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The impact of COVID-19 on EU economies: a panel VAR analysis

Dissertation submitted

by

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Abstract:

This thesis aims to examine the influence of COVID-19 on the members of the European Union's economies by employing a Panel Vector Autoregression Model (panel-VAR). Economic activity is represented by the leading stock markets and Nitrogen Dioxide (NO_2) emissions for every member of the European Union (EU) and the number of new reported infections and government responses were used to quantify the impact of COVID-19 and its most dominant variations, Alpha, Delta and Omicron. We discover that both economic activity proxies are sensitive to the spread of the virus and the government's response policies in most countries. A sudden increase in the number of cases and tightened government response cause a decline in our two economic indicators, except Austria and Hungary in the case of NO_2 emissions. Furthermore, we observe different reactions when introducing the three dominant variations. In the presence of Alpha and Delta variations, the response of stock prices to a shock in cases and GRI is the same, and stock prices fall. On the contrary, when the Omicron variant is dominant, stock prices respond positively to a shock in cases and negatively to a shock in GRI.

Keywords: Covid-19, stock market, NO_2 emissions, panel-VAR

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1. Introduction

The COVID-19 pandemic hit the European countries in early 2020, leading the economic activity to a fall. People, in response to the unknown virus, were hesitant to go out, travel, and even go to work. This is one of the reasons, the economic activity decreased. Another reason was the response of governments. They imposed lockdowns and closures of businesses and transportation to slow down the spread of the new virus. To stabilize the economy, governments also, issued support packages to businesses and households.

The main aim of this paper is to examine the magnitude of the impact of the virus and government responses and examine the impact of the main variants of the virus. To achieve this, a panel Vector Autoregression Model (panel-VAR) was estimated for the twenty-seven members of the EU.

To capture the full effect of COVID-19 on the economy, high-frequency series had to be used and most of the macroeconomic series were available on a monthly or quarterly basis. Hence, the leading stock market prices and NO_2 emissions for each country were used as proxies for the economic activity as used by Klosen and Tillmann (2022). The former reflects the response of the economic activity, and the latter is positively correlated with real GDP. In the sample used the correlation between NO_2 and real GDP is 0,14 and is statistically significant at 10%. The index for the government responses used in the model was estimated by Hale et al. (2021) for the Oxford COVID-19 government response tracker and includes the response of governments over several indicators[1]. The reported cases were preferred as the leading indicator of COVID-19 because if the reported cases increase then hospitalizations and deaths increase in about one to two weeks. Furthermore, three dummy variables were included in the

[1] The indicators included in the government response index are containment and closure, economic, health system and vaccine policies.

model, each one reflects the presence of a dominant variation of the virus, the Alpha, the Delta, and the Omicron variation.

The analysis is performed in four steps. One part of the analysis is to estimate a panel VAR without any exogenous variables and another step is to estimate the panel VAR with one variation of the COVID-19 at a time. First, we estimate the impact of cases and government responses index on stock prices, we find that stock prices slightly decrease when a standard deviation shock is imposed on cases and government responses index. Then, we incorporate one of the dummy variables that correspond to one of the three most dominant variations of COVID-19 in our estimation as exogenous variables. So, three more estimations were made. Two of the dummy variables give the same result as the estimation without the dummy variables, i.e., negative impact of cases and government response index to stock prices, the two dummy variables are the Alpha and Delta variants. As for the Omicron variant, we see that stock prices increase when a shock to cases is imposed, and the impact of the government response remained the same. A further discussion regarding these results is presented in Section 5.

The next step of our analysis is to estimate the panel VAR using NO_2 emissions as a proxy for economic activity. We follow the same steps as before; we estimate the panel VAR without the dummy variables and then with the dummy variables. When we estimated the panel VAR without the dummies and impose a standard deviation shock on cases and government response index, we find that NO_2 responded positively to cases and negatively to government response. We expected that an increase in cases will decrease the NO_2 emissions since people will stay at home, many businesses will be closed, and transportation will be very low. To further investigate this result, we estimate individual VAR models and discover that NO_2 emissions for two of the countries in our sample, react positively to cases. As for the impact of GRI on NO_2 emissions, we observe that NO_2 emissions decrease for all other countries. Our final step is to incorporate the variations of COVID-19 in this model. After the estimation of the model, we impose a standard deviation shock on cases and government response index, and we observe that NO_2 emissions respond in the same manner and magnitude when the Alpha and Delta variants are present while when Omicron is present the magnitude of the impact is different. A further discussion regarding the results is presented in Section 5

The rest of the paper is structured as follows: In the second section, a literature review is presented. Section 3 describes the data set used and presents a descriptive analysis. Section 4 presents the methodology used, Section 5 includes the empirical results and Section 6 concludes.

2. Literature Review

From the start of the pandemic, the literature on the economic impact of COVID-19 has rapidly expanded. Ng (2021) used covid indicators such as cases, hospitalization, and deaths as controls to remove the effect of covid from the data before estimating the VAR model. The author found that responses to economic shocks vary substantially from those to a covid shock and differentiating between the two types of shocks is critical in post-covid macroeconomic modelling. Ludvigson et al. (2021) used a VAR model to calculate the macroeconomic impact of recent costly and fatal disasters in the United States and to convert these data into a prediction of COVID-19's anticipated impact. In a VAR framework, Caggiano et al. (2020) evaluate the impacts of a COVID-induced uncertainty shock on the global financial cycle and industrial production. They showed that this shock has a significant impact on economic production and the financial cycle.

The economic impact of the COVID pandemic that has been studied the most, is the response of stock markets to the virus and government measures. In order to observe changes in the estimated coefficients before and after the appearance of the COVID-19, Dong et al (2021) employ the MSCI emerging Asia and MSCI world indexes in a time-varying parameter framework. Their main findings are that economic variables have the greatest impact on stock markets during the COVID-19 pandemic and have a bigger impact on developed stock markets than they do on rising Asian markets. Brueckner and Vespignani (2021) concentrate their research on the effects of the COVID-19 on Australian and US stock markets using a VAR framework. They first estimate VAR using two variables, the newly reported cases, and ASX-200, the leading indicator for the Australian market and then compared the results with the same model estimated using the daily growth rate of the Dow Jones. They discover that both Australian and US stock markets respond positively to an increase in COVID-19 cases. Rehman et al (2021) examined the relationship between G7 stock returns and the number of verified COVID-19 cases and causalities using daily data from the 31st of December 2019 until the 13th of November 2020. The wavelet coherence approach is used to assess the impact of the number of confirmed cases and deaths on the G7 stock markets. The number of verified COVID-19 cases and deaths has a significant link with the G7 equity markets, according to their research. Kapar et al. (2021) adopted an occasion analysis in the initial stages to the pandemic to look at its impact on international markets employing a wide sample of sixty-three stock markets. Their analysis indicates that stock markets around the world fell as a result of the COVID-19 pandemic and the associated containment measures. Heyden and Heyden (2020) investigated the short-term stock market reactions in the United States and Europe during the start of the COVID-19 and showed that markets react negatively to the report of the first death in a specific country using an event analysis. The study of Zhuo and Kumamoto (2021) used a panel VAR model of 15 countries and divided the sample period into initial and latter stages of contagion to look at how stock markets respond to the virus and the containment measures governments imposed as evaluated by the Oxford COVID-19 Government Response Tracker. They discovered that as the number of confirmed cases and deaths rises, volatility rises as well, with the effect is lasting longer in cases. Furthermore, government restrictive measures have a major negative impact on stock returns. They found that an increases in confirmed cases and deaths cause a spike in volatility, with the influence lasting longer in cases. Furthermore, government containment efforts significantly reduce stock returns. Klose and Tillmann (2022) investigated the effect of the COVID-19 pandemic in ninety-two countries employing panel VAR models. The vast number of countries allowed them to examine the heterogeneity of the stock market and NO2 emissions reactions as high-frequency indicators of economic activity.

Emissions are used as a measure of economic activity and scientists have studied the consequences of a COVID pandemic on emissions extensively. Mzoughi et al (2020) used an unrestricted VAR, to evaluate the influence of the COVID-19 pandemic on oil prices, CO_2 emissions, and stock market volatility from January 22, 2020, to March 30, 2020. They showed that, while an increase in COVID-19 infections induced a drop in crude oil prices, the negative reaction of the oil market was only temporary and throughout the projected period, however, the reaction of economic activities as measured by CO_2 emissions to a shock on COVID-19 infections is negative. Using daily data from all over the world on restraint measures, positive cases, and economic activity indicators such as Nitrogen Dioxide emissions, both domestic and international air travel, power utilization, shipping, and movement indicators, Deb et al. (2022) examined the effects of the containment actions taken for COVID-19 on economic activity. The findings imply that containment measures had a considerable influence on economic activity, which amounts to a ten percent decrease in manufacturing output after 30 days of implementation. Other researchers' emphasis was placed on CO_2 emissions such as Kumar et al. (2022) came to the conclusion that the actions taken to control the spread of the virus caused a substantial deceleration of economic activity, which affected positively the environment, by reducing CO_2 levels in the atmosphere. Other studies investigate the effects of the COVID-19 pandemic on a larger group of greenhouse gas emissions such as Gettleman et al. (2021).

3. Empirical Analysis

3.1 Data Description

In this paper, the sample consists of the twenty-seven members of the EU and the sample period for each country begins with the first reported COVID-19 case and ends uniformly on the 31st of January 2022[2]. As a result, the panel dataset is unbalanced. Most macroeconomic variables were available on monthly or quarterly frequency and because the timeline of COVID-19 is quite small, consequently daily frequency variables were used in the model so that the full impact of the virus can be captured.

The leading stock market index[3] and daily reports of $N0_2$ emissions[4] for each country are used as proxies for economic activity. The stock market indices were obtained via Investing and the NO_2 emission via Air Quality Index. The daily new reported cases and government response index are used to represent the impact of COVID-19. The data for the daily new cases were obtained from Our World in Data and the government policy index from the COVID-19 Government response tracker[5].

[2] In February 2022, the Ukrainian crisis began, and this may be affected the macroeconomic variables.
[3] The Leading stock market indices are: Austria: ATX; Belgium: BEL 20; Bulgaria: BSE SOFIX; Croatia: CROBEX; Cyprus: Cyprus Main Market; Czechia: PX; Denmark: OMX Copenhagen 20; Estonia: OMX Tallinn; Finland: OMX Helsinki 25; France: CAC 40; Germany: DAX; Greece: Athens General Composite; Hungary: Budapest SE; Ireland: ISEQ; Italy: FTSE; Latvia: OMX Riga; Lithuania: OMX Vilnius; Luxembourg: LUXX; Malta: MSE; Netherlands: AEX; Poland: WIG30; Portugal: PSI 20; Slovakia: SAX; Slovenia: Blue-Chip SBITOP; Spain: IBEX 35; Sweden: OMX Stockholm 30.
[4] For the following countries there were no available data: Latvia; Lithuania; Luxembourg; Malta; Slovenia and Belgium had many missing data
[5] The index aggregates the data into a single number from 0 to 100 as calculated by Hale et al. (2021)

3.2 Descriptive Analysis

Due to the nature of the series of COVID cases, $N0_2$ being daily and stock market prices being available only on business days, the series were transformed to five days moving averages of percentage growth rates as suggested by Klose and Tillmann (2022) in order to smooth them. The same technique was applied also to the government response index.

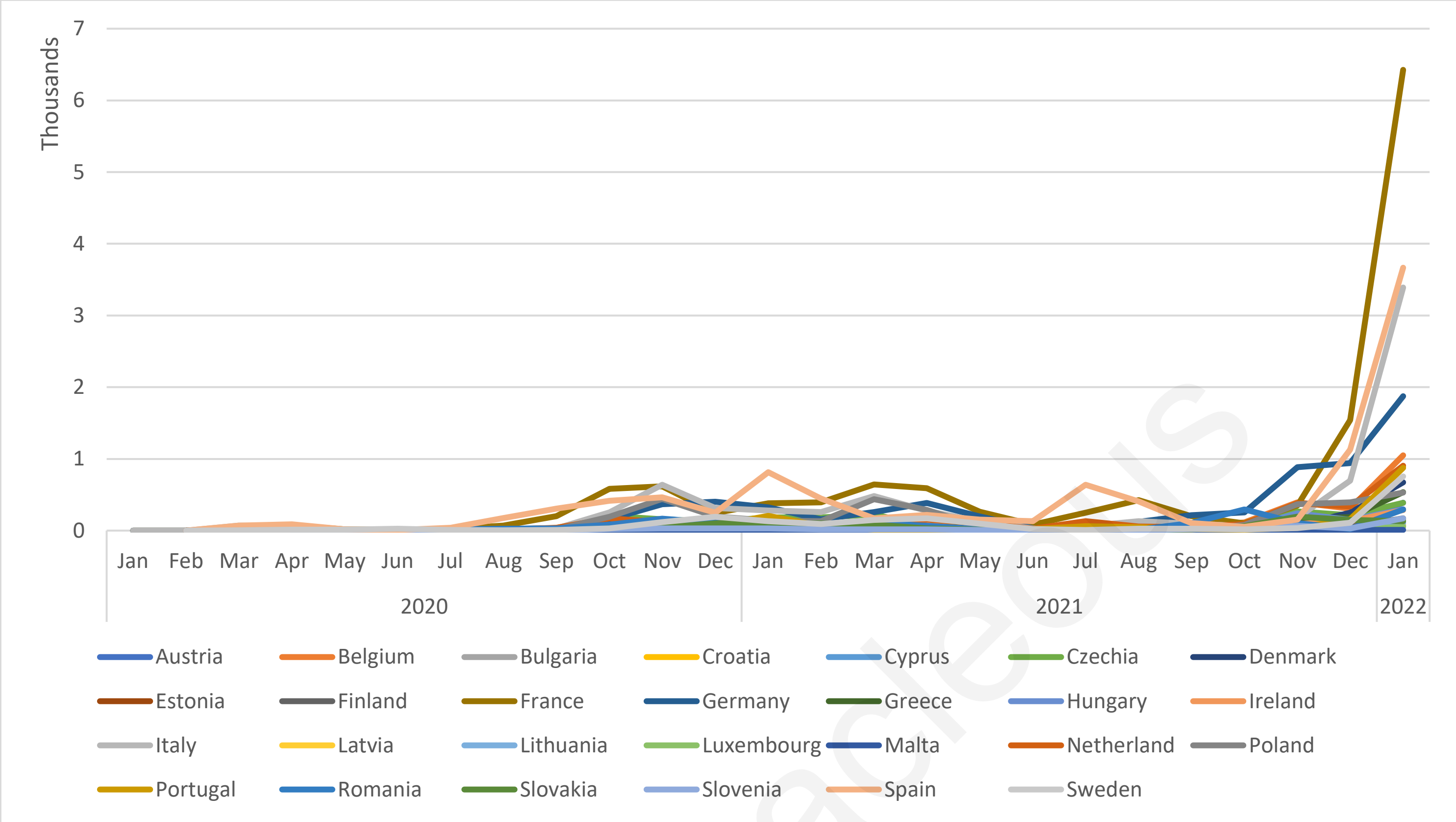
Also, three dummy variables were included to reflect the three most dominant variants of COVID-19: the Alpha, Delta, and Omicron variant. Each variation takes a value of 1 when it was dominant and zero otherwise.

Table 1:Descriptive Statistics

Variables	***Observations***	***Mean***	***Std. Dev.***	***Min***	***Max***
stock	13,220	1.742757	7.76183	-21.63	61.898
no2	10,810	.0873573	.1806904	-.3809432	2.211045
cases	13,220	.3301341	5.445935	-.6863149	278.7408
gri	13,220	.0047417	.0374797	-.0738843	.9055224

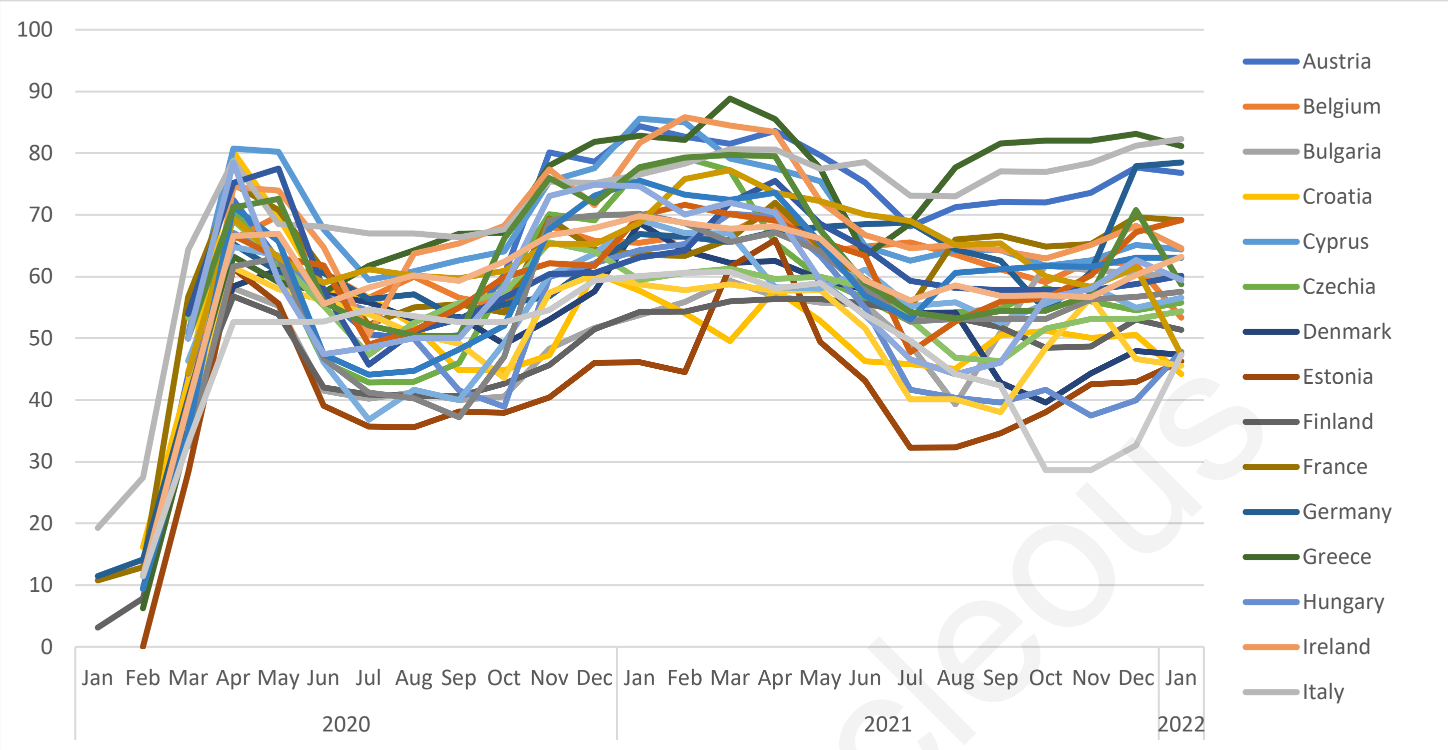
Table 1 shows Table 1 shows the variables' statistics, including the number of observations, mean, standard deviation, and lowest and maximum values. The stock represents stock market values, the no2 represents NO2 emissions, the cases represent daily reported cases, and the gri represents the government reaction index. The number of observations for NO_2 emissions is smaller compared to the other variables because five countries have no available data, and one country has missing observations. In the following figures we will discuss our variables further.

Figure 1: COVID-19 cases in thousands



The first figure presents the average monthly cases in thousands per country. The first members of the EU to report a positive case of COVID-19 were Finland, France, Germany, and Italy at the end of January 2020. In March 2020, COVID-19 spread through the entire European Union. As we can observe from the graph above, cases move in the same direction but have different magnitude through the members of the EU. Furthermore, we can see that during the autumn and winter seasons, covid cases were higher while during summertime were lower. From November 2020 until mid-2021, the Alpha variant was dominant in most of the countries and during the summer of 2021, the Delta variant appeared and remained dominant until early December 2021. As for the Omicron variant, it made its presence in mid-December 2021, and it is dominant until today, with its own variations. We observe that from November 2021and onwards, cases increased rapidly since the Omicron variant is the most contagious of all the variants and has the mildest symptoms.

Figure 2:Average Government Response Index



The Government Response Index (GRI) records how the overall response of the government varied, ranging from 0 to 100, 0 being the weaker and 100 being the stronger response. The indices included in the GRI are the following: containment and closure, economic, health and vaccine policies. We can see from the graph above that most Governments responded when the first cases were reported and all the countries responded strongly in April 2020, with Cyprus and Croatia responding the most with a score of 81 and 80 respectively. Furthermore, we observe that all countries weakened their response during summertime and the again returned to a stronger response during autumn and winter seasons. It is noticed that during December 2021 and January 2022, most countries remained to a medium level response, except for Greece, Italy, Austria and Germany which had a response of around 80.

Figure 3: Average percentage change of stock prices

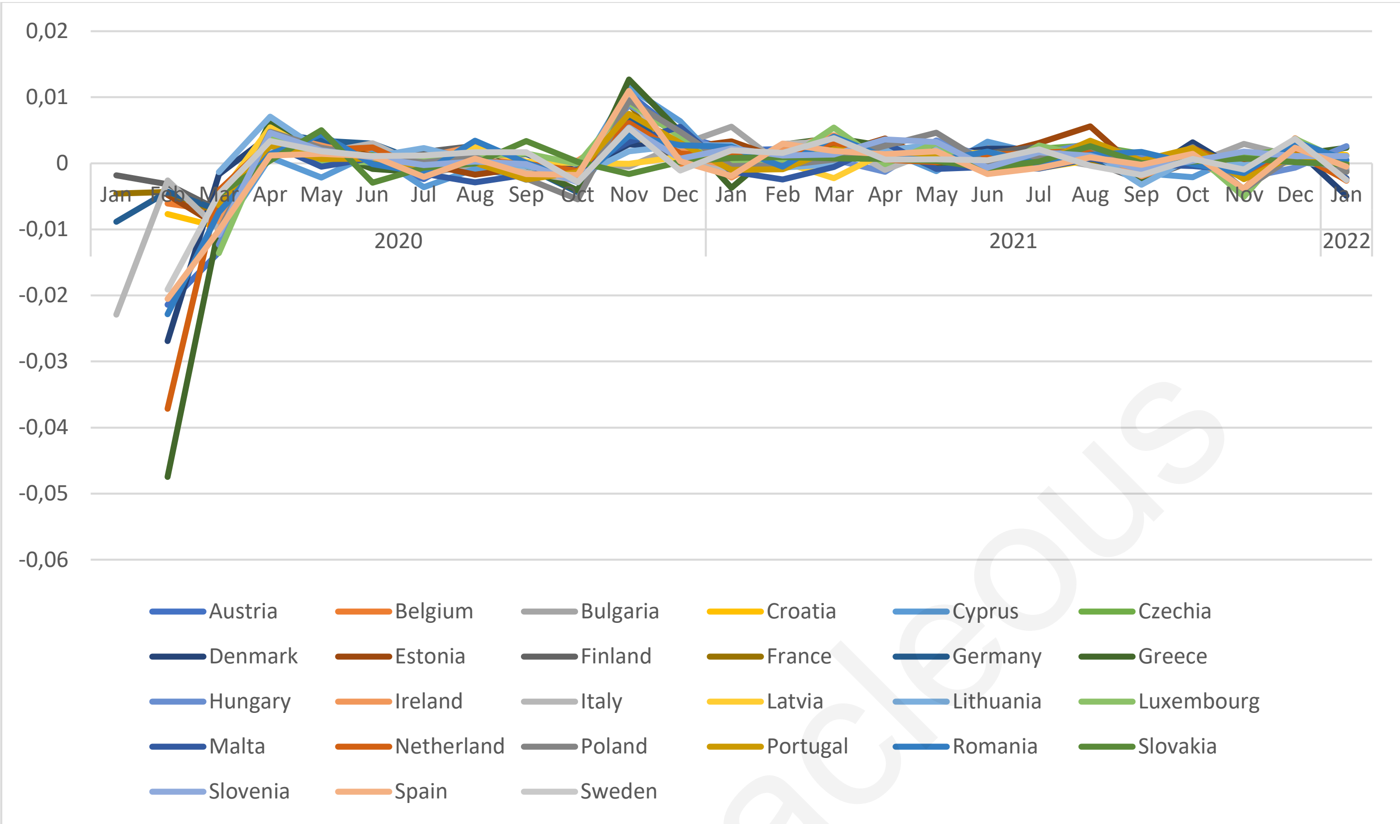


Figure 3 presents the average monthly change of stock prices for each country. We can observe that in the begging of the pandemic, stock prices fell and from April onwards they bounced back, with slight changes.

Figure 4: Average change of NO_2 emissions

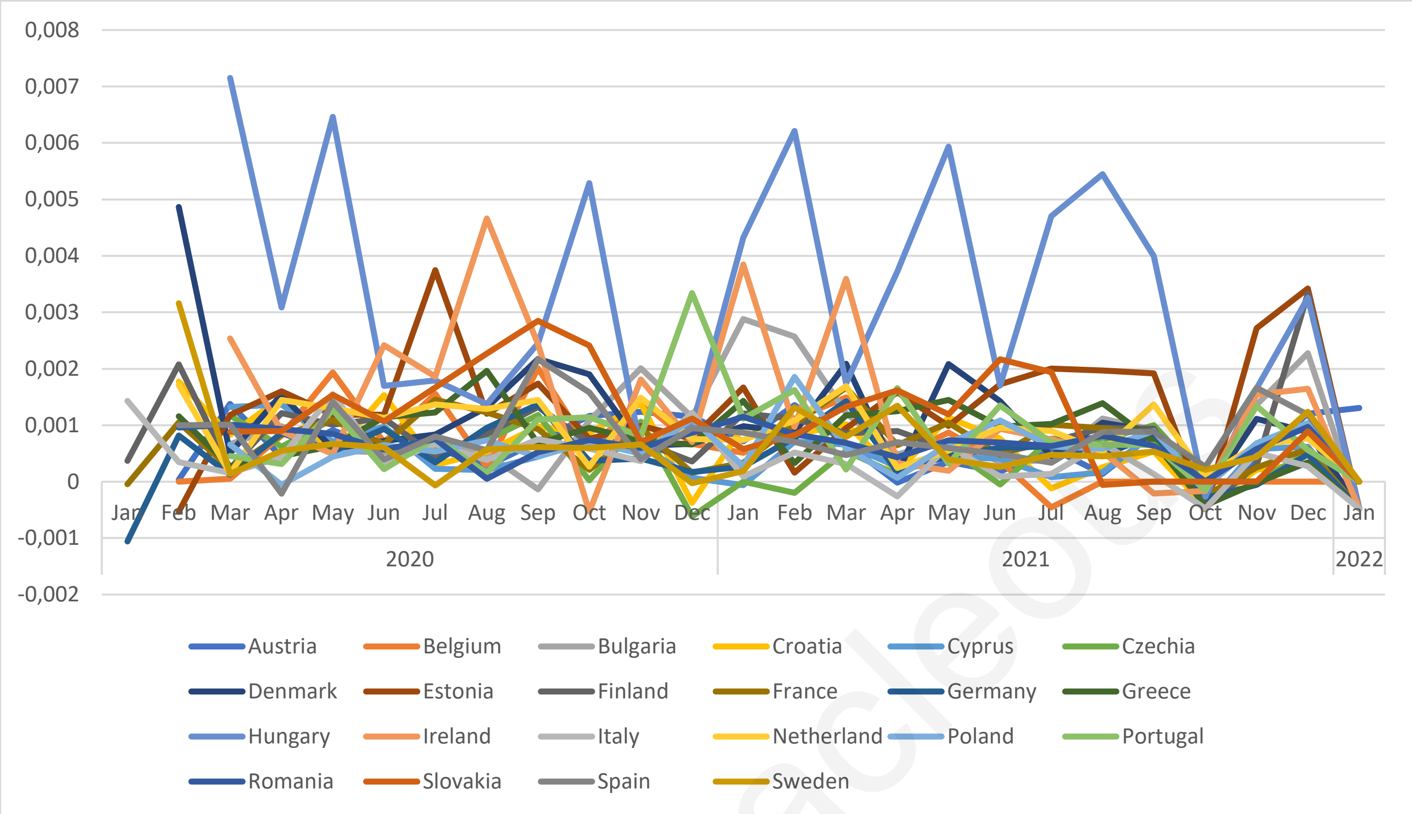


Figure 4 show the average change of NO_2 emissions for twenty-two members of EU. For Latvia, Lithuania, Luxembourg, Malta and Slovenia data were not available and Belgium has missing observations. From the beginning of February, we can see that most countries reduced their NO_2 emissions. Hungary, Sweden and Denmark experienced the highest decreased of NO_2 emissions. It is observed that from October 2021 NO_2 emissions increased and in January 2022 again dropped.

4. Methodology

4.1 Econometric Methodology

The primary purpose of this study is to determine the economic impact of COVID-19. Panel VAR models were calculated to accomplish this. The panel VAR model offers a cross sectional dimension in addition to the regular VAR's capabilities. All of the variables in the model are endogenous and interconnected, and the order in which they appear is crucial. Additionally, the model allows for exogenous variables to be incorporated.

The model is given by:

$$y_{it} = A_{i1}y_{it-1} + A_{i2}y_{it-2} + \cdots + A_{ip}y_{it-p} + F_i x_{it} + e_{it} \qquad (1)$$

$$i \in \{1,2,\ldots.N\}, t \in \{1,2,..,T\}$$

a n-variate panel VAR of order p where y_{it} represents the vector of $(n \times 1)$ dependent variables; x_{it} represents an exogenous variables vector of (1×1); e_{it} represent the $(1 \times n)$ vector of idiosyncratic errors; the $(n \times n)$ matrices $A_{i1}, \ldots, A_{ip}$ and the $(1 \times n)$ matrix F_i contain the VAR coefficients. Furthermore, it is assumed that the errors are uncorrelated: $\boldsymbol{E}[\boldsymbol{e_{it}}] = \boldsymbol{0}, \boldsymbol{E}[\boldsymbol{e'_{it}}\, \boldsymbol{e_{it}}] = \boldsymbol{\Sigma}$ and $\boldsymbol{E}[\boldsymbol{e'_{it}}\, \boldsymbol{e_{is}}] = \boldsymbol{0}\ \forall\ t > s$

First, the optimal lag order must be selected. This is achieved using the consistent moment and model selection criteria (MMCS) for GMM models. This approach is based on Hansen's J statistic (1982) of over – identifying restrictions. After the estimation of the panel VAR model the stability of the model must be checked to proceed with the estimation of the impulse response functions. The impulse response functions describe the reaction of the endogenous macroeconomic variable to a shock imposed on the endogenous variables. In this analysis, the impulse response functions are the focus. When we impose a shock on the COVID-19 variables, we will be able to assess the impact on the economic activity.

4.2 Model

In this paper, the model explained above has three endogenous variables. The (3×1) vector of endogenous variables is

$$y_{it} = [cases_{it} \; gri_{it} \; u_{it}]' \quad (2)$$

The number of new reported covid cases is $cases_{it}$, the government responses is gri_{it} and u_{it} is either the daily stock prices or the NO_2 emissions in country i. Two different models are estimated, one with the daily stock prices and the other with the NO_2 emissions in order to keep the panel VAR compact.

The main interest of this analysis is the effect of the COVID-19 variables on the other endogenous variables, so an order identification is needed. Fortunately, the nature of the variables gives a straightforward ordering. The number of cases is first in order since they respond with a delay to any of the government's responses. The governments can respond simultaneously to a change in the reported cases, so the government's response index is second in order. As for the stock prices and NO_2 emissions, they can respond simultaneously to a change in the reported cases or in the government's responses and they are third in order.

Furthermore, we estimate the above-described models with one of the three exogenous dummy variables at a time.

$$x_{it} = [\, dummy_q]' \quad (3)$$

Where $dummy_q$ is either $dummy_a$ which represents the Alpha variant, $dummy_d$ the Delta or $dummy_o$ the Omicron variant. The three dummy variables represent the three most dominant covid variants. Each dummy takes the value of 1 when the respective variant was dominant in a country and zero otherwise.

5. Empirical Results

The main objective of the empirical work in the estimation of the impulse response functions to quantify the effect of a shock on the representative covid variables to the economic activity. The tables below show the optimal lag order for the models.

Table 2:Optimal Order Selection (a)

LAG	CD	J	J p-value	MBIC	MAIC	MQIC
1	.9998759	622.9989	.753338	-5363.007	-673.0011	-2258.384
2	.9998846	774.6443	.0001763	-5128.223	-503.3557	-2066.719
3	.9998805	699.6387	.0279056	-5120.089	-560.3613	-2101.705
4	.998879	582.6853	.8624452	-5153.904	-659.3147	-2178.64

Table 2 presents, the optimal order selection for the model with variables *cases, gri* and *stock.* The optimal lag to be included in this model is two, as it has the lowest MAIC and MQIC and the Hansen's J statistic is minimized.

Table 3:Optimal Order Selection (b)

LAG	CD	J	J p-value	MBIC	MAIC	MQIC
1	.9900863	609.6568	.8572938	-5246.588	-686.3432	-2243.323
2	.9807121	505.5428	.9999698	-5269.365	-772.4572	-2307.812
3	.9825144	463.8884	.9999999	-5229.683	-796.1116	-2309.842
4	.8122352	423.1195	1	-5189.115	-818.8805	-2310.986

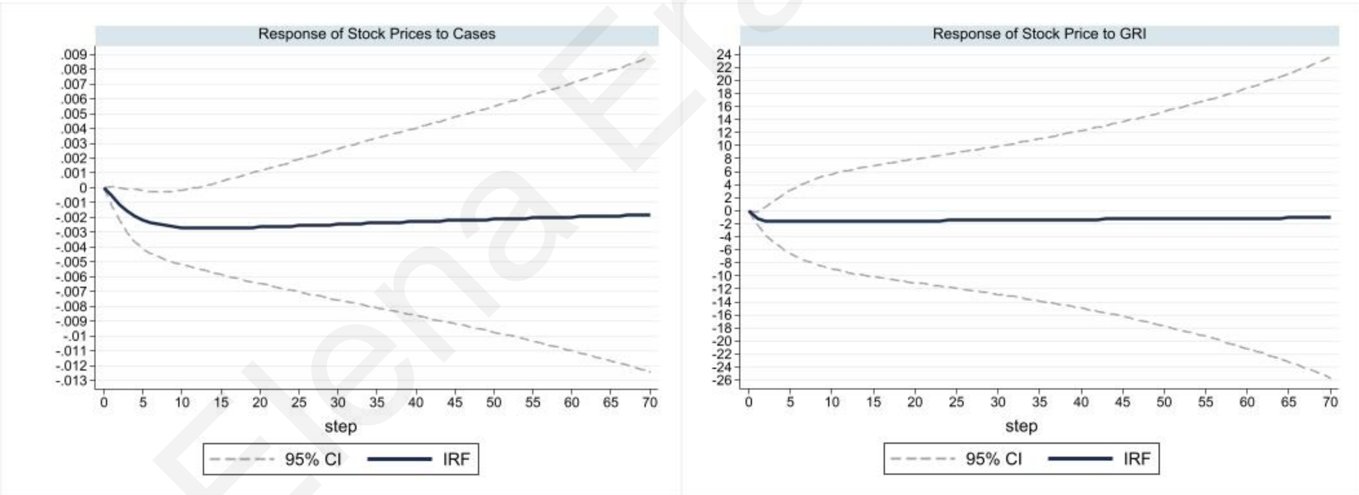
Table 3 presents, the optimal order selection for the model with variables *cases, gri* and *no2.* The optimal lag to be included in this model is one, as it has the lowest MAIC and MQIC and the Hansen's J statistic is minimized.

After the optimal lag selection, we estimate the panel VAR models without the exogenous variables and then with the exogenous variables. All models were stable. First, we present the results from the estimations including stock prices as an economic activity proxy and then the results from the estimations including NO_2 emissions. In each figure, we present the response of the economic activity proxies, which are the variable we are interested in the most, to a standard deviation shock on cases and government response index. Each figure also includes the 95% confidence intervals around the estimated impulse response.

5.1 Response of Stock Prices

The results of the impulse response functions from the first estimation without any exogenous variables are presented in Figure 5.

Figure 5: Response of Stock Prices without exogenous variables



Note: Impulse response of stock prices to a standard deviation shock in covid cases and government response index. The dashed lines indicate the 95% confidence interval.

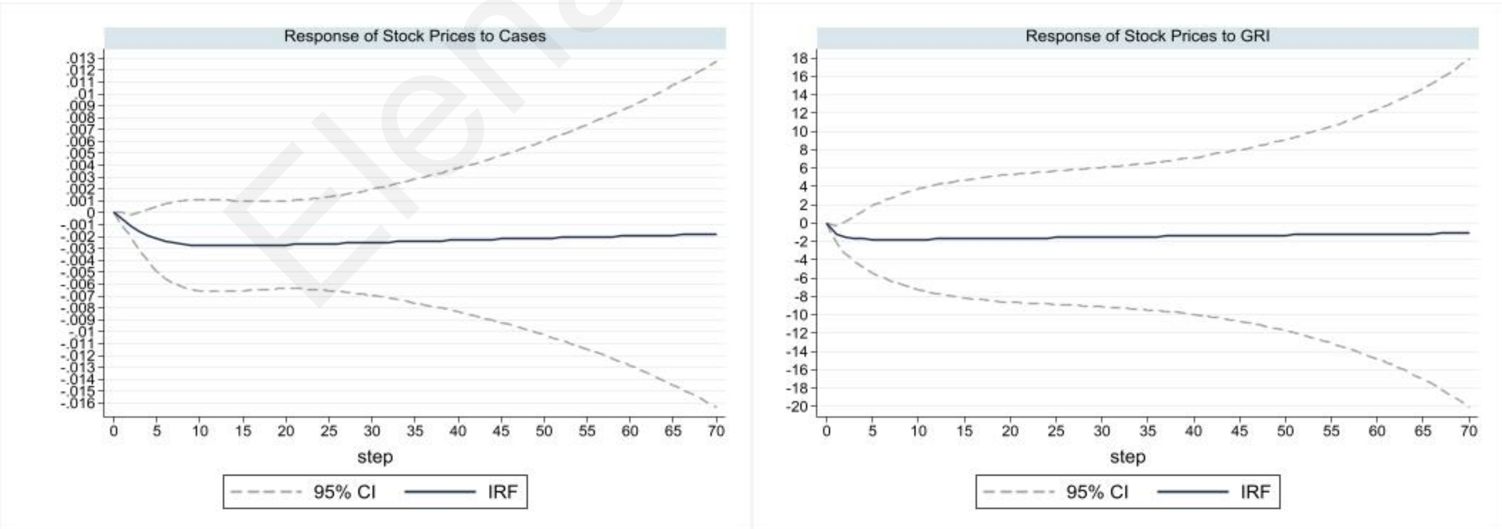
In the left figure we observe the response of Stock prices to a standard deviation shock on cases and in the right figure we observe the same response to a tightening of the government response index (GRI). These responses correspond to the economic intuition; stock prices decrease when the number of daily new cases increases, and the government responses tighten. Even though stock prices respond negatively to both shocks, the reaction to each one differs in time response and magnitude. The peak of the response to cases occurs thirteen days after the shock and stock prices decrease by 0,002 percentage points, while the largest response to government response index occurs five days after the shock, decreasing by 1.69%. It is observed that the effect of both shocks after forty days starts to fade away.

We can see that stock prices are affected more by the government responses, because governments imposed lockdowns, businesses were closed for long periods and many employees were out of office because they were covid positive.

Regarding the confidence intervals, it is noted they are quite large, these is because the sample is quite small.

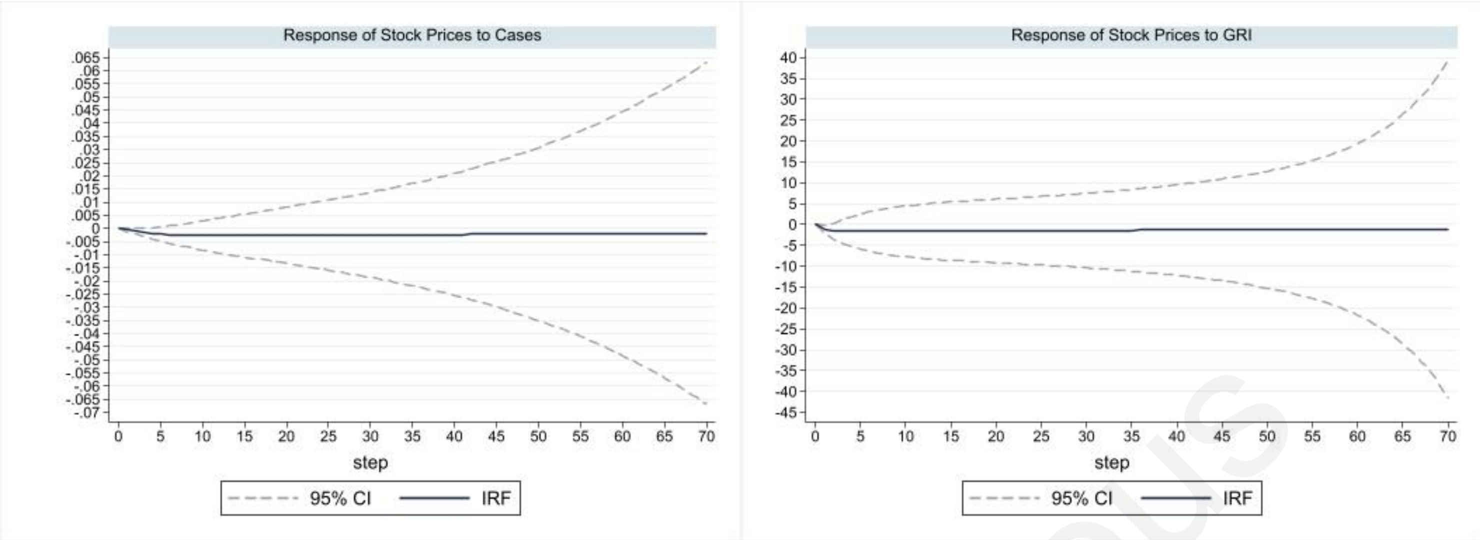
The following figures present the response of stock prices to a shock on cases and GRI when exogenous variables are added to the model. The exogenous variables being dummy variables for the three dominant covid variations.

Figure 6: Response of Stock Prices when Alpha variant is present



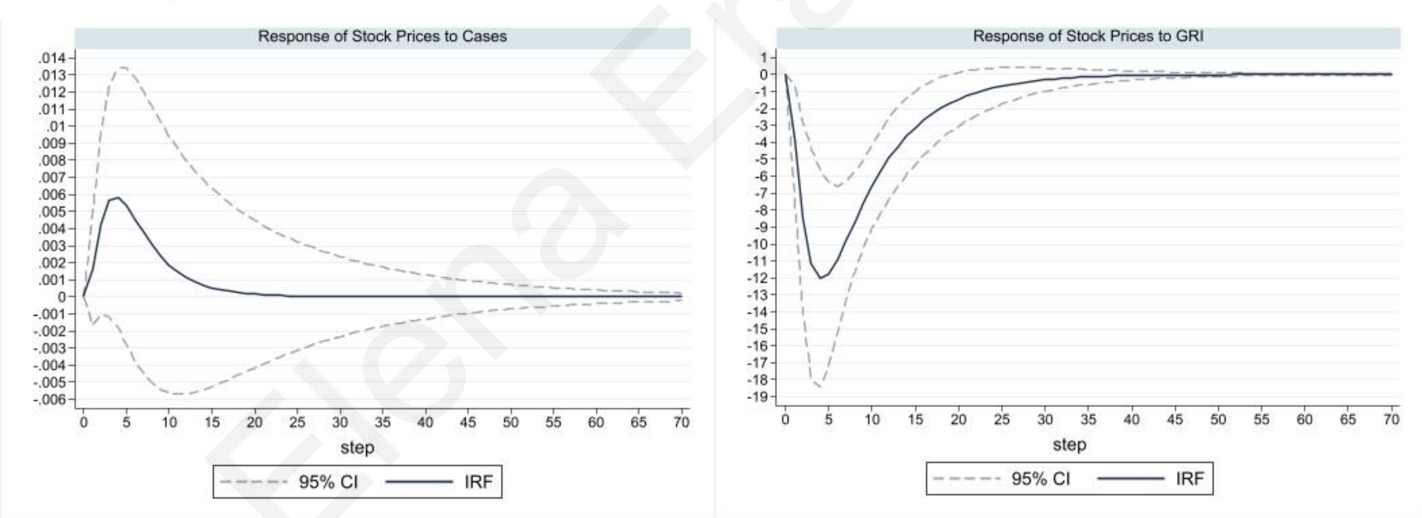
Note: Impulse response of stock prices to a standard deviation shock in covid cases and government response index when dummy variable for Alpha variant is used. The dashed lines indicate the 95% confidence interval.

Figure 7:Response of Stock Prices when Delta variant is present



Note: Impulse response of stock prices to a standard deviation shock in covid cases and government response index when dummy variable for Delta variant is used. The dashed lines indicate the 95% confidence interval.

Figure 8:Response of Stock Prices when Omicron variant is present



Note: Impulse response of stock prices to a standard deviation shock in covid cases and government response index when dummy variable for Omicron variant is used. The dashed lines indicate the 95% confidence interval.

Figures 2 through 4 present the different responses of stock prices to a shock of cases and GRI in the presence of an exogenous variable. In figure 2, only the dummy variable of Alpha variant was included, in the third figure the dummy variable of Delta variant is present and in figure 4 the dummy variable of the Omicron variant was included.

We can see that in the presence of Alpha and Delta variant stock prices respond in the same manner to the shocks to cases and GRI. Regarding the response of stock prices to an increase in covid cases, in both cases the decrease reached a peak at the 13^{th} day with a decrease of 0,0028% in the presence of Alpha variant and a decrease of 0,0027% in the presence of Delta variant. As for the response of stock prices to an increase in the GRI, in the presence of the Alpha variant, the largest decrease appears in the seventh day reaching 1,77% while in the presence of the Delta variant, the decrease reached a peak of 1,67% in the fourth day. The difference in the days of the response is that the Delta variant was more deadly than the Alpha variant and governments responded faster in order to contain the spread of this variant. The impact of a shock on cases and GRI on the stock prices is slightly lower when the Delta variant was present compared to when the Alpha variant was present maybe because most population received at least two doses of the vaccine and people started to adjust to the presence of covid.

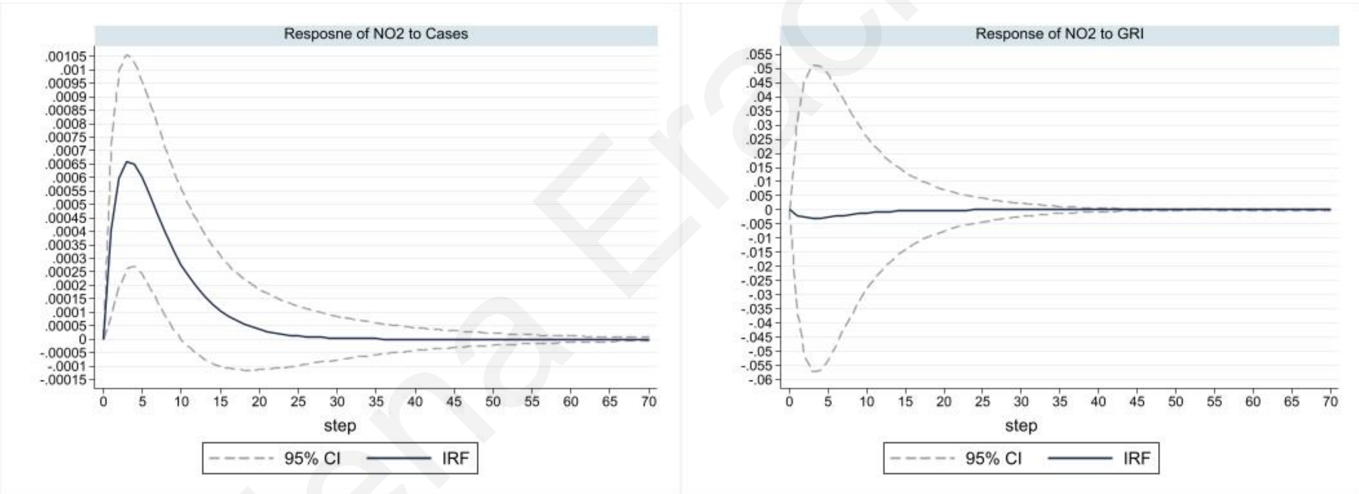
The response of stock prices to an increase in covid cases when the Omicron variant is present, in contrast with the Alpha and Delta variant, is positive. On the fourth day, the increase in stock prices is at its peak, 0.006%. The main reason for this response of stock prices is that the omicron variant is less deadly and most of the population were vaccinated with at least two doses and booster people felt more confident to return to their workplace and travel. Furthermore, after two years of presence of COVID-19 people learned how to live with COVID and slowly returned to normality. On the other hand, we observe a sharp negative impact of a shock to GRI on stock prices with the highest decrease being 12% on the fourth day. Then the shock starts to fade off. Since the Omicron variant is more contagious, at first governments imposed many restrictions to contain the spread. They imposed restrictions to number of people in public spaces and wearing masks. They imposed the Safe pass and traveling pass a well to certify that people are vaccinated and tested negative to Covid-19. When it was discovered that the Omicron variant had flu like symptoms, governments started slowly lifting restrictions and that is the reason the shock starts to fade away on the 23rd day.

5.2 Response of NO_2 emissions

In the following figures, the responses of NO_2 emissions to a standard deviation shock on cases and GRI are presented.

The figure below shows the response of NO_2 emissions to a standard deviation shock on cases and GRI without including any exogenous variables.

Figure 9:Response of NO_2 emission without exogenous variables



Note: Impulse response of NO_2 emissions to a standard deviation shock in covid cases and government response index. The dashed lines indicate the 95% confidence interval.

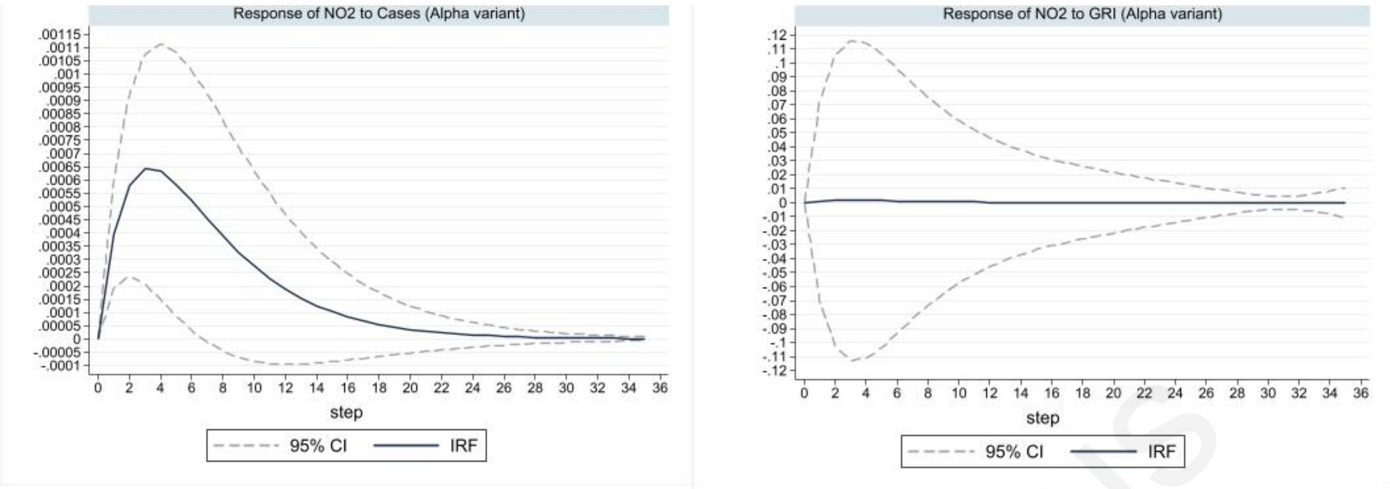
It is noticed that a shock in covid cases, increases the NO_2 emissions. This is not in line with economic intuition. We expected that when an increase in covid cases, NO_2 emissions will decrease since people were hesitant to go to work, travel and they preferred to stay more at home to feel protected. To further investigate this response, individual VAR models were estimated. The individual VAR models showed that for the following countries a shock to covid cases increase NO_2 emissions; Austria and Hungary, while the rest of the countries responded negatively to an increase in covid cases. We estimated two panel VAR models, one that excludes Austria and Hungary[6] and one that includes only them. Regarding the results of the estimation excluding Austria and Hungary, it is observed that on the third day of both shocks, NO_2 emissions decreased by 0.025% when infections increase and by 0.015% when government responses tighten, and by the 19th day, the shocks fade away. As for the results of the estimation including only Austria and Hungary, emissions increased by 0.13% on the second day of the shock to cases and then decreased until the 22nd day. When a shock on GRI is imposed, we observe an increase of 1% on the first day, then a decrease that reached 0,3% on the ninth day and recovering on the 22nd day. observed that on the third day of the shock, NO_2 emissions decreased by 0.025% while when we included the two countries in the panel a very small increase of 0.0065% in NO_2 emissions is observed during the 3rd day.

From the results above, excluding Austria and Hungary, we can conclude that when covid cases increase and Governments impose strict measures NO_2 emissions decrease in response to people stay in at home and not using any type of transportation and businesses being closed. As for Austria and Hungary, their government did not impose harsh restrictions at the beginning but as time passed, more restrictions were imposed.

The following figures presents the response of NO_2 emissions to a standard deviation shock to cases and GRI when the three dummy variables are included in the model as exogenous variables.

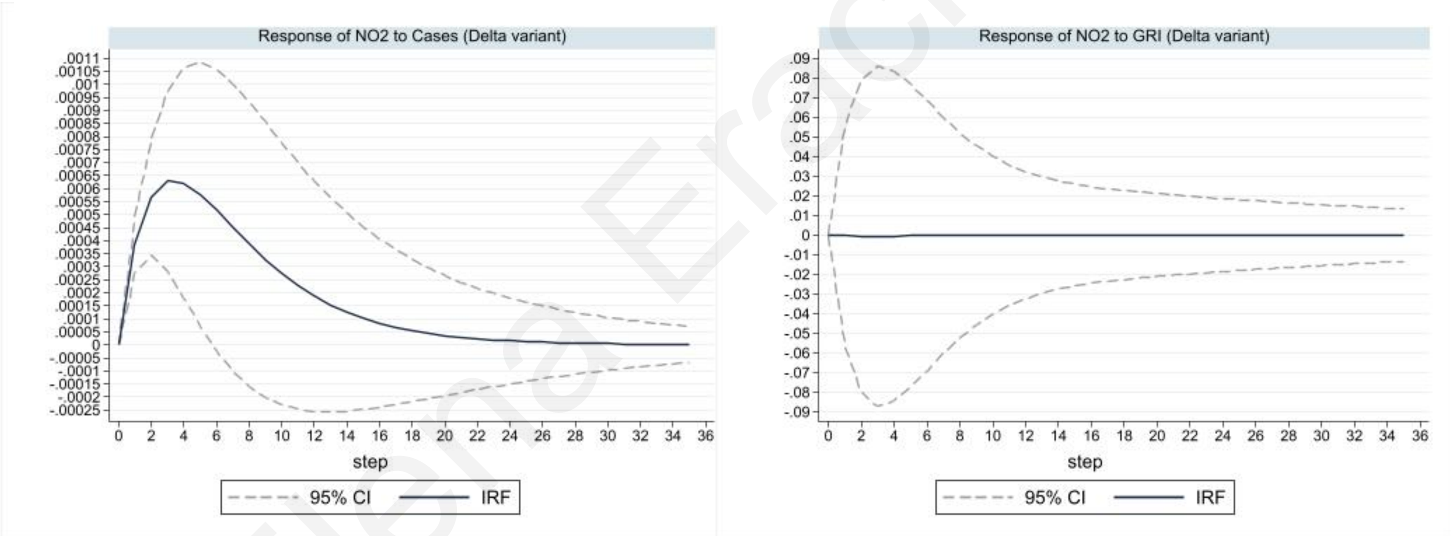
[6] The impulse response of the two estimated panel VAR can be found in Appendix II.

Figure 10: Response of NO_2 emissions with Alpha variant as exogenous



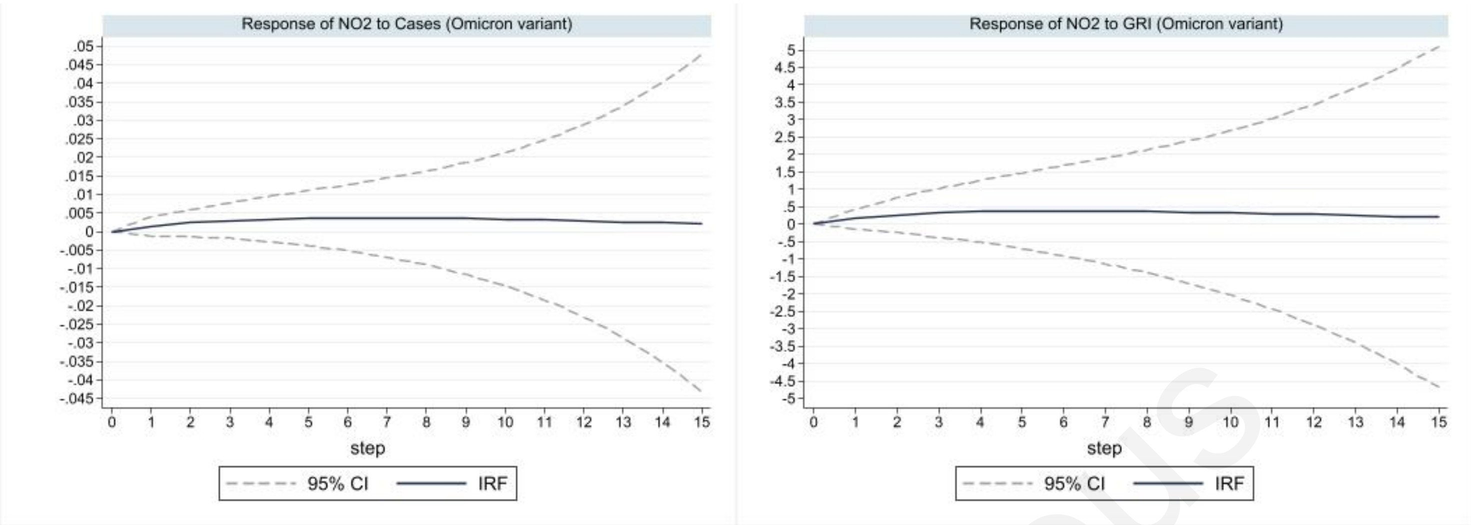
Note: Impulse response of NO_2 emissions to a standard deviation shock in covid cases and government response index when Alpha variant is included. The dashed lines indicate the 95% confidence interval.

Figure 11:Response of NO_2 emissions with Delta variant as exogenous



Note: Impulse response of NO_2 emissions to a standard deviation shock in covid cases and government response index when Delta variant is included. The dashed lines indicate the 95% confidence interval.

Figure 12:Response of NO2 emissions with Omicron variant as exogenous



Note: Impulse response of NO_2 emissions to a standard deviation shock in covid cases and government response index when Delta variant is included. The dashed lines indicate the 95% confidence interval.

Figures 5 through 7 present the different responses of NO_2 emissions to a shock of cases and GRI in the presence of one of the exogenous variables each time. In figure 5, only the dummy variable of Alpha variant was included, in the sixth figure the dummy variable of Delta variant is present and in figure 7 the dummy variable of the Omicron variant was included.

In the figures above, we see again something that was not expected. NO_2 emissions respond positively to cases and GRI when each variant is present. To investigate further we estimated as before two different panel VAR models, one that excludes Austria and Hungary and another that includes only them[7]. When we impose one standard deviation on cases and GRI when the variants are present, we observe different response of NO_2 emissions for Austria and Hungary compared to the rest of the countries.

When we exclude Austria and Hungary, we find that NO_2 emissions respond negatively to cases when the Alpha variant was dominant while when Delta and Omicron were dominant

[7] The impulse responses for the two estimations are presented in Appendix II.

NO_2 emissions respond positively. The Alpha variant was dominant during the end of December 2020 until mid-2021, during this period lockdowns and other containment measures were still being imposed in many countries and vaccinations were in early stages. So, an increase in cases affected negatively NO_2 emissions. The Delta variant appeared during the summer of 2021 in most of the countries. Even though the Delta variant caused more serious symptoms, people started to go out and travel and most businesses opened their doors with some restrictions because vaccination rates went up and most of the population had received its second dose. Under these circumstances, NO_2 emissions slightly increased. As for the Omicron variant, it appeared in December 2021 and although it is the most contagious it has flu like symptoms. Hence, people and businesses slowly started to return to normality. After two years of the pandemic, the world adjusted and learned to live with the virus. So NO_2 emissions increased even more when a positive shock to cases was imposed when the Omicron variant was dominant.

As for the response of NO_2 emissions to a shock to GRI, we observe that in the presence of the Alpha and Delta variant, Government responses decrease the NO_2 emissions. As discussed above, during the Alpha variant, lockdowns and containment measures were still in place and during the Delta variant event though lockdowns were lifted, most governments imposed restrictive measures, such as restriction in the number of persons in public spaces and events and a percentage of employees had to work from home. Therefore, during both variants, Alpha and Delta, businesses were not working in full capacity in the sense of employees and customers and people started to travel and go out more when the vaccination rate increased. When the Omicron variant appeared in the end of 2021 and it was discovered that the variant is the less deadly compared to others, governments started to lift even more restrictions and the economy slowly started to return to normality.

Regarding Austria and Hungary, NO_2 emissions seem to not respond differently when the variations of the virus are introduced to a standard deviation shock to cases and GRI. In all cases, when covid cases increase, during the first six days of the shock NO_2 emissions increase by 0.1% on average and then the shock fades away. One of the reasons for this reaction is the fact that both countries provided strong economic support throughout the pandemic. As for the response of NO_2 emissions to a shock on GRI, we observe that in all cases an increase of 1% on average in the first day of the shock and then on the sixth day a decrease of 0.3% is observed and then again rising and fades away. The reason we observe these reactions is that in the GRI, economic support and containment measures are included and while there was high economic support, strict restrictions were also in place.

6. Conclusion

The impact of the COVID-19 and its most dominant variations and policy responses in a panel of the member of the European Union were estimated in this paper. We focus on the response of stock returns and the increasing rate of NO_2 emissions to quantify the economic impact at a high frequency. These variables are available daily, while macroeconomic measures like industrial production, inflation, and employment are only available monthly and real GDP quarterly.

We find that both proxies of the economic activity are sensitive to the spread of the virus and the government's response policies in most countries. A sudden spike in the number of cases causes a decline in our two economic indicators, except Austria and Hungary in the case of NO_2 emissions. Also, when a stronger government response is imposed again both stock prices and NO_2 emissions fall. Furthermore, when we introduce the three dominant variations of the virus, we observe different reactions. In the presence of Alpha and Delta variations, the response of stock prices to a shock on new cases and GRI is the same. The stock prices fall.

On the contrary, when the Omicron variant is dominant, stock prices respond positively to a shock on cases and negatively to a shock on GRI. The main reason for the response of the stock prices to cases is that after two years of the presence of COVID-19 people learned how to live with COVID and slowly started to return to normality and as for the response of stock prices to GRI, since the Omicron variant is more contagious, at first governments imposed many restrictions to contain the spread and then slowly relaxing the restrictions when it was discovered that this variant has the mildest symptoms.

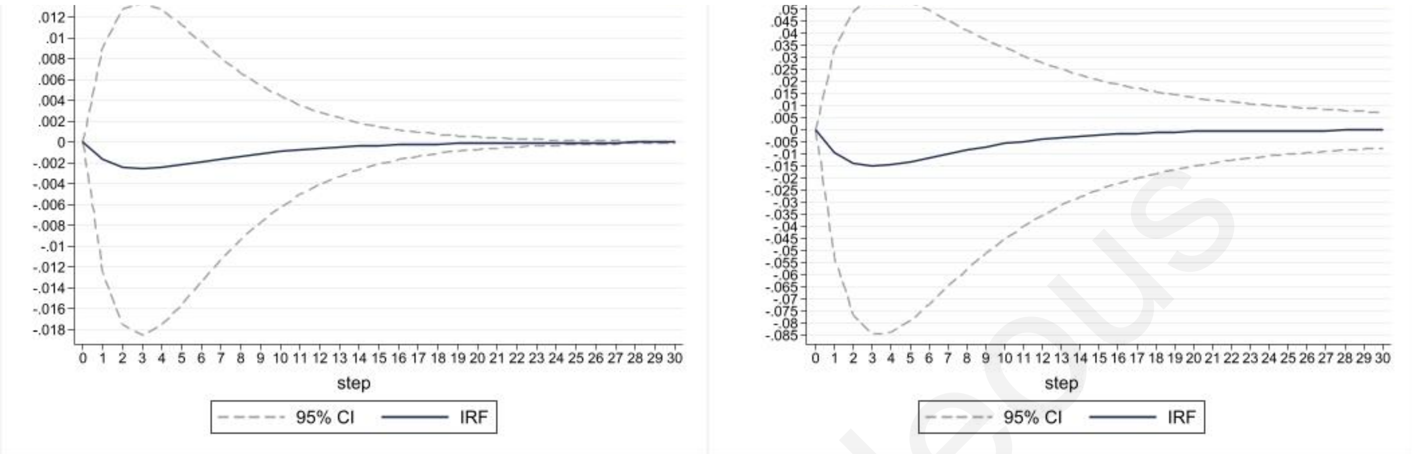
Regarding the NO_2 emissions, we find that two countries in our sample respond differently compared to the rest of the countries. Austria and Hungary are indifferent to variations and respond in the same manner as when we do not include the variations. When covid cases increase, NO_2 emissions increase, and then the shock fades away. One of the reasons for this reaction is the fact that both countries provided strong economic support through the pandemic. As for the response of NO_2 emissions to a shock on GRI, we observe that in all cases an increase on the first day of the shock and then on the sixth day a decrease is observed and then again rise and fades away. The reason we observe these reactions is that in the GRI, economic support and containment measures are included and while there was high economic support, strict restrictions were also in place. As for the rest of the countries, we find that NO_2 emissions responded negatively to an increase in cases and higher GRI when the Alpha variant was dominant while when Delta was dominant NO_2 emissions responded positively to a standard deviation shock on cases and negativity in response to GRI. When it comes to the Omicron variant, a positive response of NO_2 emissions to a shock to cases and GRI is observed.

On a final note, improvements can be made to study the impact of the COVID-19 pandemic and government policies. In our analysis, the dataset is quite short even when we use daily data. Furthermore, government policies can be evaluated in different groups, i.e., economic support, containment measures, and health policies. Finally, the countries in our sample can be split into different groups depending for example on geographical location or even on vaccination rate.

Appendix I

Impulse response functions excluding Austria and Hungary:

Figure 13:Response of NO_2 emissions without exogenous variables



Note: Impulse response of NO_2 emissions to a standard deviation shock in covid cases and government response index. The dashed lines indicate the 95% confidence interval.

Figure 14:Response of NO_2 emissions with Alpha variant

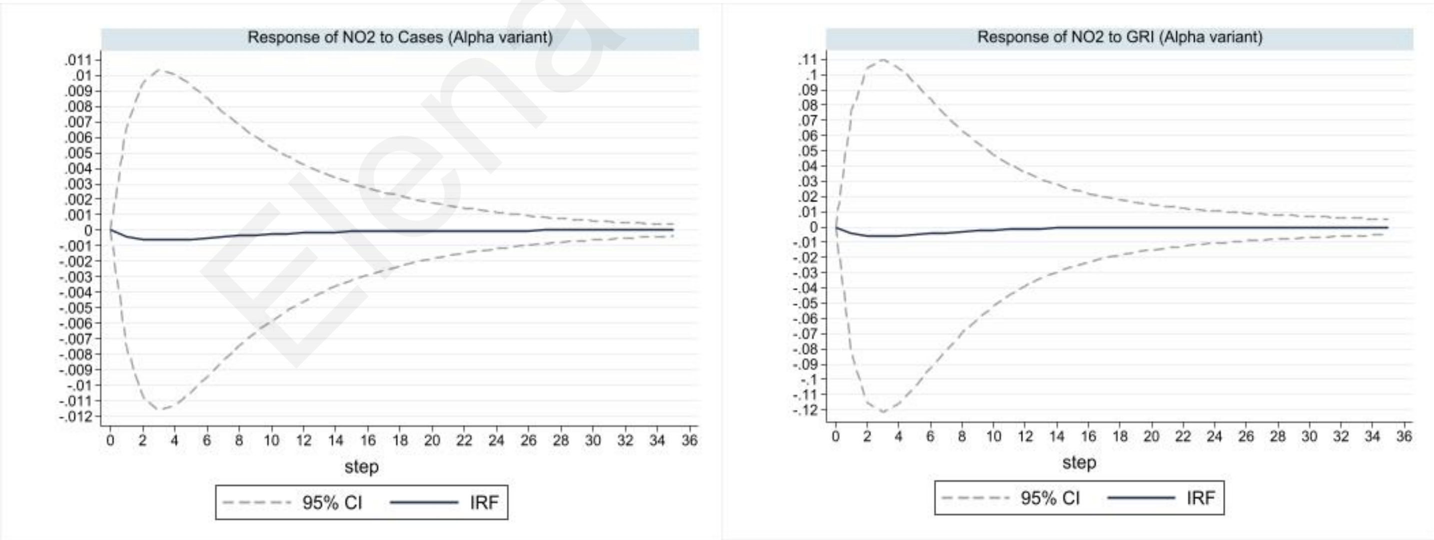


Figure 15: Response of NO_2 emissions with Delta variant

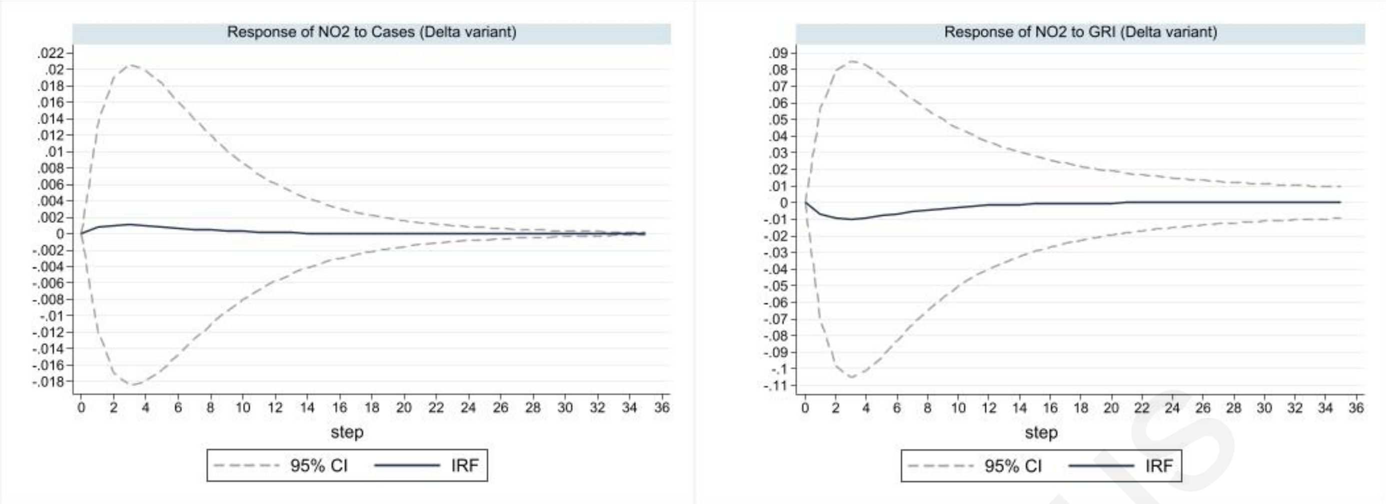
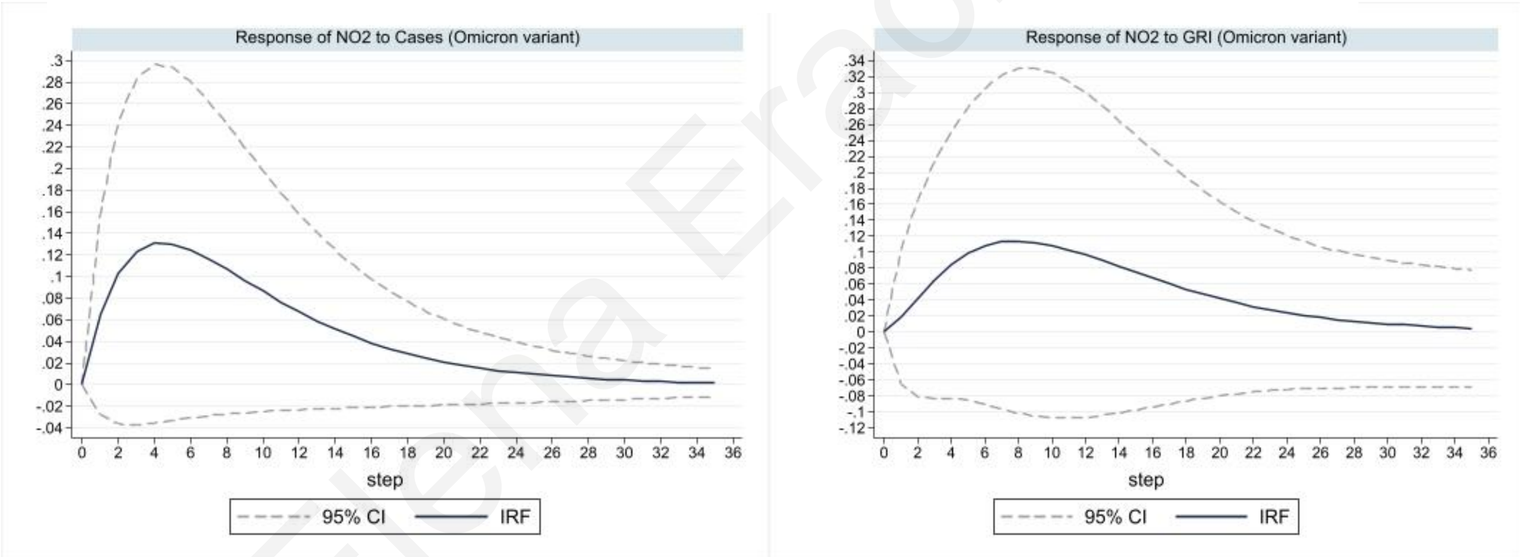


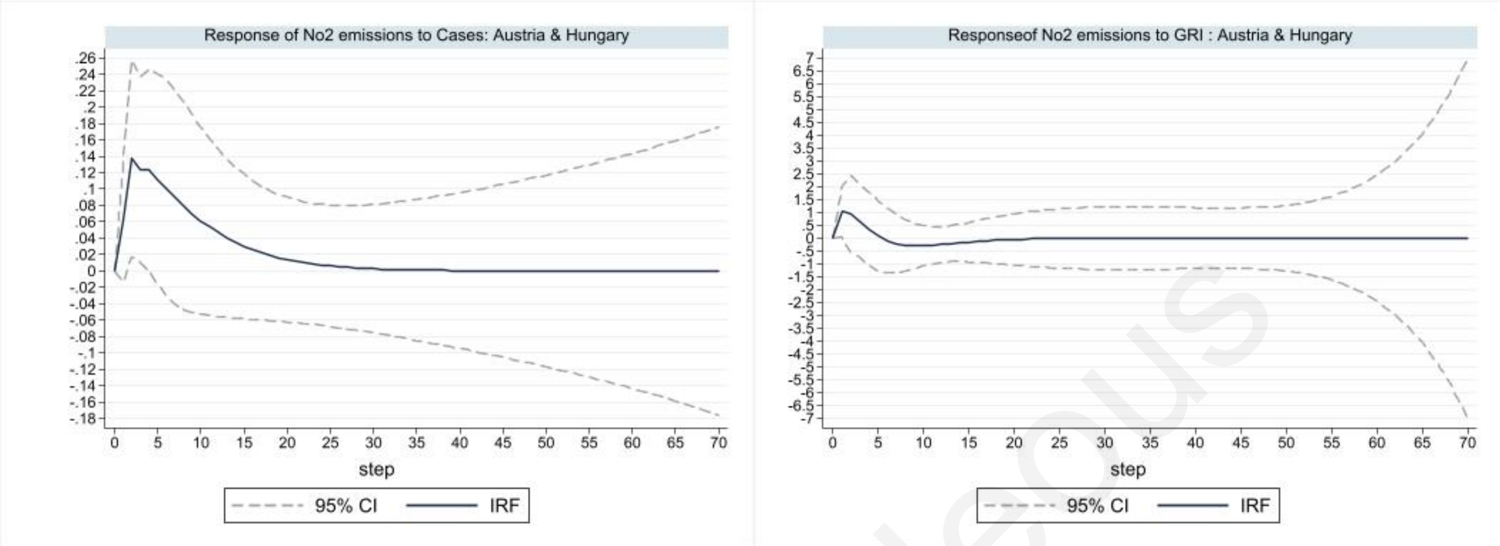
Figure 16: Response of NO_2 emissions with Omicron variant



Note: Impulse response of NO_2 emissions to a standard deviation shock in covid cases and government response index when exogenous variables are included. The dashed lines indicate the 95% confidence interval.

Impulse response functions for Austria and Hungary:

Figure 17: Response of NO_2 emissions excluding exogenous variables



Note: Impulse response of NO_2 emissions to a standard deviation shock in covid cases and government response index. The dashed lines indicate the 95% confidence interval.

Figure 18: Response of NO_2 emissions with Alpha variant

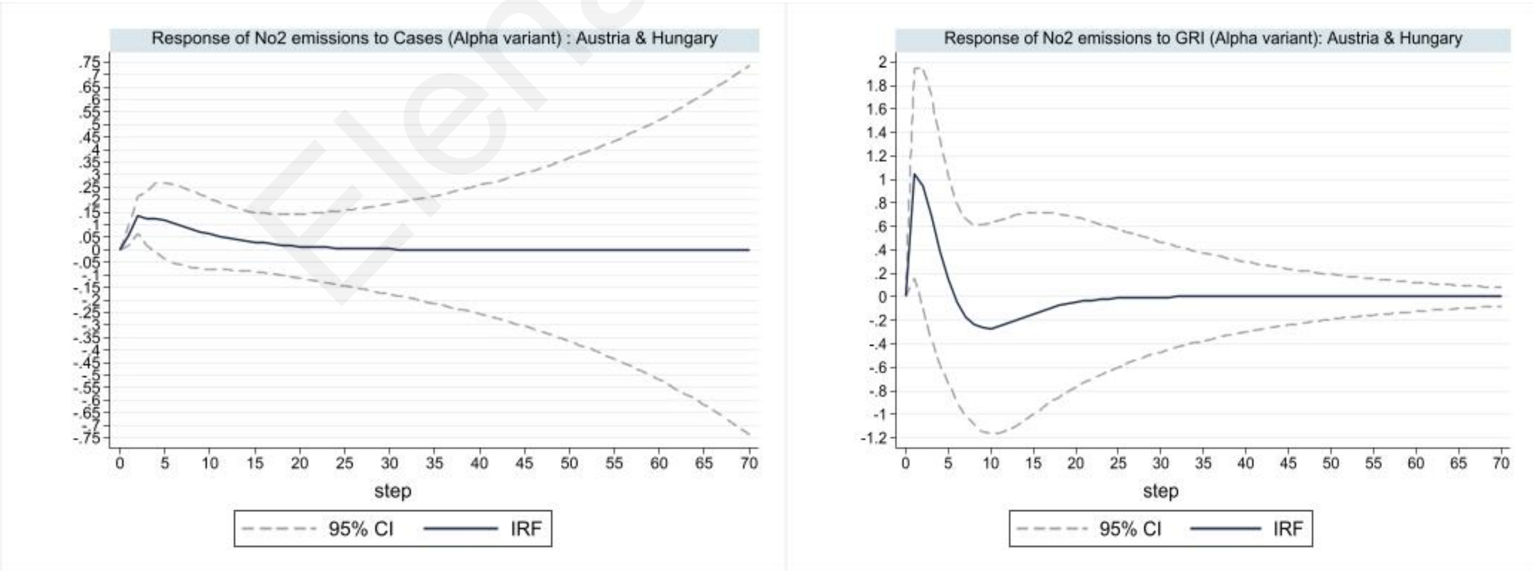


Figure 19: Response of NO_2 emissions with Delta variant

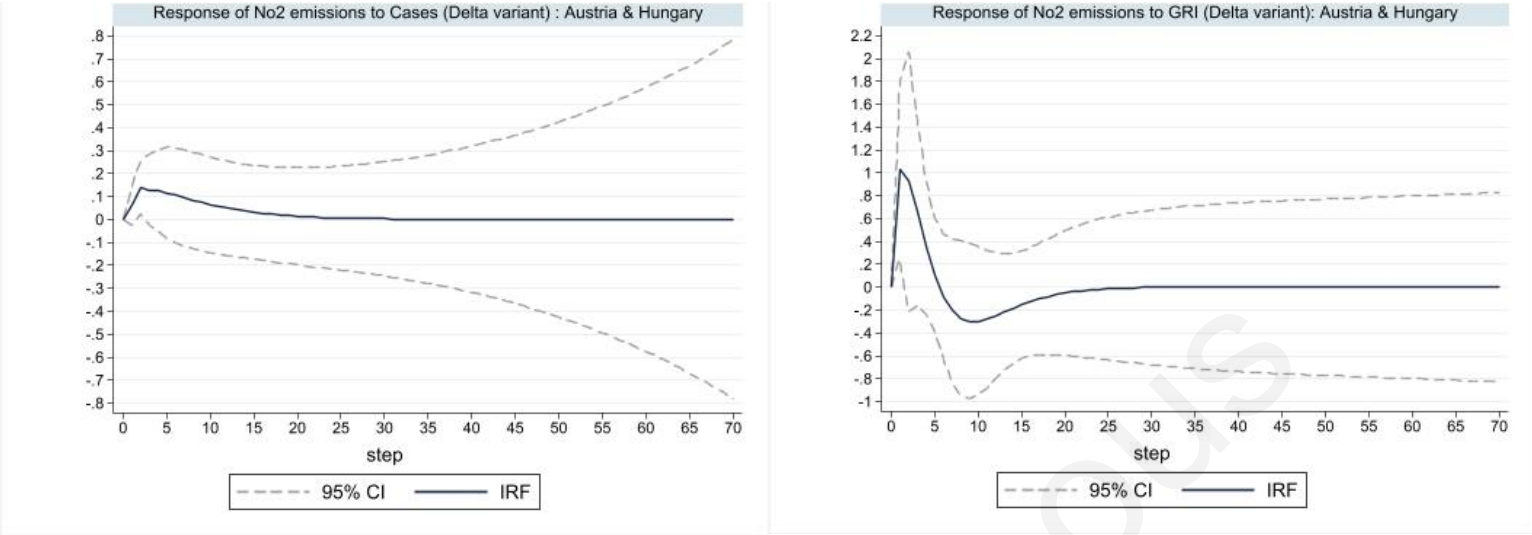
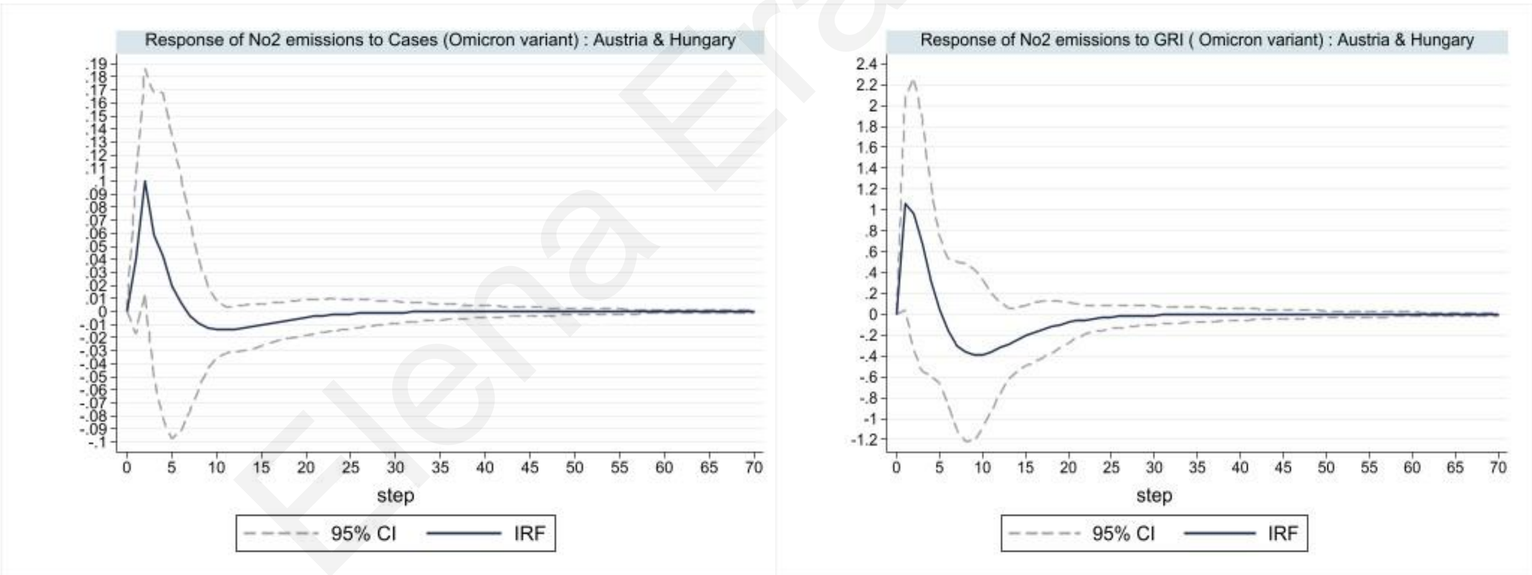


Figure 20: Response of NO_2 emissions with Omicron variation



Note: Impulse response of NO_2 emissions to a standard deviation shock in covid cases and government response index when exogenous variables are included. The dashed lines indicate the 95% confidence interval.

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