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An Effectiveness Analysis of Non-Pharmaceutical Interventions (NPIs) Implemented in European Countries through Machine Learning

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Abstract. Non-pharmaceutical interventions (NPIs) were demonstrated as effective measures for mitigating SARS-CoV-2 transmission during the early stages of the pandemic. This study aims to explore the impact of NPIs by utilizing a Seasonal ARIMA (SARIMA) model to capture the characteristics of the time series of new COVID-19 cases in four countries—Italy, Germany, Austria, and Portugal—before the implementation of specific policies. Using this model, we predict the trend of new cases for the next month (30 units), assuming the NPIs had not been implemented. By comparing these predictions to the actual trends observed after the NPIs were applied, we evaluate the effectiveness of the interventions in reducing case numbers.

Keywords: SARS-CoV-2 transmission, Non-pharmaceutical interventions (NPIs), Seasonal ARIMA.

1. Background and motivation

This study is conducted against the backdrop of most countries around the world having completely lifted COVID-19 control measures. Unlike many other contemporaneous articles focusing on COVID-19 control, this experiment allows for the collection of relatively complete and mature data across multiple dimensions for the specific NPI. However, this also implies that although this study is based on COVID-19 control measures, its motivation is not to provide immediate assistance or recommendations for COVID-19 management. Instead, it aims to offer insights into the potential multi-

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faceted impacts of NPI implementation—both before and after intervention—in the context of future outbreaks of viruses that share transmission characteristics similar to COVID-19.

2. Causal inference

This study employs Interrupted Time Series Analysis (ITSA) to assess the causal effects of different NPIS, aiming to ensure that the trend in daily new COVID-19 cases and the implementation of NPIs are causally related [1-2]. In this study, we primarily focus on whether the variable "time_post_intervention" is statistically significant. The detailed ITSA procedure and analysis can be found in the Methods and Results sections. The underlying logic of this study is similar to that in the study of Yang et al. [3], which evaluated NPIs in various U.S. counties. Specifically, Yang's study estimated weekly values of the effective basic reproductive number (Reff) using a mechanistic metapopulation model and associated these with county-level characteristics and NPIs in the U.S.

In contrast, this paper explores how trends in daily new cases would have evolved in the absence of the NPIs, based on previously accumulated case trends. The overall decline in the trend calculated in this study does not represent actual effectiveness. As pointed out in *Causal Inference: What If*, it is impossible to create a new world that aligns perfectly with the experimental assumptions to determine the real impact of an intervention on a given outcome [4]. Therefore, the observed decrease in the trend is merely an assessment under the criteria defined in this study. Its value as a reference for future disease control still requires overcoming numerous limitations and further optimizations based on this foundation in the future.

3. Data selection

When collecting data for this study, it was observed that the daily new cases in countries implemented studied NPIs exhibited seasonality, which prompts the use of the SARIMA model. What's more, the SARIMA can find the nonlinear fluctuations of data and improve the accuracy of prediction results. To achieve a more reasonable prediction of the trend in daily new cases assuming that a particular NPI had not been implemented, the training data for the model were selected to preserve the complete cycle as much as possible [5]. Specifically, when studying particular NPIs, the implementation date in a given country was taken as the reference point. Data collection began from the most recent trough at least 60 days prior to the implementation date and ended at the nearest trough before the intervention day to train the SARIMA model effectively.

For ITSA, the data used was extended by 30 days beyond this standard period, including both the predicted period and the actual data for comparison. This approach ensures that the changes in the trend over the 30 days following the NPI implementation are causally related to the intervention.

4. Methodology

4.1. Decline Ratio

Formula: $\frac{\sum_{i=1}^{n}\{\frac{Prediction_i - Actual_i}{Prediction_i}\}}{n}$

This formula is used to calculate the average reduction rate in daily new cases following the actual implementation of NPIs compared to the predicted values. This metric does not represent the actual effectiveness but rather serves as an assessment under the criteria defined in this study.

4.2. ITSA

Before using the data to predict future trends, ITSA was conducted. ITSA is a widely used method in public health policy analysis for evaluating the effectiveness of interventions [2]. In this experiment, a dummy variable "post_intervention" was defined, which takes the value of 0 before the implementation of the NPI and 1 afterwards. The variable "time" ranges from 0 to the length of the dataset used for ITSA. The focus of this study is the coefficient estimate for the interaction term "time_post_intervention," which is derived from the product of the "post_intervention" and "time"

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variables. This coefficient measures the impact of the intervention on the trend over time—that is, whether the rate of change in cases over time has been altered following the intervention. A negative coefficient indicates that the rate of growth slowed or even declined after the intervention.

In the Ordinary Least Squares (OLS) regression result table, if the p-value corresponding to the coefficient of the "time_post_intervention" term is less than 0.05, it suggests that the impact of the NPI on the time trend is statistically significant. This result supports the conclusion that the subsequent downward trend is causally related to the implementation of the NPI. Additionally, The OLS regression model in this paper accounted for heteroscedasticity and autocorrelation consistent (HAC) standard errors. It helps correct for possible heteroscedasticity and autocorrelation of datasets, making the estimates more robust to these issues.

4.3. SARIMA

In this study, the optimal model parameters were determined by utilizing the auto-tuning SARIMA code, which operates by finding the parameter combination that minimizes the Akaike Information Criterion (AIC) [6] after manually defining the seasonal length. The determination of the seasonal length was particularly challenging due to the frequent policy changes. If data from too far before the implementation of NPIs were used to train the SARIMA model, the results could be compromised, making it impossible to verify if the observed decrease was genuinely attributed to the NPIs under study. After reviewing and analyzing a substantial number of papers and datasets, we ultimately decided to use only the two months of data preceding the implementation of NPIs to predict the subsequent trends.

However, this limited data input into the SARIMA model, combined with the upward trend of daily new cases in the early phase of the pandemic, made it difficult to observe clear peaks at specific lags on the Autocorrelation Function (ACF) plot (i.e., points exceeding the 95% confidence interval). This limitation affected the determination of the seasonal length, even though the cyclical pattern could be clearly seen in the line graph. To address this issue, an alternative approach was used: calculating the average cycle length from one trough to the next trough in the model training data and using this value as the seasonal length for the time series. The feasibility of this method has been confirmed in a previous study [7].

5. Result

The results of this study are divided into three aspects:

1. The NPIs this study aims to analyze as well as the NPIs implemented during the two months prior.
2. Effectiveness of Pandemic Control: Presenting the reduction in daily new cases, comparing predicted values to actual outcomes, calculated using the proposed formula.
3. OLS Regression Result & SARIMA Model's Parameters Selection.

5.1. Country 1 — Germany

This article examines the following NPIs implemented in Germany on January 5, 2021:

1. Hotspot Travel Ban, 2. Private Meeting Limit (≤2 people), 3. Double Testing Requirement
4. Extra Leave for Parents.

The NPIs implemented in Germany during the two months prior to this date are as follows:

1. Closure of Nonessential Shops and Services, 2. Online Schools and Closure of Daycare,
3. Encouragement to Work from Home, 4. No Public Alcohol Consumption, 5. Restriction on Religious Events, 6. Christmas Gathering Restrictions (≤ 4 adults plus any number of children under 14), 7. Ban on Fireworks for New Year's Eve, 8. Recommendation to Isolate Before Family Gatherings [8].

Effectiveness of Pandemic Control:

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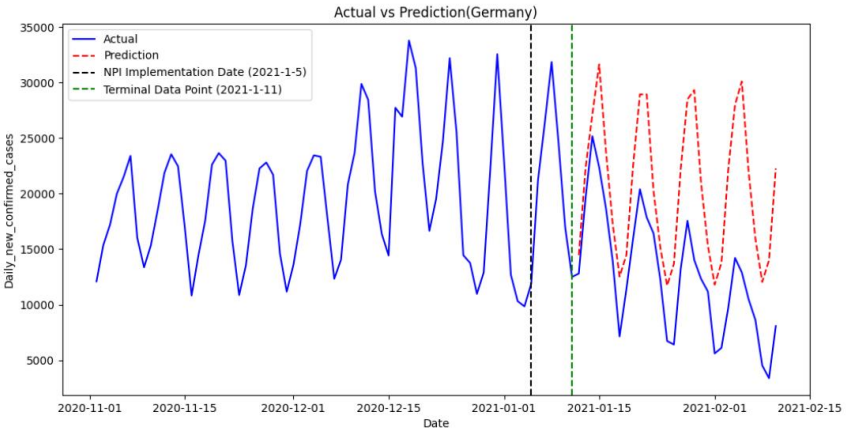

Figure 1. Line chart that illustrate the actual and predicted daily new confirmed cases of Germany.

Figure 1 shows the changes in daily new cases in Germany from November 2, 2020 to February 10, 2021. Although there were already many restrictions in place before the new NPIs were implemented, the time series plot displays that the number of daily new cases was still on an upward trend. In mid-December, restrictions were tightened compared to the NPIs of November, leading to a slight decrease in daily new cases, which stabilized about half a month before the implementation date. A noticeable decline in daily cases was observed after the "terminal data point."

Based on the prediction of daily new cases under the NPIs in place over the previous two months (2020.11.2-2020.1.11), the implementation of Germany's new NPIs resulted in a decline ratio of 0.389 (to three decimal places).

5.2. Country 2 — Italy

This article examines the follow NPIs implemented in Italy on November 14, 2020:

1. Curfews and Regional Classifications, 2. School Closures(varied according to different classification), 3. Business Restrictions, 4. Restrictions, 5. Public and Private Gatherings restriction.

The NPIs implemented in Italy during the two months prior to this date are as follows:

1.Mandatory Face Masks, 2. Limit on Private Gatherings (≤ 6 people), 3. Restricted Operating Hours, 4. Closure of High-Risk Venues, 5. Remote Work Encouragement, 6. Educational Adjustments, 7. Travel Restrictions [9-11].

Effectiveness of Pandemic Control:

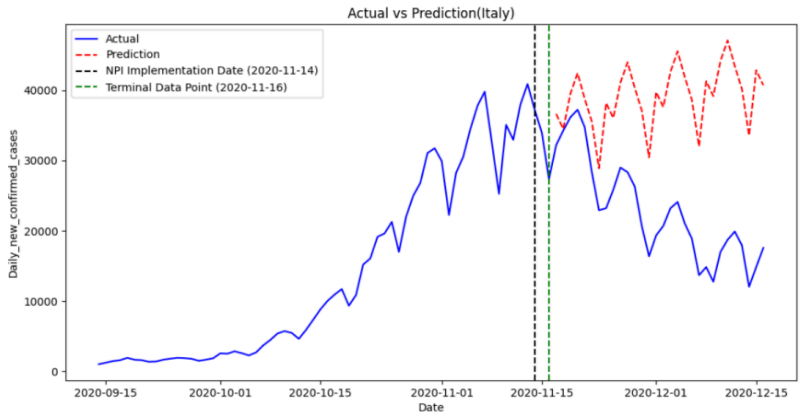

Figure 2. Line chart that illustrate the actual and predicted daily new confirmed cases of Italy.

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Figure 2 illustrates the trend of daily new cases in Italy from September 14, 2020 to December 16, 2020. It can be observed that since the implementation of the new NPIs, the daily new cases have been consistently declining. This contrasts with Germany, where there was a fluctuation lasting six days between the day of implementation and the final data point, maintaining consistency with the prior trend.

Based on the prediction of daily new cases under the NPIs in place over the previous two months (2020.9.14-2020.11.16), the implementation of Italy's new NPIs resulted in a decline ratio by 0.413 (to three decimal places).

5.3. Country 3 — Austria

This article examines the follow NPIs implemented in Austria on November 3, 2020:

1. Curfews, 2. Closure of Non-Essential Businesses, 3. Remote Work and Schooling, 4. Social Gatherings ($\leq$ Two Households).

The NPIs implemented in Austria during the two months prior to this date are as follows:

1. Mandatory Mask Wearing, 2. Social Distancing, 3. Gathering Restrictions (Indoor: $\leq$ 10 People, Outdoor: $\leq$ 100 People), 4. Hospitality Industry Regulations, 5. Event Limitations, 6. Border Controls, 7. Increased Testing and Contact Tracing, 8. Remote Work Encouragement [12-14].

Effectiveness of Pandemic Control:

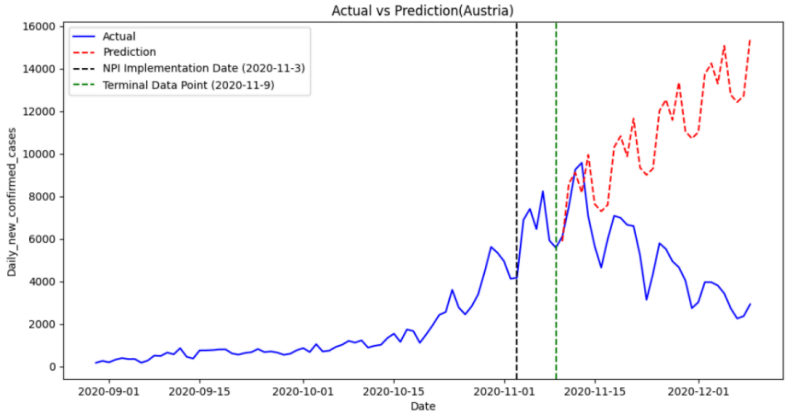

Figure 3. Line chart that illustrate the actual and predicted daily new confirmed cases of Austria.

Figure 3 shows the trend of daily new cases in Austria from August 30, 2020 to December 9, 2020. Unlike Germany and Italy, Austria experienced a continued upward trend in daily new cases even after the terminal data point. This led to some predicted values being higher than the actual values, until, after one complete cycle beyond the terminal data point, a downward trend was observed in the subsequent periods.

Based on the prediction of daily new cases under the NPIs in place over the previous two months (2020.8.30-2020.11.9), the implementation of Austria's new NPIs resulted in a decline ratio by 0.487 (to three decimal places).

5.4. Country 4 — Portugal

This article examines the follow NPIs implemented in Portugal on January 15, 2021:

1. Stay-at-Home Order, 2. Mandatory Teleworking, 3. Closure of Non-Essential Businesses, 4. Economic Support Measures, 5. Increased Fines for Non-Compliance.

The NPIs implemented in Portugal during the two months prior to this date are as follows:

1. Curfew Measures, 2. Restrictions on Gatherings ($\leq$ 5 People), 3. Limitations on Commercial Activities, 4. Remote Work Encouragement, 5. Educational Institutions Restrictions, 6. Inter-Regional

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Travel Restrictions, 7. Mandatory Mask-Wearing and Hygiene Measures, 8. Temperature Measurement [15-17]

Effectiveness of Pandemic Control:

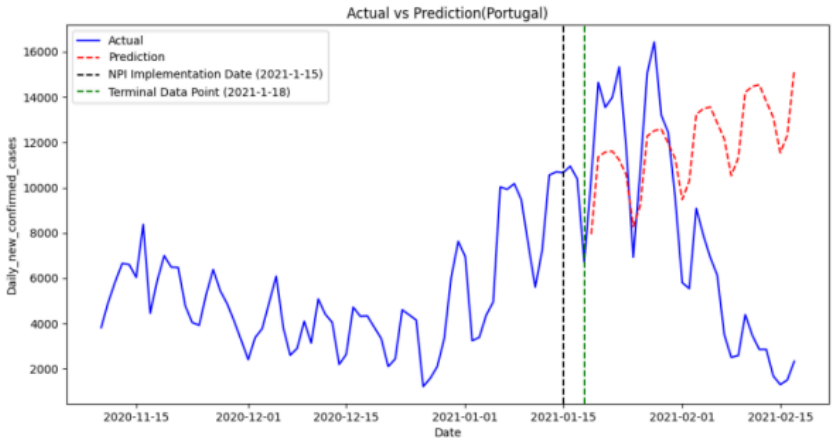

Figure 4. Line chart that illustrate the actual and predicted daily new confirmed cases of Portugal.

Figure 4 shows the trend of daily new cases in Portugal from November 10, 2020, to February 17, 2021. It can be observed that from the end of December 2020 until the terminal data point, the number of new cases consistently increased, with two troughs at periodic intervals. These values were significantly higher than the predicted values of the SARIMA model. It was only in subsequent cycles that the number of new cases began to decrease over time.

Based on the prediction of daily new cases under the NPIs in place over the previous two months (2020.11.10-2021.1.18), the implementation of Portugal's new NPIs resulted in a decline ratio by 0.314 (to three decimal places).

OLS Regression Result:

The study examines four specific NPIs implemented in different European countries and considers the results from OLS regression with HAC standard errors. The coefficients preceding the "time_post_intervention" variable are all less than zero, suggesting a slowdown in the previously increasing trend of new cases or even a decline following the intervention.

For Germany, the coefficient for the NPIs in this study is -471.590 (95% CI: -589.735 to -344.445), for Italy it is -1361.948 (95% CI: -1560.447 to -1163.448), for Austria it is -186.887 (95% CI: -231.302 to -142.471), and for Portugal it is -398.587 (95% CI: -533.990 to -263.184). The p-values for all four parameters are less than 0.05, indicating that the effect is statistically significant. Thus, it can be concluded that the four NPIs studied in this paper all had a causal impact on the time series of new cases in the subsequent month.

SARIMA Model's Parameters Selection:

For the four different NPIs studied in this paper, the artificially calculated period was set to 7 days (as the closest integer). The optimal SARIMA model parameters selected for Germany were (1, 0, 0)(2, 1, 0) [7], for both Italy and Austria were (0, 1, 1)(0, 1, 0) [7], and for Portugal were (0, 1, 2)(1, 1, 1) [7]. Under these SARIMA model parameter selections, the corresponding AIC values were 1228.732, 995.640, 980.258, and 1060.900, respectively, all of which were the lowest among the different combinations of model parameters attempted.

6. Limitation

One major limitation of this study is the insufficient training data for the SARIMA model, which was mentioned earlier in the methodology section. Extending the timeline of the model's training data could lead to significant fluctuations in the predicted trend, primarily due to frequent policy changes.

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Fluctuations in the predicted trend could affect our assessment of the effectiveness of target NPIs. However, during a respectively short period the overall trend of new cases is relatively stable under a consistent policy.

According to the research by Fajgenblat [18], the implementation of general interventions typically has a delay effect, meaning that their effective date is later than their announcement date. In that study, it was found that the delayed effect of general interventions on the Stringency Index was most significant on the fourteenth day. However, the different NPIs discussed in this paper combined impact of mixed interventions, making it challenging to calculate their collective delay effect. In Figures 1 and 2, we observe that the predicted values for Germany and Italy remain higher than the actual values beyond the terminal data point, whereas a different pattern emerges in the corresponding graphs for Austria and Portugal. This discrepancy is likely due to the varying delay effects of different combinations of interventions. This undoubtedly affects the assessment of the effectiveness of NPIs in this experiment. Estimating the delay effects of the NPIs in these four cases requires further extensive experiments and analysis.

The method in this experiment can only evaluate short-term changes in trend predictions. During the experiment, it was found that although the SARIMA model generally captured the periodicity of the training data, it also showed an overall linear upward trend. While this may be reasonable in the short term, the long-term forecast of daily new cases would not exhibit a linear upward trend. Factors such as total population, population density, and herd immunity would inevitably cause the daily new cases to decline after reaching a certain point, even without any interventions [19]. This phenomenon has been observed in many countries after lifting all restrictions.

7. Conclusion

In contrast, the NPIs implemented by Austria on November 3, 2020, demonstrated the highest effectiveness, with a Decline Ratio of 0.487, followed closely by Italy, with a Decline Ratio of 0.413. Comparing the studied policies implemented by the four countries, most of them included the closure of non-essential businesses, restrictions on gathering sizes, and travel limitations. The main distinction between Austria and Italy and the other two countries lies in their added NPIs, which included restrictions on education. Both Austria and Italy introduced remote schooling on the day that the target NPIs were announced. This finding aligns with Yang's analysis [3] of NPIs implemented in different U.S. counties, which showed that school closures had the most significant impact on reducing the effective basic reproductive number (Reff).

Germany, on the other hand, had already started remote schooling two months before the implementation of the target NPIs in this study, which explains why the impact of its additional NPIs was slightly lower compared to Austria and Italy (0.389 Decline Ratio). Regarding the analysis of the NPIs implemented in Portugal on January 15, 2021, Portugal experienced the longest period where actual values exceeded the predicted values and demonstrated the lowest Decline Ratio of 0.314 among the four countries. A more in-depth investigation revealed that Portuguese media [20] reported school closures occurring on January 21, 2021. As shown in Figure 4, around late January 2021, the actual values surpassed the predicted values for the first time. Before this, schools in Portugal had remained open, which could be a potential reason for the non-decreasing trend in daily new cases after implementation of new NPIs.

In addition, curfews were another restriction newly introduced in Austria and Italy, distinguishing them from the other two countries. According to the study by Sharma [21], which analyzed the effectiveness of different interventions, curfews also demonstrated notable effectiveness. Specifically, curfews contributed more significantly to the reduction of the instantaneous reproduction number compared to the closure of some non-essential businesses and stricter mask-wearing policies.

Data and Code Available

Both data and code used in this paper can be found at:

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https://github.com/Imjustlooking/An-Effectiveness-Analysis-of-NPIs-Implemented-in-European-Countri.

The daily new cases used in this study were calculated using the lagged difference method on the cumulative data which could be found at https://github.com/datasets/covid-19.

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Tong Yu should be considered first author.

Xinrui Chen, Yifei Jiang, Ji Chen, Bohan Li contributed equally to this work and should be considered co-second authors.

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