing strategies are changing due to introduction of mass rapid antigen testing without their PCR confirmation is very important. We introduce simple, short time prediction model for hospital admissions, where positive PCR and AG tests are used.

1 Introduction

The COVID-19 pandemic is overwhelming hospital capacities all over the world. Slovakia is a small country with 5.5 million inhabitants and limited resources of healthcare system (Figure 1). Slovakia has fared very well during the first wave of the COVID-19 pandemic but was hit much harder in the second wave. Expecting second wave of the pandemic, 1000 new ventilators were procured. Despite that, healthcare workers are significantly understaffed, especially anaesthesiologists and intensivists, including nurses. Understanding the evolution of hospitalisations and ability to make short term forecasts can improve strategy and preparedness. Projection models are dependent on known disease prevalence, partially reflecting results of PCR tests. However new testing strategies, especially introduction of mass use of antigen rapid tests, changed the relationship between PCR-confirmed infections and hospitalizations.

Slovakia has attempted various non-traditional strategies to contain the spread of the epidemic. Most notable is a mass testing of the whole adult population (10–65 years old) with antigen tests. Mass testing started with a pilot phase on October 23–25, followed by a nationwide test on the weekend of October 31 to November 1, and a subsequent second round of mass testing limited to districts with high positivity in the first round (over 0.7%, covering slightly more than half of the country) on November 7–8. Pilot testing in the four most affected districts covered 145 945 inhabitants with 5 594 positive findings. During the second round 3 625 332 tests were performed with 38 359 positive findings. Third phase of testing identified 13 509 positive tests in 2 044 855 participants. Overall, in only three weeks 5 811 163 tests were performed with 57 467 positive results (Ministry of Interior of the Slovak Republic, 2020; Ministry of Defence of the Slovak Republic, 2020). Subsequently, mobile test centres were set up in most of 80 administrative districts of country, where inhabitants have opportunity to get tested free of charge. These performed 1 702 679 tests with 96 475 positive findings as of December 21, 2020 (korona.gov.sk, 2020). Most results of the rapid antigen tests were not confirmed with PCR test. Mass testing had an instant effect on lowering the number of subsequent positive PCR tests, but as of the beginning of December 2020 the epidemic was on the rise again (Public Health Authority of the Slovak Republic, 2020). The decline in confirmed infections via PCR tests after the two rounds of mass testing shows that the series is a poor determinant of the evolution of the epidemic. We find that both types of tests and also the positivity rates contribute to the description of the situation.

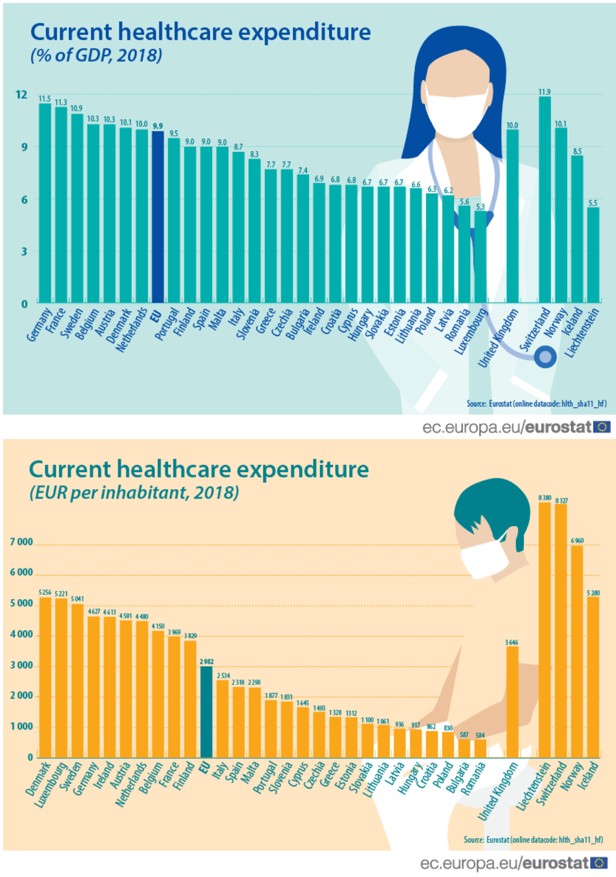

Figure 1: Comparison of healthcare spending among EU countries. Source: Eurostat

In this paper, we present a model explaining COVID-19 hospitalizations in Slovakia. We are able to make short-

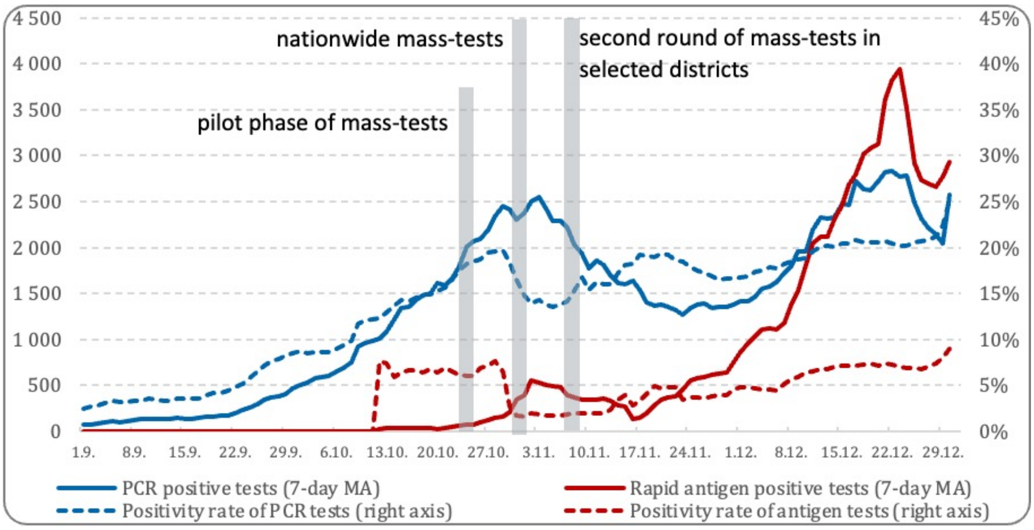

Figure 2: Comparison of PCR and rapid antigen test results. Statistics form the pilot and two rounds of mass tests are not included in the figure. Source: own calculations based on korona.gov.sk.

term projections of hospitalizations, giving the authorities some advance notice to adjust social distancing measures or to reorganize healthcare capacities.

The data collected until December 20, 2020 were used for analysis and short-time hospital admission predictions for the time period between December 21, 2020 and January 31, 2021.

2 Model

We model admissions to hospitals and discharges separately, as they follow very different processes. The admissions are mostly determined by the epidemic situation in the general population. The discharges follow the medical situations of individual patients, and partly also the existing procedures in hospitals.

2.1 Admissions

As the SARS-CoV-2 infection spreads among the population, some infected individuals develop symptoms of COVID-19 severe enough to warrant hospital admissions. It follows, therefore, that admissions should be related to the new infections in the population, and possibly the severity of new infections. We have identified four significant epidemiological factors that contribute significantly to hospital admissions:

- **Number of positive PCR tests;** this factor is commonly interpreted as the number of confirmed infections, a globally and thus far most consistently reported dynamical variable that allows comparison of the epidemic situation among countries. In general, the number of positive PCR tests provides a measure that represents a systematic part of all infected individuals in the country, particularly in countries with high test volumes and developed large scale contact tracing, where most of infected individuals are tested and detected sufficiently early. Thus, it is an important factor that contributes to hospital admissions as a part of infected individuals develop symptoms, and with some lag, the symptoms become severe enough to lead to hospitalization. (As discussed above, the Slovak healthcare infrastructure was severely overwhelmed with mass-testing in November, leading to a systematic decrease in traditional PCR testing and a subsequent fall in confirmed infections.)

- **Number of positive antigen (AG) tests;** this factor is commonly interpreted as the number of confirmed individuals in the early stages of infection. Since mid-November 2020 Slovakia has offered AG testing for the general population. AG tests are popular among the public (there are approximately 4-times more Ag tests than PCR administered over the recent weeks), since tested individuals do not need any test prescription or official indication, and the test results are available in approximately 15 minutes after a sample collection. To some degree the AG tests are a substitute for PCR tests, albeit imperfect. Both the sensitivity and specificity of the AG tests are lower. Since AG tests tend to detect individuals in early stages of the COVID-19 infection, we expect a longer lag between a positive AG test and eventual hospitalization than between a positive PCR test and hospitalization.

- **Positivity of PCR and positivity of AG test;** these two factors identify the fraction of administered AG and PCR tests with positive results. Numbers of positive PCR and AG tests characterize the epidemiological situation only partially, as they are strongly influenced by the number of tests administered. An addition of the two test positivity factors contains information needed to asses both the number of tests taken and the information provided by their results.

Note that the test sample is selected by either contact tracing, self-selected by symptoms, or a need for a certificate of non-infectiousness. Therefore, we expect that the test positivity is systematically higher than the infection incidence in the general population. As long as the selection for the tests and the number of tests are not changing rapidly, the tested sample can be thought of as a condensed sample of the population and the fraction of positive tests is proportionally related to the overall SARS-CoV-2 incidence.

Regression estimates. We use the four time series of the factors described above as the explanatory variables for the time series of the observed hospital admissions. We allow the explanatory variables to have individual time lags that are also optimized within the model.

Both AG and PCR tests are subject to significant fluctuations over the week, with much lower figures over the weekends. Therefore, we use 7-day averages of all explanatory variables. MA-7 was centered to the right. A weekend dummy (alias weekend effect, which has value 1 during weekend, and 0 during week) is included to capture the lower admissions on Sundays, Saturdays, and national holidays. The data on tests are provided by the National Health Information Center on a dedicated website (Public Health Authority of the Slovak Republic, 2020). Hospital admissions data are provided by the Ministry of Health in a public data repository for researchers (Bodova and Kollar, 2020).

The functional form of the model is a linearized version of a multiplicative power function:

$$\begin{aligned}\text{Admissions} &= (\text{PCR\_tests} + \beta \cdot \text{AG\_tests})^{\alpha} \cdot \\ &\quad e^{\gamma \cdot \text{PCR\_rate}} \cdot e^{\delta \cdot \text{AG\_rate}} \cdot \text{weekend\_effect}\end{aligned}$$

or after partial log-linearization:

$$\begin{aligned}\ln(\text{Admissions}) &= \alpha \ln(\text{PCR\_tests} + \beta \cdot \text{AG\_tests}) + \\ &\quad \gamma \cdot \text{PCR\_rate} + \delta \cdot \text{AG\_rate} + \\ &\quad \text{weekend\_effect} + \varepsilon\end{aligned}$$

The estimation results are summarized in Table 1 and Figure 3. Overall, we explain 96% of the variability in the admissions. All the included variables have expected signs and are very significant, except for AG positivity rate being not statistically significant, as relevant AG testing was present only in the second half of our sample. We decide to keep the variable, as it is significant in alternative (linear) specifications of the model.

The optimal time lag for the time series of PCR tests turns out to be zero, while the optimal time lag for AG tests is 4 days. This agrees with our hypothesis that the AG tests detect individuals on average in an earlier stage

Table 1: Model for hospital admissions

Variable	Coefficient	Std. error	t-statistic	P-value
ln(tests)	0.5482	0.0120	45.636	0.000
AG tests (-4) weight	0.6239	0.2997	2.081	0.040
PCR positive rate	4.9983	0.7164	6.977	0.000
AG positive rate (-10)	1.0687	1.0789	0.991	0.324
Weekend dummy	-0.4438	0.0449	-9.874	0.000

Sample: September 1 - December 18, 2020. Included observations: 109
R^2 0.958, Adj. R^2 0.956, S.E. of regression 0.211
Log likelihood -17.11, Durbin-Watson stat. 1.634
AG tests $(-4) = -4$ days lag, AG positive rate $(-10) = -10$ days lag

of the infection, with a longer lag before hospitalization. Note, however, that due to the 7-day moving averages of the explanatory variables, the average time between a positive PCR test and hospitalization is 3 days, and the respective time between AG test and hospitalization is one week, which agrees with the generally accepted time course of the COVID-19.

Both the PCR and AG positive rates have expected positive signs. On average the rate of positive PCR tests in December was 20.6%, the figure for AG tests being 6.9%. This indicates that the tests are scarce—the rate of PCR tests is significantly above the recommended WHO standard of 5%. Increasing the PCR rate by one percentage point (i.e. from approximately 20% to about 21%) will lead to 4.4 additional hospitalizations per day, while each percentage point of positive AG tests will lead to about 2.3 extra hospitalizations per day. The optimal lag of AG test positivity is 10 days, which means the voluntary free AG testing is an important early warning indicator of an impending worsening of the situation. Since AG testing is available on demand, without screening, the population tested is likely more similar to the general population. High positivity of AG testing indicates 10 to 14 days ahead, that there will be high demand for admissions to hospitals.

2.2 Discharges

A vast majority of patients is discharged from the hospital for two different reasons: they are either reasonably cured to be released for home treatment, or they die. On average over 20% of discharges in December were reported as deaths—although this figure may include some earlier deaths reported in December, since it takes several weeks for the pathology results to be reflected in death statistics. (Slovakia is very particular in classification of COVID-19 related deaths. Only patients who died primarily for the reason of the respiratory form of the disease are classified as COVID-19 related deaths.)

We considered a model for the two different processes, and also for a longer hospital stay of patients hospitalized at ICU or ventilated. We were not able to distinguish statistically between the different treatment regimes or their outcomes. The best fit of the hospital discharges time series we obtained as 9.2% of the 7-day moving average of time series of hospitalizations without a time lag. This corresponds to approximately 11 days of average hospital stay

Table 2: Model for hospital discharges.

Variable	Coefficient	Std. error	t-statistic	P-value
Hospitalizations	0.1129	0.0017	64.55	0.000
Hospitalizations · weekend dummy	-0.0735	0.0032	-23.20	0.000

Sample: September 1 - December 22, 2020. Included observations: 113
R^2 0.942, Adj. R^2 0.942, S.E. of regression 17.96
Log likelihood -485.72, Durbin-Watson stat. 1.55

per patient. The only other significant variable is a weekend dummy, reflecting a much lower number of patients discharged on weekends.

Linear regression. The estimation results are presented in Table 2 and Figure 4. Despite the simplicity of the model, we are able to explain 94% of the variability of hospital discharges. On weekdays 11% of the COVID-19 patients are discharged, while on weekends and holidays this falls to just 4%. Note again that the hospitalizations variable is a 7-day moving average, thus the number of discharges roughly corresponds to the volume of hospitalizations three days prior to the discharge. Thus the equation for discharges is:

$$\text{Discharges} = \alpha \text{Hospitalizations} + \beta \text{weekend\_effect} + \varepsilon$$

3 Short-term hospitalization forecasts

A forecast of time series of hospitalizations requires as an input time series of the four explanatory variables described above with appropriate time lags. Thus, a prediction model is needed for the number of positive PCR and AG tests and the overall PCR and AG positivity. In the main scenario, we assume that both PCR and AG positivity is constant for the period of prediction (using values as of December 27, 2020). This assumption is reasonable due to the fact that the rate of positive tests is rather stable in recent history and also it allows to use the observed trends in the number of positive tests observed in individual countries.

Based on the regression used in the volume of hospitalizations prediction it is only necessary to forecast a weighted linear combination of the appropriately time-lagged time series of the number of positive PCR and AG tests (see Table 1). The weighted linear combination is then a measure representing the overall observed incidence of COVID-19. The trends in the overall observed incidence were described by Bodova and Kollar (2020). For the purpose of this projection we use an ARMA model with automatically optimized lag structure.

We also add two alternative scenarios. An optimistic scenario assumes the incidence declines by about 1.5% a day during the lockdown scheduled until January 10. This roughly corresponds to a 7-day reproduction number of 0.9. After January 10 the incidence grows approximately as in the main scenario. A pessimistic scenario assumes a high rate of contacts during the holiday period. An alternative way to interpret the pessimistic scenario is materialization of the risks from a recently reported more infectious virus strain (Davies et al., 2021). In this scenario incidence grows by 4.4% until January 10 and then continues growing at the same rate as in the main scenario.

Figure 3 shows the weighted sum of test incidence used for the forecasts in the three scenarios described above. Figure 4 and Figure 5 show the forecasts for hospital admissions and discharges. Figure 6 shows the forecast of the number of hospitalized patients.

The projection interval is constructed from one standard error confidence band of admissions, while using respective point estimates for discharges, conditional on the dynamics of hospitalizations stocks. This is given by the larger uncertainty in the exogenous variables, notably results of AG and PCR tests, that determine admissions, while discharges are endogenous to the model system.

Based on the data available at the ond of December 2020, our model predicted continuation of the trend of rising hospital utilization (even in the optimistic scenario), which started at the very end of December 2020. The model predicted the increase from 2895 hospitalized patients (as of December 31) to around 3700 by the end of January 2021. Model for the pessimistic scenario predicted over 5100 hospitalized COVID patients at the end of January 2021.

4 Discussion and conclusions

Different hospital admissions prediction strategies were previously published (Wesner et al., 2021; Mohimont et al., 2021; Gerlee et al., 2021). We have presented a set of simple statistical models robustly explaining the hospitalizations, hospital admissions and discharges in Slovakia. The model, applied to the data available at the end of December 2020, predicted gradually increasing demand on hospital resources in January 2021. The model has shown that even if there was a marked improvement in COVID-19 containment policies, the explanatory variables were on a trajectory with a high degree of inertia. To the best of our knowledge, this is the first work using both PCR and AG tests as predictors of hospital admissions.

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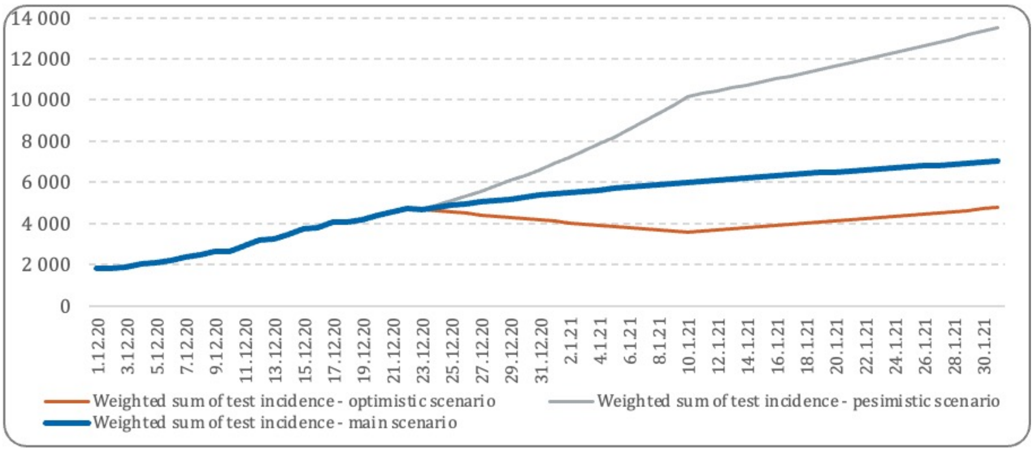

Figure 3: Weighted sum of test incidence used in the forecast

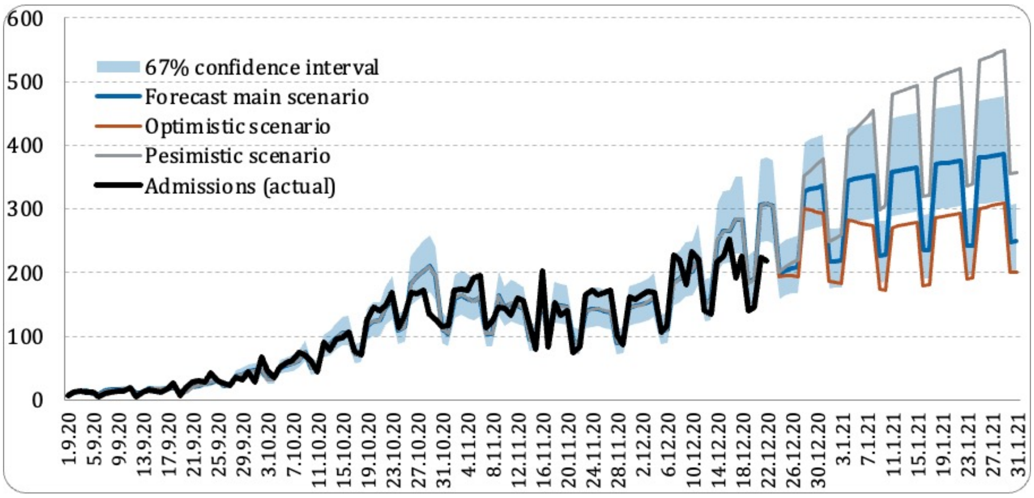

Figure 4: Hospital admissions and their short-term forecast

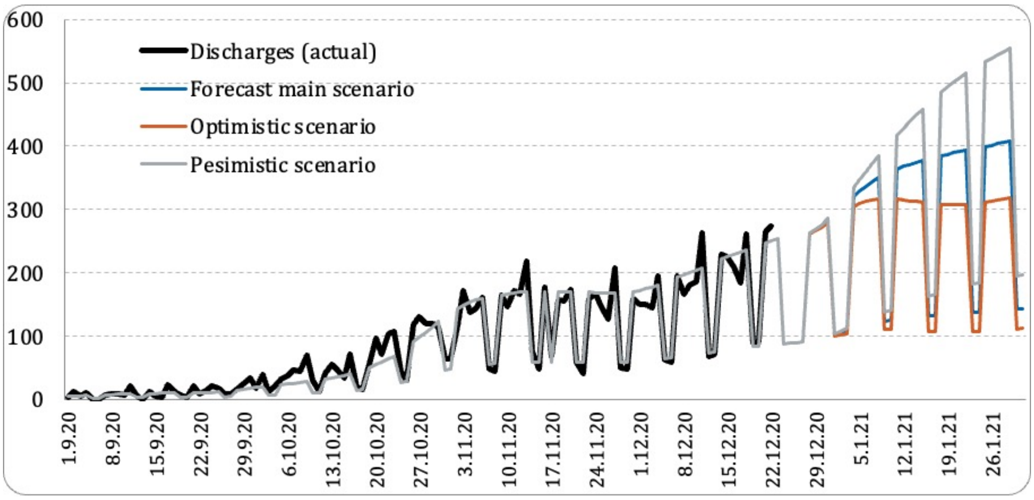

Figure 5: Hospital discharges and their short-term forecast

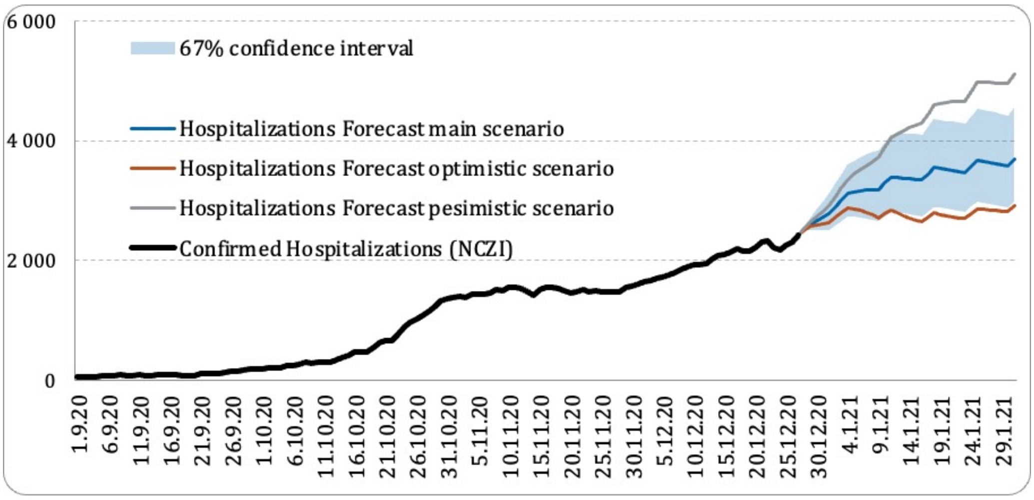

Figure 6: Volume of hospitalizations and their short-term forecast

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