 doi:10.20944/preprints202108.0111.v1

Article

A Bayesian analysis of the inversion of the SARS-COV-2 case rate in the countries of the 2020 European football championship

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Abstract: While Europe was beginning to deal with the resurgence of COVID-19 due to the Delta variant, the European football championship took place, June 11 - July 11, 2021. We studied the inversion in the decrease/increase rate of new SARS-COV-2 infections in the countries of the tournament, investigating the hypothesis of an association. Using a Bayesian piecewise regression with a Poisson Generalized Linear Model, we looked for a changepoint in the timeseries of the new SARS-COV-2 cases of each country, expecting it to appear within four weeks since the date of their first match. The two slopes, before and after the changepoint, were used to discuss the reversal from a decreasing to an increasing rate of the infections. 17 out of 22 countries (77%) have had a changepoint 14.97 days after their first match [95% CI 12.29 to 17.47]. For all those 17 countries, the changepoint coincides with an inversion from a decreasing to an increasing rate of the infections. Before the changepoint, the new cases were decreasing, halving on average every 18.07 days [95% CI 11.81 to 29.42]. After the changepoint, the cases begin to increase, doubling every 29.10 days [95% CI 14.12 to 49.78]. This inversion in the SARS-COV-2 case rate, happened during the tournament, provides evidence in favor of a relationship.

Keywords: SARS-COV-2; Bayesian regression; Changepoint detection; European football championship

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1. Introduction

Europe, as well as other countries around the world, is seeing a resurgence in the COVID-19 pandemic, after a brief respite given by the effects of the vaccination that started in the first half of 2021. This new wave of the pandemic seems to be driven by a new strain of virus that has been referred to as the Delta variant. This is the scenario in which the European football championship has taken place, from June 1 to July 11, 2021 (one year later than it should have been). This 2020 edition, being a special celebration for the 60th anniversary of the tournament, has had the peculiarity to be hosted by several different countries, instead of just one as it normally happens.

The decision to allow such a massive event across the European continent, in such a delicate time, has immediately triggered a debate on the problems it would have caused. Nonetheless, the competition has been held, leaving each hosting country some freedom on the restrictions to apply (e.g., the number of fans allowed at each football stadium). This resulted in very different behaviors, ranging from Hungary hosting its matches at a full stadium capacity at Puskás Arena (~ 68 thousand seats), to Germany limiting the attendance to the 22% of the maximum stadium capacity [1-4]. Obviously, there has been more than the stadium, with fans, massively gathering in pubs, squares and public places, to watch the matches, thus leading to infection clusters that surged all around Europe, as witnessed by the media coverage of these events [5-8]. Not only, but even the gathering of teams and their staff may have given their contribution to the spread of the virus (given the itinerant nature of this edition), as the COVID-19 literature on football and other sports suggests [9-11].

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On one side, one could conclude that those who considered this event to be a minor risk did not take into any consideration those theories that maintain that, with COVID-19, super-spreading events may be the main driver of an epidemic spread, under specific circumstances [12-13]. Exemplar, on February 19, 2020, was the Champions League match, between Atalanta and Valencia, that attracted a third of Bergamo's population to Milan's San Siro stadium. Also, more than two thousand and a half of Spanish supporters took part. Experts, now, point to that 2020 football match as one of most relevant reasons why the city of Bergamo had become the epicenter of the COVID-19 pandemic, during the first wave in Italy, with a very high death toll; not to consider that also the 35% of Valencia's team became infected [14]. On the other side, it is well known that the return of supporters to stadiums is the highest priority for football's business, and the financial impact of the COVID-19 pandemic on football will depend, almost exclusively, on both the timing and the scale of supporters' return to stadiums [15].

Following this debate, this work has focused on the European football championship and its matches, looking for a possible compatibility with the reversal of the decrease/increase trend of the SARS-COV-2 cases, observed in many countries participating in the tournament. To investigate the hypothesis of an association between those football matches and the resurgence of the virus, we searched for a changepoint in the daily timeseries of the new SARS-COV-2 cases registered in each country, expecting it to appear within four weeks since the date of the first match that national team had played. Upon finding such a changepoint, we have investigated if that changepoint was coincidental with a change in the infection rate, from a decreasing trend to an increasing one. It should be noted that our type of analysis has been observational in nature, and it has been used to determine if the exposure to the specific risk factor, given by the frequent mass gatherings following the football events, might have correlated with the particular outcome of the virus resurgence in many European countries. With this type of study, we cannot demonstrate any cause and effect, but we can make preliminary inferences on the correlation between the participation in the European football championship of a given country and the inversion in the SARS-COV-2 case rate that may have hit, at a particular point in time, the population living in that country. After this premise, we can anticipate that 17 out of 22 countries (77%) have a reversal from a decreasing to an increasing rate of the infections which is temporally coincident with their participation to the European football championship, thus providence evidence to the hypothesis of a link between the upturn of new cases and the tournament.

The remainder of the paper is structured as follows. In the next Section, we describe more precisely the data we used, their sources, as well as the methodologies we employed. Section 3 presents the results we obtained, while Section 4 discusses them, along with its limitations, and concludes the paper, presenting our final considerations.

2. Materials and Methods

In this Section, we will provide a description of the data on which our analysis is based, along with the methods used for its collection and the sources from which we collected it (Section 2.1). Then, we will present the methodologies we have chosen to conduct our analysis (Section 2.2).

2.1 Data Collection

The timeframe for this study starts two weeks before the start of the tournament on May 28 and ends two weeks after the final match on July 25, 2021. All data regarding COVID-19 infections were collected from the online repository: *Our World in Data* [16], that in turn aggregates various sources. In particular, confirmed cases are provided by the *COVID-19 Data Repository by the Center for Systems Science and Engineering at the Johns Hopkins University*. The timeseries of daily confirmed cases was then smoothed using a rolling average with a 7-day long window. This was useful to remove the periodicity patterns of the various testing and registering case processes, with some countries that unfortunately release numbers once every few days (e.g., Sweden) or slow down on weekends (e.g., Italy). Data for the European football championship were collected from the relevant Wikipedia page [17]. We looked at the participating countries, their first and last matches in the competition, and their

 doi:10.20944/preprints202108.0111.v1

last hosted match (if they were a hosting country). These dates were then compared with the changepoints found with the Bayesian method described in the next Section. For the sake of simplicity, given that the data for the United Kingdom were given as a whole in the dataset we used, we considered Wales, Scotland and England as a single entity, even if the three countries have participated individually.

2.1.1 Patient and Public Involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research. All data come from publicly available repository where they are stored in an aggregated and anonymized format.

2.2 Bayesian Changepoint Detection and Analysis

Using a changepoint estimation technique based on a Bayesian piecewise regression, we have looked for a changepoint in the trend of the infection curve, whether it was growing or falling. In particular, we fitted a Poisson Generalized Linear Model where the dependent variable was the number of new daily confirmed SARS-COV-2 cases, and the independent variable (i.e., x) was just the number of days since May 28, 2021 (until July 25). The result was a model comprised of a changepoint and two segments, whose slopes represent, respectively, the decreasing case rate before the changepoint and the increasing case rate after it. To be noticed is the fact that our interest was not in modeling the spread of the virus with the maximum precision, but rather in finding the point in time when the infection rate inverted its trend, with the added bonus of a Bayesian uncertainty estimation, baked in the process. The model, takes the mathematical form below:

$$\begin{aligned} \ln\big(E(Y|x)\big) &= a_1 + xb_1 \text{ if } x < \tau \\ \ln\big(E(Y|x)\big) &= a_2 + xb_2 \text{ if } x > \tau \end{aligned} \tag{1}$$

To be noticed is that our dependent variable (the natural log of the confirmed daily cases) was modelled as a Poisson distribution, whose mean depends on the regression coefficients a_1 and b_1, respectively the intercept and angular coefficient before the changepoint τ (while a_2 and b_2 play the same role after the changepoint). To be considered are the two following facts. First, since the two regression lines are joined at the changepoint τ, the second intercept term a_2 is not estimated as it is bound to be $a_2 = \tau\,(b_1 - b_2) + a_1$. Second, the presence of the algorithm in the formula returns both the exponential decay before τ and the exponential growth after it as easily identifiable slopes. We used the R package mcp to fit the model above using a Markov Chain Monte Carlo method [18]. For starting the Bayesian estimation, the default priors for τ, a_1, a_2 and b_1 were chosen as suggested in the already mentioned reference [18], thus considering the prior of τ as a uniform, and the parameters a_1, b_1 and b_2 as normally distributed, as reported in the following formulas:

$$\tau \sim \text{Uniform}\,(\min(x)\,, \max(x)) \tag{2}$$

$$a_1, b_1, b_2 \backsim \mathcal{N}(0,10) \tag{3}$$

It is now worth noticing that the mean value of the computed changepoints was used to calculate the distance in time between the date of a given changepoint and that of the first match played the corresponding team. Similarly, the mean values for the coefficients b_1 and b_2 were used to compute the steepness of the two slopes, respectively before and after the changepoint. Aggregate statistics of all these values were obtained, with their confidence intervals (CI), using bootstrap. To conclude, the general methodology with which we verified the hypothesis of an association between the resurgence of the virus and the participation in the tournament. With the method above, for each given country we looked for a changepoint in the corresponding infection curve. If a changepoint was detected

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within four weeks since the date of the first match that national team had played, we checked if an inversion occurred from a decreasing to an increasing rate in the number of the new infections, coincidental with the changepoint. If such reversal occurred, we considered that country in the group of those providing an evidence in favor of a relationship.

3. Results

These are the results we obtained with the data and methodology explained before. 17 out of 22 (77%) countries taking part in the European football championship have shown a changepoint within four weeks since their first match (i.e., during the tournament). For all these 17 countries, the changepoint coincides with a reversal in the new daily SARS-COV-2 cases from a decreasing to an increasing rate. The group of all these countries provides an evidence in favor of the hypothesis. Precisely, the group is comprised of all the following countries: Austria, Belgium, Croatia, Czechia, Denmark, Finland. France, Germany, Hungary, Italy, Netherlands, North Macedonia, Poland, Slovakia, Spain, Switzerland and Ukraine. Table 1 provides the lists of those countries, where under the τ column we listed for each country the mean value of the days passed before the changepoint was detected since the beginning of the period of observation (i.e., May 28, 2021). Since we are working with a distribution, in brackets the 95% CI are indicated. In the *diff* column, instead, we have listed the difference, in terms of days, between the point in time when the changepoint occurred and the date of the first match played by that given national team. The third and fourth column of Table 1 show the mean values (with the corresponding 95% CI intervals) for the coefficients b_1 and b_2, that have been used to compute the steepness of the slopes, respectively before and after the changepoint. The fifth column, finally, reports the average value of the first intercept a_1, with its 95% CI. We can further work with the numbers comprised in Table 1 by rounding the mean changepoint value for all the 17 countries and then calculating the difference, in terms of days, between that value and the date when they played their first match. This way, we obtain that the average date of the changepoint, for all the 17 countries of interest, falls 14.97 days [95% CI 12.29 to 17.47] after the beginning of their participation in the tournament (approximately two weeks).

Country	τ	diff	b_1	b_2	a_1
Austria	36.4 (35.8, 37.1)	20	-0.05 (-0.06, -0.05)	0.08 (0.08, 0.09)	6.28 (6.25, 6.32)
Belgium	24.9 (24.6, 25.2)	10	-0.06 (-0.06, -0.06)	0.04 (0.04, 0.04)	7.70 (7.68, 7.71)
Croatia	28.7 (27.4, 30.3)	13	-0.06 (-0.06, -0.06)	0.02 (0.02, 0.03)	5.87 (5.83, 5.92)
Czechia	26.2 (25.3, 27.2)	9	-0.06 (-0.06, -0.05)	0.02 (0.02, 0.03)	6.30 (6.26, 6.34)
Denmark	28.2 (27.8, 28.6)	13	-0.06 (-0.06, -0.06)	0.05 (0.05, 0.06)	7.13 (7.11, 7.15)
Finland	19.8 (18.4, 21.0)	5	-0.03 (-0.04, -0.03)	0.04 (0.04, 0.05)	4.98 (4.90, 5.05)
France	34.7 (34.6, 34.8)	17	-0.06 (-0.06, -0.06)	0.11 (0.11, 0.11)	9.28 (9.28, 9.29)
Germany	35.1 (34.6, 35.5)	17	-0.07 (-0.07, -0.07)	0.05 (0.05, 0.05)	8.60 (8.59, 8.62)
Hungary	40.3 (38.4, 42.0)	22	-0.06 (-0.06, -0.06)	0.03 (0.02, 0.05)	5.99 (5.95, 6.03)
Italy	36.5 (36.3, 36.8)	23	-0.05 (-0.05, -0.05)	0.09 (0.09, 0.10)	8.25 (8.24, 8.26)
Netherlands	26.4 (26.2, 26.6)	10	-0.06 (-0.06, -0.06)	0.09 (0.09, 0.09)	8.18 (8.17, 8.20)
N. Macedonia	34.8 (31.9, 37.6)	19	-0.05 (-0.05, -0.04)	0.05 (0.04, 0.07)	3.59 (3.46, 3.72)
Poland	35.2 (33.5, 36.8)	18	-0.07 (-0.07, -0.07)	0.01 (-0.00, 0.01)	6.92 (6.89, 6.94)
Slovakia	39.4 (36.8, 42.1)	22	-0.05 (-0.05, -0.04)	0.02 (0.00, 0.03)	5.02 (4.96, 5.08)
Spain	24.9 (24.8, 25.0)	8	-0.01 (-0.01, -0.01)	0.07 (0.06, 0.07)	8.45 (8.44, 8.46)
Switzerland	32.9 (32.5, 33.5)	18	-0.07 (-0.07, -0.07)	0.08 (0.08, 0.08)	6.93 (6.91, 6.96)
Ukraine	25.8 (25.1, 26.5)	10	-0.05 (-0.05, -0.05)	0.00 (0.00, 0.01)	8.06 (8.04, 8.07)

Table 1: Countries with a changepoint coincidental with a reversal from a decrease to an increase in the SARS-COV-2 case rate, occurred during the European football championship.

Now, we can make a step further and, taking the mean values for the coefficients b_1 and b_2, we can estimate how the slopes for the two lines have changed, on average, before and after the

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changepoint. We obtain that all the 17 countries have had a decreasing number of daily cases until the changepoint and ended up with a reversed trend afterwards.

Table 2 shows the halving time before and the doubling time after the changepoint, for each given country of this group. More precisely, the mean halving time before the changepoint is 18.07 days [95% CI 11.81 to 29.42], while the mean doubling time after the changepoint is 29.10 days [95% CI 14.12 to 49.78]. The confidence intervals are quite wide but if we better investigate the values reported in Table 2, we recognize that most of the deviation depends on just three countries, namely: Spain, Ukraine and Poland, with their exceptionally large values.

Country	Days needed to halve the number of cases (before τ)	Days needed to double the number of cases (after τ)
Austria	12.69	8.18
Belgium	11.05	17.60
Croatia	11.77	28.32
Czechia	12.05	28.22
Denmark	11.49	12.71
Finland	21.81	15.84
France	11.86	6.32
Germany	10.14	13.17
Hungary	11.10	22.10
Italy	13.56	7.43
Netherlands	12.11	7.69
N. Maced.	14.88	13.20
Poland	9.67	92.80
Slovakia	14.91	41.59
Spain	103.50	10.62
Switzerland	10.03	8.56
Ukraine	14.43	159.00

Table 2: Quantifying the inversion from a decrease to an increase in the SARS-COV-2 case rate for the countries of Table 1.

To better highlight and summarize all the results we have discussed so far, we also present Figure 1 and Figure 2, where the same results are portrayed from a clear graphical viewpoint.

In particular, Figure 1 takes into account the inversion of the SARS-COV-2 case trend of the following countries: Austria, Belgium, Croatia, Czechia, Denmark, Finland. France, Germany, Hungary, Italy, while Figure 2 shows the inversion of the SARS-COV-2 case trend of Netherlands, North Macedonia, Poland, Slovakia, Spain, Switzerland and Ukraine.

We used two separate Figures just for the sake of manageability. At the end, based also on these Figures, we can maintain that these results are fully compatible with the tournament being a factor.

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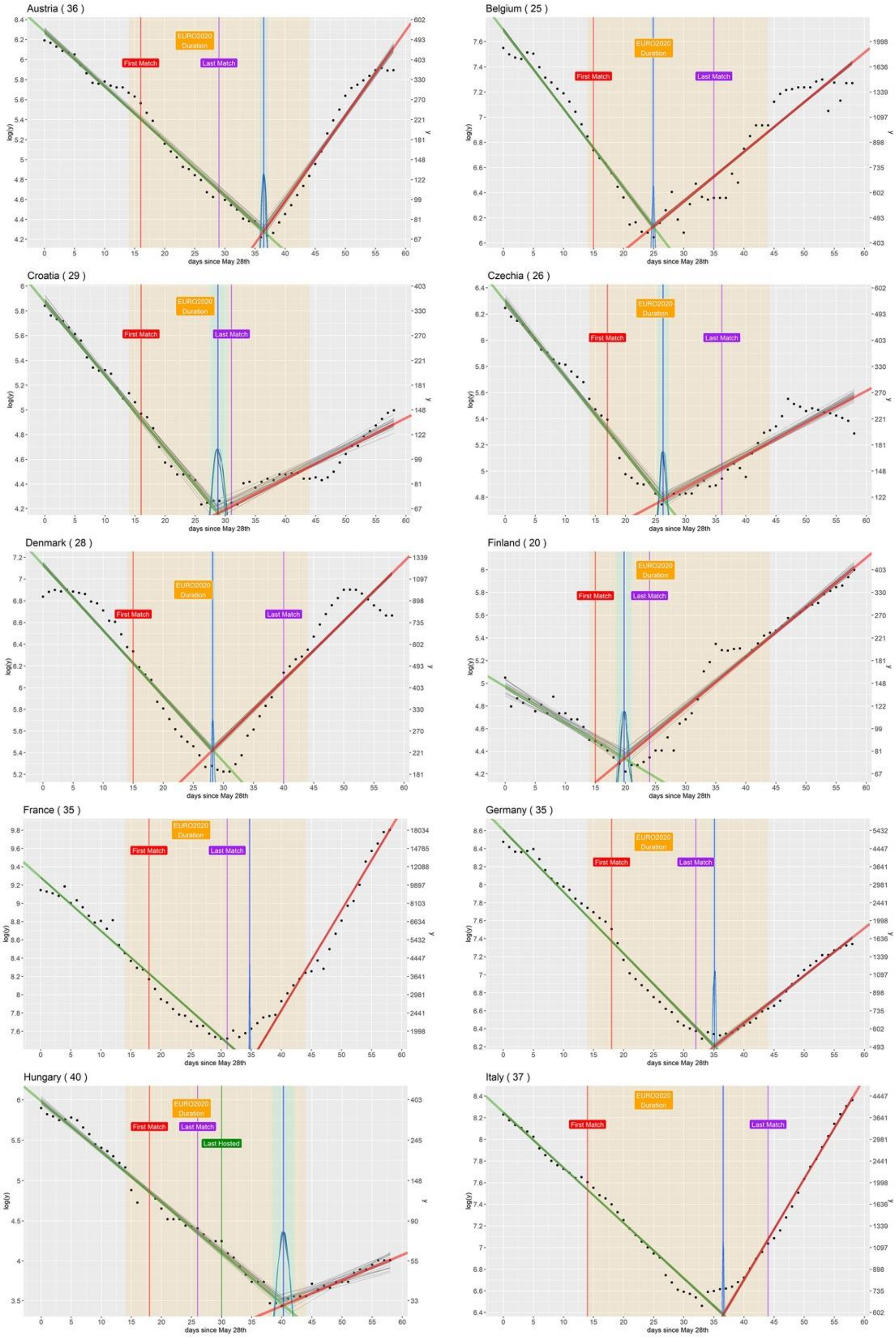

Figure 1: Inversion of the SARS-COV-2 case trend **for** Austria, Belgium, Croatia, Czechia, Denmark, Finland. France, Germany, Hungary, Italy.

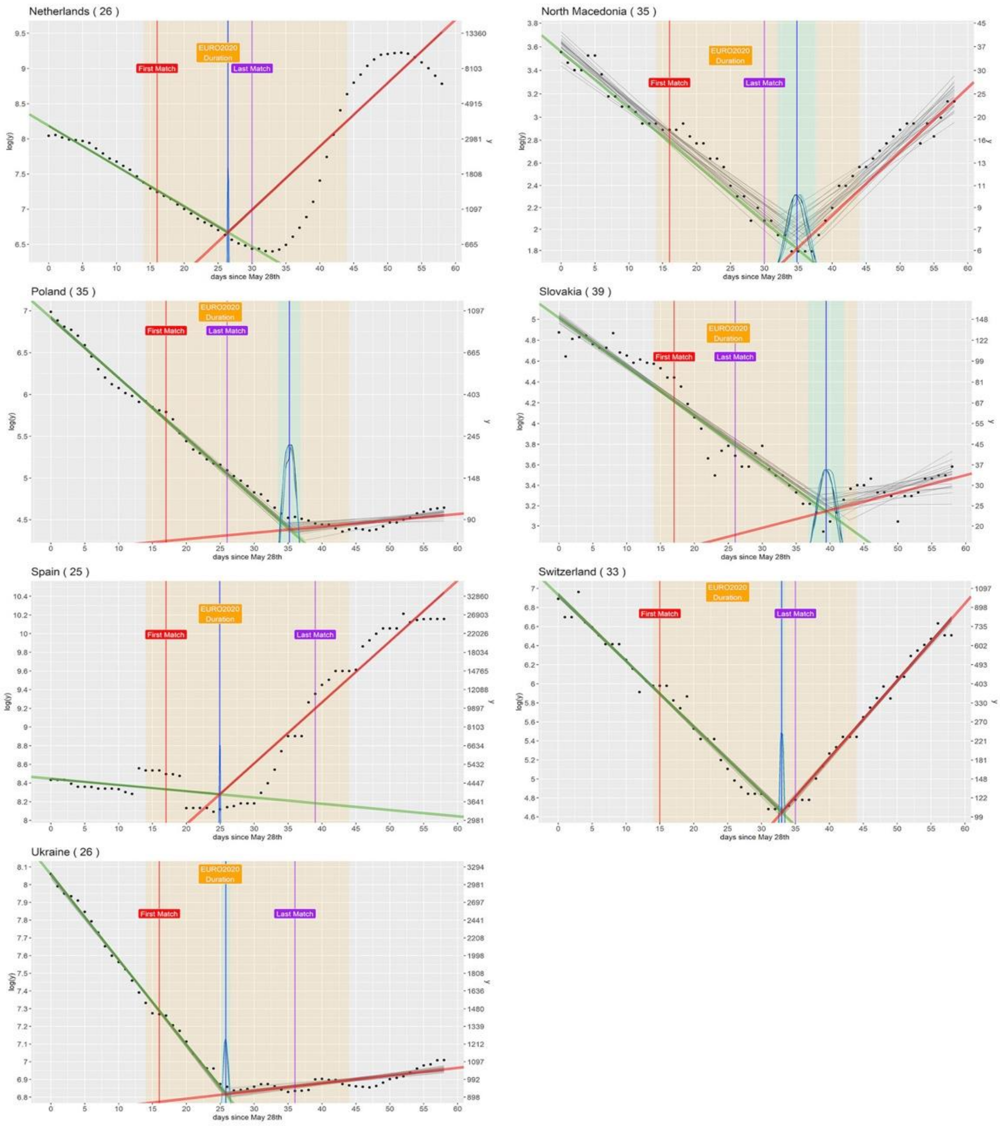

Figure 2: Inversion of the SARS-COV-2 case trend for Netherlands, North Macedonia, Poland, Slovakia, Spain, Switzerland, Ukraine.

All the 5 remaining countries (i.e., Portugal, Russia, Sweden, Turkey and UK), instead, break the pattern and cannot and considered an evidence in favor of the research hypothesis. In particular: i) Portugal, Russia and UK show a robust increasing trend in the SARS-COV-2 infection case starting well before the beginning the tournament, hence the detected changepoints, as well as the relative slopes, are simply nonsensical, ii) Turkey seem to show quite a regular pattern, with a well identifiable changepoint and the usual inverting trend in the case rate, nonetheless the problem here is that that changepoint happens well after the team left the competition, more than four weeks since its first match; iii) finally, for Sweden, the model fails to fit because there seems to have two different changepoints, that are either before or after the tournament, making them irrelevant. The situations mentioned above are illustrated in Figure 3, where it is evident that all those five country break the pattern. Finally, Table 3 reports the value of τ, diff and of all the other parameters, with the corresponding 95% CI intervals. Of particular interest, here, is the large excursion in the CI for Sweden that witness the peculiarity of that situation. Obviously, for all these 5 five country the attempt to compute halving/doubling times makes no sense.

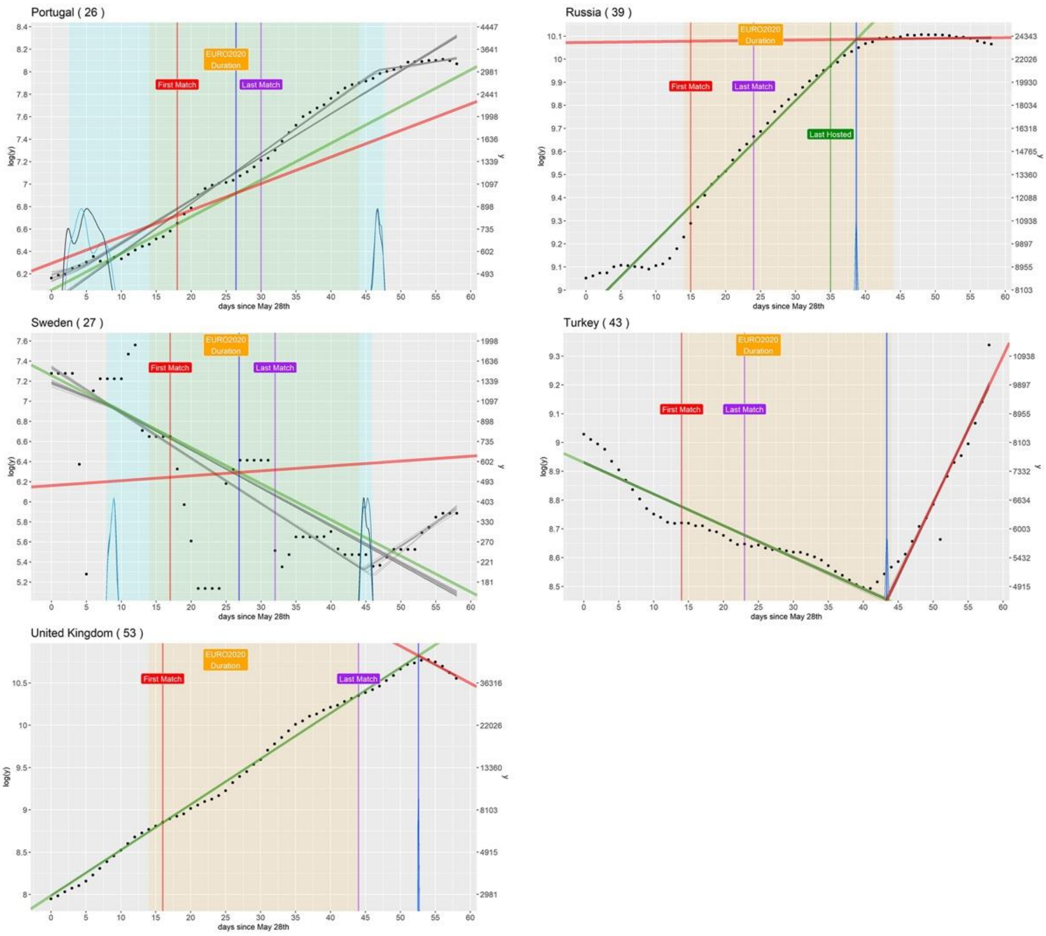

Figure 3: Portugal, Russia, Sweden, Turkey and UK break the pattern, without: i) a well recognizable changepoint and ii) a reversal from a decrease to an increase in the SARS-COV-2 case rate, occurring within four weeks since the beginning of the tournament.

Country	τ	diff	b_1	b_2	a_1
Portugal	26.4 (2.4, 47.7)	8	-0.05 (-0.06, -0.05)	0.08 (0.08, 0.09)	6.28 (6.25, 6.32)
Russia	38.7 (38.4, 39.0)	24	-0.06 (-0.06, -0.06)	0.04 (0.04, 0.04)	7.70 (7.68, 7.71)
Sweden	26.9 (7.9, 45.8)	10	-0.06 (-0.06, -0.06)	0.02 (0.02, 0.03)	5.87 (5.83, 5.92)
Turkey	43.4 (43.1, 43.6)	29	-0.06 (-0.06, -0.05)	0.02 (0.02, 0.03)	6.30 (6.26, 6.34)
UK	52.6 (52.5, 52.7)	37	-0.06 (-0.06, -0.06)	0.05 (0.05, 0.06)	7.13 (7.11, 7.15)

Table 1: Regression parameters for the five countries that break the pattern.

4. Discussion and Conclusion

With this study, we found that in 17 out of 22 countries involved in the 2020 European football championship there has been a changepoint in the number of daily new SARS-COV-2 cases during the tournament, falling on average 14.97 days [95% CI 12.29 to 17.47] after the first match they played. Not only, but the case rate of the new daily infections was inverted for all these 17 countries, changing from a decreasing trend to an increasing one. We have quantified this inversion by measuring, for each national infection curve, the halving time before the change and the doubling time after it; they are respectively, on average: 18.07 days [95% C 11.81 to 29.42] days and 29.10 days [95% C 14.12 to 49.78].

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There are five countries that break the pattern, and the presence of which could be seen as a first limitation of this study. Nonetheless, a careful consideration of the situation of these countries could provide a plausible explanation to this behavior. For example, it is evident that, for many of them (UK, Russia and Portugal), it is not possible to detect a changepoint in the infection rate which is coincidental with their participation in the tournament. This because the inflation of the new COVID-19 cases was already in act in all these countries when the tournament started, with the effect of the football championship probably absorbed in that inflation. The causes for this premature upturn of SARS-COV-2 cases are quite clear for UK, which was the first European country to face the Delta variant. Portugal, instead, could have been the first European country to face the tourism impact, with many early tourists coming just from UK. The situation in Russia, because of its enormous geographical extension, is, instead, too complex to look for a single explanation. Sweden, which reports COVID-19 numbers four days a week, is of difficult interpretation, with the model not able to spot plausible changepoint. Different is the situation for Turkey. It seems to follow the pattern, with an easily identifiable changepoint coincidental with a reversion in the decrease/increase trend of the new COVID-19 cases. Nonetheless, this changepoint comes a bit too late (29 days after its last match). Hence our decision not to consider it as a further evidence in favor of the investigated link.

A second limitation of this study is that it has ignored the possible effects of other confounding factors that could have played a role. Unfortunately, they are too many, and also country-specific in many cases, to be considered as a whole. Nonetheless, the following two facts should also be considered. A general trend toward the decrease of the new daily SARS-COV-2 cases had already begun during the beginning of the 2021 spring, in almost all the considered countries, as an effect of the vaccination. In response to the benefits of the vaccines, almost all these European countries had consequently begun to lift the restrictions that were imposed to combat the third wave of the contagion. This happened well before the beginning of the tournament, and without any evident effect in terms of an upturn of new SARS-COV-2 cases (with the only exception of the already discussed situation in UK). It is a matter of fact, instead, that many infection clusters have surged in Europe during the football tournament. At the end, in spite of many possible country-specific confounding factors that could have played a role, our study has revealed that the temporal coincidence between the tournament and the inverting trend of the infections in many participating countries is an issue which cannot go unnoticed.

A third and final limitation touches more upon the mathematical and statistical nature of our analysis. We have already anticipated that our study is purely observational, without any possibility to demonstrate the existence of a clear relationship of cause and effect. Our intent has simply been that of enquiring if all the mass gatherings following the football matches could have correlated with the virus resurgence in many European countries. For this reason, to study the plausibility of the correlation of interest, we have developed a simple model (similar to that employed in [19]) that does not possesses the ambition of being exhaustive in the representation of the COVID-19 dynamics [20], but it is very effective in detecting changepoints in the infection curves, with the two corresponding slopes (before and after it) with which the decrease/increase case trends can be analyzed. At the end, we can conclude that the results of our analysis are compatible with the hypothesis that most of the countries involved in the European football championship have seen a rise in the number of new SARS-COV-2 cases, or a slowdown in the fall, temporally coincident with their participation. While this study has no ability to establish a final causal relationship, we think that the tournament, with its mass gatherings inside and outside the stadiums, has surely had an effect, that coupled with the release of restrictions, could have given a relevant contribution to ignite a new wave of the COVID-19 spread.

Author Contributions: Conceptualization, L.C. and M.R.; methodology, L.C. and M.R.; software, L.C..; validation, L.C. and M.R.; formal analysis, L.C..; investigation, M.R.; resources, M.R.; data curation, L.C.; writing—original draft preparation, L.C. and M.R.; writing—review and editing, L.C. and M.R.; visualization, L.C..; supervision, M.R.; project administration, M.R.; funding acquisition, M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Conflicts of Interest: The authors declare no conflict of interest.

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