CHARLES UNIVERSITY

FACULTY OF SOCIAL SCIENCES

Institute of Economic Studies

Bachelor Thesis

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Charles University

Faculty of Social Sciences
Institute of Economic Studies

The COVID-19 measures: Impact on economies and mitigating spread of the disease

Bachelor Thesis

Prague 2021

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Academic Year: 2020/2021

Declaration of Authorship

I hereby proclaim that I wrote my bachelor thesis on my own under the leadership of my supervisor and that the references include all resources and literature I have used.

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Prague, May 4, 2021

Signature

Acknowledgments

I would like to express my gratitude to the supervisor of this thesis, PhDr. Lucie Bryndová, for her time, guidance and valuable insights in the process of writing of this bachelor thesis.

Bibliographic note

ŽIAČIK, Jan. *The COVID-19 measures: Impact on economies and mitigating spread of the disease* 2021. 62 pp. Bachelor thesis (Bc.) Charles University, Faculty of Social Sciences, Institute of Economic Studies. Thesis supervisor PhDr. Lucie Bryndová

Abstract

The thesis analyzes effect of non-pharmaceutical interventions on economic growth and transmission of COVID-19. At first, on the quarterly panel data from 96 world countries, the U.S. states and the District of Columbia, covering period between 2014 and 2020, several fixed effect regressions are used in order to estimate effects of voluntary reduction of economic activity and stringency of the measures, represented by proxy variables Stringency Index and deaths per 100 000 inhabitants, on economic growth. Then, on the same data, again utilizing fixed effects, effects of individual non-pharmaceutical interventions on economic growth are analyzed. The effects of the measures on the transmission of COVID-19 are then estimated on panel data with two-week periods, approximately covering last 3 quarters of 2020. The results of the first part of the analysis suggest that of the two estimated effects, economic growth was determined solely by the stringency of the measures in 2020. As for the individual measures, statistically significant effect of cancellation of public events is identified. Analyzing their effect on the transmission of COVID-19, closure of schools, closure of workplaces, restrictions on gatherings and mask wearing requirements have statistically significant negative effect on the growth rate of the new cases and income support has a positive one but only if they are implemented with a sufficient stringency. Stay at home order seems to significantly lower transmission, even if it is in force with a low stringency but further strengthening of the measure does not seem to have additional impact. Finally, cancellation of public events negatively affects transmission with statistical significance if it is implemented with a low stringency and further strengthening of it has additional significant effect.

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Keywords

Fixed effects model, panel data, transmission of virus, economic growth, the COVID-19 pandemic, non-pharmaceutical interventions

Abstrakt

Tato práce analyzuje efekt nefarmaceutických zásahů na ekonomický růst a šíření COVID-19. Nejprve je, na datech pro 96 zemí světa, unijních států USA a Washingtonu D.C., z období mezi lety 2014 a 2020, estimováno několik modelů fixních efektů, za účelem určení vlivů dobrovolného snížení ekonomické aktivity a síly opatření, reprezentovaných proxy proměnnými Stringency Index a počtem smrtí na 100 000 obyvatel, na ekonomický růst. Následně jsou, znovu s využitím stejných dat a modelu fixních efektů, estimované vlivy jednotlivých opatření na ekonomický růst. Vliv opatření na šíření COVID-19 je pak estimován na panelových datech s dvojtýdenními periodami, které přibližně odpovídají posledním třem čtvrtletím roku 2020. Výsledky první části analýzy naznačují, že ze dvou estimovaných efektů, jenom negativní vliv síly opatření determinoval ekonomický růst v roce 2020. Co se týče jednotlivých opatření, je identifikován statisticky signifikantní negativní efekt rušení veřejných akcí. V případě efektů opatření na přenos COVID-19, zavírání škol a pracovišť, restrikce shromáždění a povinnost nošení roušky mají statisticky signifikantní negativní efekt na růst nových případů, náhrada příjmů má statisticky signifikantní pozitivní vliv, oboje ale jenom když jsou opatření implementována dostatečně přísně. Zákaz opuštění domácnosti pak signifikantně omezuje přenos viru, i když je v platnosti v mírnější podobě, ale jeho další zpřísnění už nemá další efekt a konečně, rušení veřejných akcí má signifikantní negativní efekt, když je opatření zavedeno v mírné podobě, a i jeho další zpřísnění má dodatečný statisticky signifikantní efekt.

Klíčová slova

Model fixních efektů, panelová data, přenos viru, ekonomický růst, pandemie COVID-19, nefarmaceutické zásahy

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Acronyms

BEA	U.S. Bureau of Economic Analysis
GDP	Gross domestic product
OxCGRT	The Oxford COVID-19 Government Response Tracker
OLS	Ordinary Least Squares
NPI	Non – pharmaceutical interventions
VIF	Variance inflation factor

Bachelor's Thesis Proposal

Institute of Economic Studies
Faculty of Social Sciences
Charles University in Prague

Author's name and surname: Jan Žiačik

Supervisor's name: PhDr. Lucie Bryndová

Proposed Topic:

The COVID-19 measures: Impact on economies and mitigating spread of the disease

Preliminary scope of work:

Research question and motivation

The *COVID-19 pandemic* poses challenge to the society, unprecedented in recent history. Countries around the world, in the fear of overloaded health care systems, introduced restrictive measures that negatively affected their economies. These restrictions will almost certainly have further serious economic consequences in the years to come. The question, I will try to answer in my thesis, how speed of implementing of the measures affected economic growth, and on the other hand, how effective it was in preventing spread of the disease, is thus important for deciding on the right policy, introduced in case of similar event occurring in the future.

Contribution

Given that pandemic began in first quarter of 2020, not much research has been done on it yet. The studies, that were already published, worked mostly with data only from the beginning of the pandemic and with different research methods for estimating the economic effects of measures, than will be used in this thesis. My contribution will thus lie assessing the consequences of both the positive and the negative effects of public health measures, with method not applied in any previous study and using the most recent data.

Methodology

The subjects of the study will be countries of the world. Two linear regressions will be employed. The first one will estimate effects of speed of measures implementation and their depth on differences between prediction of GDP growth before crisis and the actual one. The data will be collected with help of databases of governments measures, which are available on the internet and my own research. The second will then examine relation between speed of implementation of different types of measures, their depth and the quickness of spread of the disease, represented by basic reproduction number. Hopefully, regressions can identify measures that individually affected the decline in economic growth the most, what role the speed of the implementation played, how important was depth of the measures and on the other hand, which of them had biggest influence on mitigating spread of the disease, if the depth of the measures have any role in it and how much speed of the implementation mattered. Effects on reducing spread of disease and economic growth will be then weighed against each other, so the overall usefulness of measures can be assessed.

Outline

1) Introduction

2) The COVID-19 pandemic

3) Literature review

4) Data and methodology description

5) Results and discussion

6) Conclusion

List of academic literature:

Barro, Robert J. and Ursúa, José F. and Wang, Joanna, The Coronavirus and the Great Influenza Pandemic: Lessons from the “Spanish Flu” for the Coronavirus's Potential Effects on Mortality and Economic Activity (March 2020). NBER Working Paper No. w26866, Available at SSRN: https://ssrn.com/abstract=3559155

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1 Introduction

The COVID-19 virus, first reported in China in December 2019, reached by the end of March 2020 most of the countries of the world and caused a pandemic unprecedented in the recent history. As a response to it, countries implemented various social distancing measures intended to contain its spread. Unfortunately, because many of the measures can affect not only personal freedom but also the economic activity, soon the question arose how big this influence is. Many studies from the beginning of the pandemic assign only small role to the introduction of the measures and instead blame voluntary reduction of economic activity ascribed to the fear of the newly beginning pandemic (Maloney and Taskin, 2020; Goolsbee and Syverson, 2021). The study of König and Winkler (2021) conducted on first 3 quarters of 2020 then shows mixed results about importance of these two effects.

If the effect of the measures implemented is not minimal, another important question naturally arises and that is which of the measures affect economy and how much and, additionally, whether their implementation is beneficial by comparing their effect on the economic activity with their ability to contain spread of the virus. At the beginning, given that the measures were implemented often in groups, their individual effects were hard to distinguish. But now, when more time has passed and the variation of the implemented measures increased, it becomes more viable.

In case of estimation of individual effects of measures on economy, there is not much literature available yet, although their effect on transmission was explored in several studies. Haug et al. (2020) find strong evidence for the fact that both the radical measures, such as lockdowns and school closures, and the less invasive ones, as, for example public informational campaign, can help to contain transmission of COVID-19. Brauner et al. (2021) do not assign as much importance to the lockdown but confirms the important role of closing of schools. Liu et al. (2021) using different specification to capture different effects of the measures find most convincing evidence for the effect of closing of schools and restrictions on internal movement. Nevertheless, even these studies are performed only on the data from the first half of 2020.

The aim of this thesis is, therefore, twofold. Firstly, it tries to establish, on the data for the whole year 2020 and on a bigger sample than in case of König and Winkler (2021) how much of an influence on the economic growth, the measures cumulatively have, in comparison with voluntary lowering of the activity in face of a pandemic and, secondly, how the individual measures are effective in containing spread of COVID-19 in comparison with their effect on the economic activity.

The results indicate that economic decline was caused mainly by the measures implemented and individual effect of cancellation of the public events is identified. As for the effect of measures on transmission, closing of schools, cancellation of public events, prohibition on gatherings, orders to wear face masks, stay at home orders and income support were all identified to be significant in containing the spread of the virus.

The thesis is structured as follows. At first, the existing literature relating to the topics of this thesis is described, in the next chapter, the research hypotheses are specified. Subsequently, the dataset, used in the analysis, and its sources are described. Then, the description of methodology of the part of the analysis which deals with the effects of cumulative effects of the measures and voluntary lowering of the consumption follows. The choices of dependent and independent variables are commented on there, as are the descriptive statistics of the data and the model which is the subject of the analysis. The next chapter is in the same way dedicated to the methodology of analysis concerning individual effects of the measures on the transmission of COVID-19 and economic activity. Then, results of the analysis are presented and discussed, and the last chapter concludes the thesis.

2 Literature review

2.1 Economic impact of NPIS

Before the beginning of the COVID-19 pandemic, most of literature on the topic, concerns itself more with overall economic influence of previous pandemics than the impact of government public health measures. In one of these earlier studies, Brainerd and Siegel (2007), analyzing growth in the United States between the First World War and the Great Depression, find significant positive relationship between the Spanish flu pandemic and individual income growth. The positive influence of severity of the pandemic on the wage growth in the USA can be found also in Garrett (2009).

One of the closest studies to the scope of this thesis from period before the current pandemic is then Smith et al. (2009), which simulates different scenarios of an influenza pandemic with the help of general equilibrium model, on the data from the United Kingdom in 2004 and find that school closures can result in additional loss of between 0,5% to 2% of Gross Domestic Product (GDP).

It is not until 2020, when more publications on the effect of non-pharmaceutical interventions (NPIs) on the performance of economy begin to appear. Some of these papers focus on analyzing the period of the 1918 influenza pandemic. Correira et al. (2020), using difference-in-differences method, comparing 43 U.S. cities, does not find any meaningful differences between the units with the strict and more lenient NPIs, although admitting, at the same time, that because of the overall leniency of the measures in comparison with the ones applied in 2020, lower employment rate of women and mortality rate for working age population, among others, it is hard to extrapolate from the findings of the study to the COVID-19 pandemic.

Nonetheless, several studies, dealing with COVID-19 pandemic, reach similar conclusions. One of them is Andersen et al. (2020), which deals with the difference between the consumption behavior of the citizens of Sweden and Denmark in March and April where Denmark applied strict measures and Sweden did not and find only relatively small difference in spending between these two countries, implying, similarly to study on the 1918 influenza, that NPIs have only small effect on the decline in the economic activity in the comparison with the pandemic itself.

Given the fact, that direct measures of economic activity are usually available with delay, some papers used instead proxies in their analysis. Using data on NO_2 emissions, electricity consumption and data on mobility from mobile phones, all of them available in daily frequency, Demirguc-Kunt et al. (2020) conclude that although NPIs are generally connected with economic downturn, quicker adoption of measures can mitigate some of the loss of the activity. According to the study it seems to derive from the fact, that when measures are adopted earlier, they also tend to be less stringent.

The data on mobility of population are utilized also in other works. Meissner and Lin (2020), analyzing data on traffic in different types of locations in the USA between March and April, find that only small difference in the mobility can be explained by the implementation of stay at home measure in individual states. The data implies that major driving force behind reduction of activity were nationwide effects, voluntary lowering of activity, before stay at home requirement was implemented seems to have also significance. The fact that the measures do not determine major part of economic downturn is supported also by data on unemployment in various states, which does not show any differences based on their implementation.

There are also other studies that come to a similar conclusion about economic effect of the measures (Maloney and Taskin, 2020; Goolsbee and Syverson, 2021), however not all papers agree on this. Gupta et al. (2020), in their study of determinants of unemployment rate in USA between March and April, estimate that almost two thirds of the new unemployment is caused by NPIs.

Kok and Lin (2020) estimate pooled regression with variables for economic growth, NPIs and other government policies of countries, from the first two quarters of 2020. The estimates of the regressions differ based on the sample that is used, but in two of the three estimations conducted, magnitude of testing, closing of schools and workplaces show statistically significant effect on the economic growth where coefficients are negative for both types of closure and positive for the magnitude of testing.

One of the latest works and also closest in the methodology to this thesis is König and Winkler (2021) who estimate effect of the measures on the quarterly GDP growth in 42 countries. Using Ordinary Least Squares (OLS), instrumental variable and fixed effects estimations, stricter NPIs show significant negative effect on the economic growth for all three methods applied.

Nevertheless, the study is conducted on only 42 countries in the sample. Because of that, more data with more varied information on NPIs could show more precise estimates.

Moreover, comparing the economic consequences of the NPIs with the effects on the epidemiological situation is also important for their evaluation.

2.2 Impact of NPIs on transmission

Since the last event, before the COVID-19 pandemic, of a similar scope, was the 1918 influenza pandemic, studies dealing with it, are the only other source of information on effects of NPIs on a transmission of a viral disease, which are comparable with the effects of social distancing measures currently implemented.

In one of these studies, Zhang et al. (2010), compare situation in two Canadian cities, Winnipeg and Montreal, with significantly different approaches to containing spread of the disease. Comparing estimated values of reproduction number, in the early stage of spread of the disease, difference in its value in Winnipeg, which introduced measures aiming to contain spread of the viral infection quickly and thoroughly and Montreal where the response was more delayed and more lenient, was found to be around 1 in favor of the Winnipeg.

In another paper, Bootsma and Ferguson (2007), comparing epidemiological situation in 1918 and 1919 in various American cities, using fitted SEIR model, shows, that social distancing measures implemented early on were associated with lower mortality. However, in the cities, which then did not reimpose social distancing policies when the number of cases began to rise again, early intervention resulted in the higher second mortality peak, in comparison with the cities with slower initial response.

The positive effect in lowering disease transmission can be found also in Fraser et al. (2011), who in their own estimation of reproduction number with the help of time series analysis, on the epidemiological data from last two months of 1918 in Baltimore, conclude that implementing of social distancing measures was associated with 42% lowering of disease transmission.

A big part of literature, which concern itself directly with COVID-19 pandemic, uses various variations of the SIR model in their analysis. In one of these studies, Salje et al. (2020), fitting expanded SEIR model to the data before and after implementation of lock down, in France in spring 2020, estimates 77% reduction in reproductive number. Similar conclusions, applying some variation of SIR model and comparing reproduction number before and after introducing NPIs in the early stages of the pandemic, are reached also by other studies (Karnakov et al., 2020; Flaxman et al., 2020).

Backer et al. (2021) do not try to estimate effect of social distancing policies on transmission directly, but instead explore relation between social distancing measures and number of daily contacts between people in Netherlands. Comparing results of survey from years 2016 and 2017, with survey taken after introduction of the lock down measures at the end of the March 2020 and finally survey from June 2020 when the measures were relaxed, they find that implementation of measures at the end of March was connected with lowering number of average contacts by approximately 10, from 14 in 2016 to 4 after implementation of the measures and rising to 9 after easing of the measures, although results varied between different age groups.

Haug et al. (2020), combining results of four different approaches, analyzing data from the spring of 2020, and verifying results on two additional datasets, find strong evidence that besides the more radical NPIs as are school closures, lockdowns and border restrictions, less intrusive measures, such as communicating risks of the pandemic to the public and economical support of people, affected negatively by the pandemic, can also reduce the spread of the disease. On the other hand, there is a little evidence supporting effectiveness of NPIs regarding public transport and disinfecting of surfaces.

Results, in another study identifying individual effects of the measures from early stages of the pandemic carried out by Brauner et al. (2021), using Bayesian hierarchical model, also show a great role of the school closures in managing the pandemic. Additionally, testing also seem to have positive effect. On the contrary, stay at home orders do not seem to have great impact.

Not all the studies, use fitted models in analyzing the effect of social distancing measures, in one of those, Ozyigit (2020), using panel data analysis on daily epidemiological data from EU-15 countries from beginning of the pandemic, founds significant negative relationship between rate of growth of the new cases and days when the more strict measures were in force. More precisely, in the model, days with measures in effect were associated with on average, approximately 20 percent lower growth rate of the new cases. Also working with panel data from the first half of the year 2020, Liu et al. (2021), finds strong association between reproduction number of the virus and internal movement restrictions and school closures.

3 Hypotheses

The thesis has two main aims. The first one, closely follows work of König and Winkler (2021) and tries to establish, whether downturn in economic growth in year 2020 was related more to voluntary reduction in economic activity as a reaction to the ongoing pandemic or if the non-pharmaceutical measures, implemented in attempt to reduce transmission of the disease, take most of the blame. In the second part of the analysis, impact of individual measures is examined both on economic growth and transmission of COVID-19.

Thus, the null hypothesis of both parts of the analysis is stated as:

$$H_0\colon \beta_j = 0,$$

where β_j stands for parameter estimate of a coefficient of the proxy variable describing either overall stringency of measures or voluntary reduction of economic activity in the case of the first part of the analysis. The null hypothesis, therefore, states, that either voluntary reduction of activity or NPIs are not significant drivers of the economic downturn. In the case of the second part of the analysis, β_j represents a parameter estimate of jth variable describing a type of NPI and the null hypothesis is that the intervention does not have a significant effect, either on the economic growth or the transmission of the disease.

The alternative hypothesis:

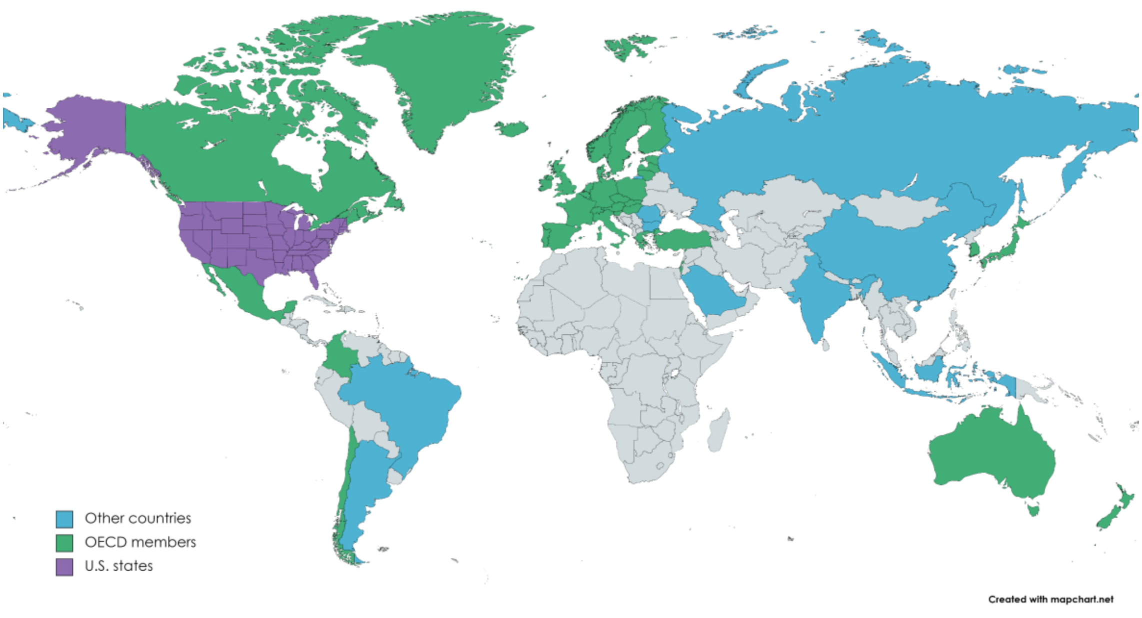
$$H_1\colon \beta_j \neq 0,$$

then is, that, either voluntary reduction of the economic activity or the stringency of the measures implemented, have significant effect on the economic growth in case of the first part of the analysis. In the case of the second part of the analysis, it is then that the jth variable describing a type of NPI has an effect either on the economic growth or the transmission of the virus. The expected effect of individual variables is described in the next two following chapters in sections 5.5 and 6.4.

4 Involved countries and data sources

In the following chapter, the countries which are included in the analysis, and the sources of the data are listed. The data itself is then more closely analyzed in sections 5.4 and 6.3. The subjects of the thesis are the countries of the world, the federal states of United States of America, except Hawaii, plus District of Columbia. Among the countries included in the analysis, there are all members of OECD except USA, because its individual states are part of the analysis, and further Argentina, Brazil, Bulgaria, China, Indonesia, India, Romania, Saudi Arabia and South Africa. Together, there are 96 units included in the analysis. Given the nature of the thesis, most of data used are taken from year 2020, even though in a part of the analysis, economic data from period starting point in 2014 are incorporated. The countries included into the research were chosen based on the fact, that that data on quarterly GDP was available for them.

Figure 4.1: Map of the states included in the analysis



4.1 Data Sources

The data for the thesis are collected from several sources. From the OECD data web page, quarterly year-over-year growth rates of GDP values are taken for all world countries (OECD, 2021). The source of same data for the U.S. federal states is U.S. Bureau of Economic Analysis (BEA), although in its case, only values of real GDP are available, so the growth rate is calculated manually (BEA, 2021).

The main independent variables of interest, in both part of the analysis, are the ones describing social distancing measures. As a source of these, created as the part of the project, the Oxford COVID-19 Government Response Tracker (OxCGRT) is used in which daily data on different types of social distancing measures are collected with its own defined variables (Hale et al., 2021).

Finally, the data regarding COVID-19 deaths and cases, are taken from COVID Data Tracker website, for individual U.S. states and from World Health Organization website, for the world countries (CDC, 2021; WHO, 2021). In case of Luxembourg, the data on the cases are included with two different specifications for first and second half of the year 2020. Because of that, the data was gathered separately through the site of the Luxembourg government (Ministry of Health, Luxembourg, 2021). Additionally, the deaths are scaled to the size of the population in the analysis. For this purpose, population estimates from U.S Census Bureau and World Bank Open Data websites are utilized (U.S. Census Bureau, 2019; World Bank, 2019).

5 NPIs vs. change in behavior

For the first part of the analysis, in attempt to find distinctive effects of NPIs and change of consumer behavior in the face of pandemic, approach of König and Winkler (2021), is adopted and, on the sample of 96 countries and individual U.S. states, a linear regression is estimated, using panel data analysis with quarterly data spanning period of time between 2014 and 2020. In the following chapter, variables, used in the analysis, and their descriptive statistics are presented followed by the description of the model and the expectations on the sings of the coefficients.

5.1 Dependent variable

The original idea for dependent variable was to use projected values of GDP from World Economic Outlook dataset from time before the fallout of the pandemic was included into estimations. From these values, the real GDP growth values would be subtracted in order to get an estimation of the effect of the pandemic. This approach would require working with only one yearly observation for every unit in the sample since only yearly forecast data are available in the dataset. Given the fact, that COVID-19 pandemic came through differently intense phases, being less severe in the summer months and after reviewing literature which became available in the meantime, following König and Winkler (2021), year-over-year quarterly value of GDP was chosen for the analysis instead.

5.2 Measuring the scope of non-pharmaceutical interventions

As a proxy for the stringency of the NPIs implemented in the individual countries, variable created as a part of the OxCGRT dataset, called **Stringency Index** (*SI*), was adopted (Hale et al., 2021). The variable, which was already used in other studies dealing with the economic effects of NPIs (Ueda et al., 2021; Ashraf, 2020), is available in a daily frequency from the beginning of the year 2020 to the present time (as of 10th of April, 2021). It is created as an average of 9 sub-indexes, each corresponding to one variable describing social distancing measures. These variables are all of the ordinal scale, which begins with 0, meaning that no measures are implemented. Then another two to four degrees of stringency follows, depending on the variable. The included variables describe, more specifically, closing of schools, closing of workplaces, cancellation of public events, restrictions on gatherings, restrictions on public transport, stay- at -home orders, restrictions on internal movement, regulation of international travel and public informational campaign.

The index takes on values ranging between 0 and 100. In the calculation of the sub-indexes used in the creation of SI, the highest value which NPI variable can attain, the value recorded on the day for which the index is calculated, whether there is a dummy variable for differentiating between values of the measure, corresponding to whole state and only to some regions in the country, available and if it is, its value, are all accounted for in the sub-index. Given the fact, that whether, the value corresponds to the situation in the whole state or only in same specific region, is incorporated in the index, there is some advantage in using it over the individual NPI variables. The exact equation used in the calculation of sub-indexes is following[1]:

$$I_j = 100\frac{v_{j,t} - 0{,}5(F_j - f_{j,t})}{N_j}$$

The index is used in the analysis in a form of average of all daily values from a quarter.

5.3 Measuring voluntary reduction of the economic activity

Many of the studies, carried out in the first few months of the pandemic imply that most of the economic downturn was caused by the voluntary reduction of the economic activity (Goolsbee and Syverson, 2021; Maloney and Taskin, 2020; Meissner and Lin, 2020).
One possible approach was taken by Andersen et al. (2020), by comparing change in spending after start of the pandemic in Sweden where there were, in the beginning, more lenient measures and Denmark where the measures were more strict, since from the

[1] N_j is the maximum value that NPI variable can attain, $v_{i,j}$ stands for its current value, F_j is a dummy variable, that takes on value 1, if the dummy variable for differentiating between state-wide and regional measures values is available for the NPI variable and f_j is its current value (1 for state-wide measure value, 0 if it applies only to a specific region). Source: Hale et al., (2020)

difference in spending in those two countries, the effect of NPIs can be estimated. The second possible approach taken, is to include variable for severity of the pandemic in the country, since more serious epidemiological situation is connected with more cautious behavior and thus lowering of the economic activity (Maloney and Taskin, 2020; Goolsbee and Syverson, 2021; König and Winkler; 2021).

The proxy variable, utilized in this thesis, is **number of deaths caused by Covid-19 per 100 000 inhabitants** (*dp100t*) per quarter. The values are calculated from data on deaths taken from the OxCGRT dataset and the population estimates for the year 2019 (Hale et al.,2021; U.S. Census Bureau, 2019; World Bank, 2021). As in some previous studies, number of deaths is chosen, instead of number of cases, because of bigger reliability of its reporting. The number of reported cases depends not only on the epidemiological situation in the country, but also on the testing and contact tracing policy and capacity (König and Winkler, 2021; Goolsbee and Syverson, 2021).

5.4 Descriptive statistics

In this section, the statistics of the sample, used in the analysis, are described. Because the pandemic situation varied through 2020, the data are included both for individual quarters separately and together. The summary can be seen in table 5.1.

In the first quarter in comparison with the rest of the year, there was only slight downturn in economic growth in comparison with the rest of the year. The values of year-over-year quarterly GDP growth rate, range between -6,8 and 4,6 percent, with approximately half of the countries recording positive economic growth in this period. The low number of deaths per 100 000 inhabitants and low average value of Stringency Index also correspond to the less severe situation.

In the second quarter, the economic situation got dramatically worse, when more than a half states recorded economic growth lower than -9 percent. Overall values range between -24 and 3 percent with only country recording positive growth value being China. Both high number of deaths per 100 000 inhabitants and average values of Stringency Index related to this negative economic growth. Although, in case of the deaths, there is very high dispersion between different countries where some of them record number lower than 1, namely, all the countries in the east Asian region included in the analysis (China, South Korea, Japan), Australia, New Zealand, Slovakia and Indonesia. On the other hand, 3 U.S. states reached numbers higher than 100 (New Jersey, Connecticut, Massachusetts). More than half of the states succeeded to keep the dp100t number below

10. The SI is more evenly distributed, and all values lay in the range between 38,5 and 92,6 with median being 71,1.

In the third quarter, the situation got substantially better, half of the countries recorded growth -3,14 percent and, in 8 of them, it was even positive. There were also fewer deaths and the measures were generally less stringent. The scaled number of deaths varied between 0 and 64, where more than half of the countries keep its value below 10. SI values seem to be more heterogenous than in the previous period, with values ranging between 28 and 89.

In the last quarter of the year, the economic growth stays on a similar level to the previous period, stringency of the measures implemented also resembles the one from the third quarter, but number of deaths got on average more than 3 times higher. In comparison with the second quarter to which the epidemiological situation was more comparable, given the fact that virus seems to be transmitted better in lower temperatures, there seem to be quite a big trade-off between level of SI and dp100t and a smaller one, between the SI and GDP growth rate.

Table 5.1: Summary statistics (GDPg, dp100t, SI)

Year 2020	Variable	Mean	St. Dev.	Min	Median	Max
Quarter 1						
	GDPg (%)	-0,28	2,12	-6,80	0,06	4,64
	dp100t	1,24	2,93	0,00	0,38	19,22
	SI	19,02	5,88	6,85	18,31	58,98
Quarter 2						
	GDPg (%)	-9,96	4,21	-24,09	-9,41	3,20
	dp100t	21,96	27,09	0,10	12,49	145,73
	SI	70,58	9,30	38,51	71,26	92,59
Quarter 3						
	GDPg (%)	-3,26	2,96	-10,55	-3,09	8,93
	dp100t	13,82	14,90	0,00	9,04	63,74
	SI	56,81	12,70	27,92	57,39	89,26
Quarter 4						
	GDPg (%)	-2,50	2,35	-8,92	-2,26	6,50
	dp100t	42,37	29,58	0,00	39,01	142,99
	SI	58,33	10,08	22,85	59,39	80,93
Overall summary	GDPg (%)	-4,00	4,71	-24,09	-2,84	8,93
	dp100t	19,84	26,09	0,00	8,83	145,73
	SI	51,19	21,67	6,85	57,39	92,59

Source: Author's s estimates

5.5 Estimated equations and expected effects

In attempt to estimate, effect of NPIs and voluntary reduction of economic activity, approach of König and Winkler (2021) is adopted. On a quarterly panel data from 96 countries of the world, U.S. states and the District of Columbia, spanning period between 2014 and 2020, altogether creating 28 observations for each unit in the sample, several different fixed effects models are estimated with various combinations of Stringency Index (SI), deaths per 100 000 inhabitants (dp100t) , their values lagged by one period (SI_1, dp100t_1) and the time dummy variables representing individual periods. Therefore, the equation of the last model with all variables included is following:

$$GDPg_{it} = \sum_{s=1}^{23} \beta_s Q_s + \beta_{24} SI_{it} + \beta_{25} dp100t_{it} + \beta_{26} SI\_1_{it} + \beta_{27} dp100t\_1_{it} + \beta_{28} 2020Q1_t + \beta_{29} 2020Q2_t + \beta_{30} 2020Q3_t + \beta_{31} 2020Q4_t;\ i = 1,2, \ldots 96, t = 1,2 \ldots 28$$

, where β_1 to β_{31} are the estimated coefficients of variables Q_1 to Q_{23} are dummy variables representing 23 of 24 quarterly periods between beginning of the year 2014 and the end of 2020. One dummy variable is excluded from the regression, because of the multicollinearity and since none of these variables are the subject of the analysis, their corresponding coefficients are not included in the results. 2020Q1 to 2020Q4 are dummy variables representing quarters of the year 2020 and their coefficients are included in the table with the results.

All the estimated the equations are tested for heteroscedasticity using Breusch-Pagan test and for serial correlation with Breusch-Godfrey test (Breusch and Pagan, 1979; Breusch, 1978; Godfrey, 1978). If the null hypothesis of either of the tests is rejected at p-value lower than 0,05, heteroskedasticity and serial correlation robust standard errors are applied. The decision which of the types of robust standard errors is chosen, is then, even though the individual time fixed effects are included in the equation, based on the Pesaran's test for cross-sectional correlation (Pesaran, 2004). If the null hypothesis of the test is not rejected at lower p-value than 0,05, the Newey-West standard errors are used. Additionally, variance inflation factor (VIF) test is also conducted on all equations to test for collinearity (Newey and West, 1987).

The literature analyzing causes of the economic downturn in 2020 shows mixed evidence about the effects of the NPIs and voluntary reduction of the economic activity. The papers, analyzing the early months of the COVID-19 pandemic, of Goolsbe and Syverson (2021), Maloney and Taskin (2020) and Meissner and Lin (2020), attribute decline in economic growth mostly to the consumer behavior. On the other hand König and Winkler (2021), using data from first three quarters of 2020, find evidence for both of these causes. Nevertheless, given the fact, that this thesis also deals with more long term effects, strong effect of NPIs is expected, same as in the case of the corresponding part of the analysis carried out by König and Winkler (2021). In accordance with this study, the coefficient of the variable describing their cumulative effect (SI) is expected to have negative sign for the same period as the economic growth and a positive one for the measures from the previous period.

6 Analysis of effects of NPIs on economic activity and transmission of COVID-19

In this chapter, the part of the analysis comparing the effect of individual NPIs on the transmission of COVID-19 and economic growth is described. Firstly, the dependent variables are listed, followed by analysis of the variables representing the individual NPIs, then the descriptive statistics are mentioned and, in the end, the specifications of the models used in the analysis and the expectations about the results are introduced.

In the beginning, as it is written in the thesis proposal, the effect of the speed of implementation of NPIs and their stringency on the economic growth and transmission of COVID-19 was going to be estimated. But given the fact that many countries implemented measures even before the first case of COVID-19 was reported, not mentioning that there might been cases before the first one was recorded or even, in some cases, the first one was discovered only in retrospect, as it happen, for example, in France[2], this approach was abandoned and the intensity of the measures became the main focus of the analysis.

The changes were made also in the time periods used in the analysis. The original intention was to estimate effect of measures on the transmission of the disease and economic growth for only one period. This was later changed and effect on economic growth is analyzed with quarterly panel data. The effect of NPIs on the transmission of COVID-19 is, then, also analyzed with panel data, but one observation represents two weeks of the data.

The data used are for the analysis of NPIs on transmission are from period between the 29th of March 2020, corresponding to 14th week of the year and the 2nd of January 2021, when the last week of the year 2020 ended. The starting point was chosen to be the beginning of the 14th week, because number of cases in all states used in the analysis, exceeded 100, and the major differences in testing between states should be no longer

[2] Source: https://www.reuters.com/article/us-health-coronavirus-france-idUSKBN22G20L

present (Ozyigit, 2020). The variables for individual NPIs are additionally included in several different specifications. The reason for this decision and their description is mentioned in the section 6.2.

6.1 Dependent variable

The dependent variable, used in economic part of the analysis, is same as in the previous chapter, quarterly year-over-year growth rate of GDP.

In the case of analyzing effects on transmission, at first, the intention was to use number of new cases as a dependent variable but, given the fact that the metric is highly dependent on the number of test performed, which varies a lot between individual countries, this approach was abandoned (Ozyigit, 2020; Jüni et al., 2020). Instead, following Ozyigit (2020), the new cases from one period of time, are at first, taken into natural logarithm and from these values using difference between two consecutive periods, the approximation of **growth rate of the new cases** (*ncgr*) is calculated. The difference in testing should affect two periods closed in time in similar way, so in the percentage change between two periods should not be affected by it, even though the difference may be more notable, between two-week periods which are included in the thesis than between individual days as in the case of Ozyigit (2020).

6.2 Independent variables

The variables, available in the OxCGRT dataset, were chosen to represent the individual NPIs in the thesis (Hale et al., 2021). There are available daily data for most of the countries plus some smaller regions describing government reaction to the pandemic. There are data available from the 1 of January 2020 up to the present (as of 10 April 2021).

In the dataset, social distancing measures are divided into 8 categories. Each of these variables is of ordinal scale with lowest possible value being 0, meaning no measure in force. The highest value varies depending on the variable. In the following paragraphs, all the variables used in the analysis are described in more detail, based on Hale et al. (2020).

The first variable describes **closures of schools** (*C1*). It can attain values between 0 and 3, where 1 means recommended closing, 2 corresponds to requirement of closing only some levels of education system or some types of schools, and 3 means compulsory closure of all levels of the schooling system.

The second variable evaluates measures concerning **closing of workplaces** (*C2*). Similarly to the first variable, it can take integer values ranging from 0 to 3, where, again, 0 means no measures in place, 1 corresponds to recommended closure of workplaces, variable attains value 2 when closure is compulsory but only for some types of places (sectors), and 3 means closure of all except for the essential workplaces.

The third variable deals with **cancelations of public events** (*C3*). The variable attains value 1 when the recommendation to cancel events is issued, and 2 when the cancellation is compulsory.

The fourth variable describes **gathering restrictions** (*C4*). It attains values up to 4, where 1 means, that events with more than 1000 attendants are banned, it takes on value 2 if also gatherings with a number of attendants in the range between 100 and 1000 are prohibited, 3 if the ban applies on events with number of attendants between 10-100, and finally 4 when even gatherings with under 10 attendants are forbidden.

The fifth variable deals with **closings of public transport** (*C5*). It takes on values ranging between 0 and 2. 1 corresponds to either recommended closure or recommendation to significantly reduce transportation in some way. 2 then means, that public transportation must be closed or that most people cannot used it.

The sixth variable describes **stay-at-home orders** (*C6*). It can take on values between 0 and 3. 1 corresponds to recommendation to not leaving the house, 2 means that people cannot leave the house with exceptions, such as the trips to the doctor or buying groceries. The variable then attain value 3 if the rules even more strict, such as if there is possibility of leaving the house only once every week or when the number of people, who can leave at once, is set.

The seventh variable deals with **constraints on travelling between different regions of one state** (*C7*). It attains values between 0 and 2, where 1 means recommendation to not to travel do different regions of the country and 2 means that it is prohibited to do so.

The last variable describing social distancing measures deals with **restrictions on international travel** (*C8*). It can take on values ranging between 0-4, where 1 means screening of people arriving from different countries, 2 corresponds to quarantining of people who come from countries identified as high-risk, 3 means prohibition of traveling to the country from specific countries and, finally, variable attains value 4 when travelling from all the other countries is forbidden or when the borders are completely closed.

The last variable used, in the economic analysis, is the **income support** (*E1*). It takes on value 1 if less than 50% of the wages are replaced by the government or if the uniform wage replacement is less than 50% of median salary and 2 when it is more than 50% of the wages or if the uniform wage replacement covers more than 50% of median salary.

In addition to the variables describing social distancing measures, there are available other variables in the OxCGRT dataset describing different types of NPIs which are proposed to affect only transmission of the virus. As in the case of social distancing measures, all variables are of ordinal scale. One of the variables describes **informational campaign for the public** (*H1*). It attains value 0 when there is no campaign against COVID-19 conducted, 1 when the warning comes from public officials and 2 if there is a campaign organized through both social and traditional media.

Another one is **testing policy** (*H2*). It takes on value 0 if there is no testing policy for Covid-19 in place, 1 when the testing is available for people who show COVID-19 symptoms and at the same time meet some other condition (being in contact with infected person, admission to the hospital…), 2 when even people with no symptoms are tested and 3 when there are drive through testing points, where even asymptomatic people can be tested, present. The variable concern itself only with testing for infection, testing for antibodies is not considered. In case of testing policy, using variable for number of tests performed rather than ordinal scale variable were considered at first, since H2 variable does not account for differences in number of tests between countries which would probably be a more precise way to analyze the effect of testing on the transmission of the COVID-19. Unfortunately, this data is not available for some countries, included in the study, so this idea was abandoned.

There is also variable describing **contact tracing policy** (*H3*) included. It attains value 1, if only limited contact tracing policy is in force (contacts of not all infected people are traced), and 2 when the tracing is done on all the cases. The **face mask wearing directives** (*H6*) are also represented by a variable in the dataset. The variable takes on value 1 if wearing of face mask is recommended, 2 when it is required to wear them in some specific public spaces, where other people are present, 3 if it is required to wear a mask in all public spaces, where other people are and, finally, 4 when it is mandatory to wear them everywhere outside of home with no exceptions.

Unfortunately, there are also several difficulties in analyzing effects of individual measures on the economy with the data from the OxCGRT project (Hale et al., 2021). One of them is that, especially in the first and second quarter, there is a strong correlation between many pairs of individual distancing measures. The reason for this is probably the fact, that measures are often adopted at the same time or in a quick succession (Vatcheva and Lee, 2016). The exact values of correlations between average quarterly values of social distancing measures variables in the first quarter can be seen in the Table 6.1, the correlations matrixes for the other quarters can be then found in the Appendix, in tables A.1, A.2. and A.3.

Table 6.1: Correlation matrix of quarterly average values of NPIs var. – 1. Quarter

	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	0,53	0,77	0,47	0,49	0,56	0,57	0,02
C2	0,53	1	0,65	0,76	0,73	0,78	0,77	-0,04
C3	0,77	0,65	1	0,71	0,53	0,71	0,65	-0,07
C4	0,47	0,76	0,71	1	0,65	0,72	0,65	-0,07
C5	0,49	0,73	0,53	0,65	1	0,68	0,62	-0,18
C6	0,56	0,78	0,71	0,72	0,68	1	0,76	-0,05
C7	0,57	0,77	0,65	0,65	0,62	0,76	1	0
C8	0,02	-0,04	-0,07	-0,07	-0,18	-0,05	0	1

Source: Author's s estimates

Another difficulty lies in the construction of the variables representing the individual variables. For every country, there is available daily only one value describing the measures that are currently implemented. If there are differences in severity between different regions, which would be described by different numbers on the scale, the highest value is included in the dataset. Although, for 8 of the variables, there is a dummy variable available which attains value 1 if the measure corresponds to the situation in the whole country and 0 if it only represents stringency of the measure in some regions, it still does not help in understanding, what the situation is in the country in general. So possibly, there can be included values describing strength of the measures in the dataset used in the thesis which are not entirely accurate, if the value of NPI variable, corresponds only to regional restriction on a significant number of days in the quarter. The average percentage of days in which the value of the measure corresponds only to some regions in the state can be seen in the table 6.2.

Table 6.2: The average percentage of days for which variable describes only some regions

2020	Q1	Q2	Q3	Q4
C1	13,29	13,9	47,93	55,47
C2	12,3	16,81	32,36	32,33
C3	14,25	13,28	24	24,63
C4	15,57	15,94	33,59	33,6
C5	29,15	31,16	27,35	24,72
C6	20,32	17,56	28,62	28,33
C7	17,98	17,8	27,07	22,22
H6	3,01	18,93	31,21	28,22

Source: Author's estimates

Furthermore, as can be seen, in the description of the variables above, number 1 on the ordinal scale represents in all cases, either only recommendation or comparatively lenient version of the measure, so it cannot be expected that the effect of individual NPIs will be same between all the numbers on the ordinal scale (Liu et al., 2021). Moreover, in some cases variables are defined too vague for the lower values, as for example closing only some levels of school system or closing only some business can mean many kinds of interventions with very different scope.

Because of that, initial intention to use only average values of individual NPIs was abandoned. In the part of the analysis dealing with effect of the NPIs on the economic growth, approach of Chen et al. (2020) was adopted, where only days, on which a measure is implemented with predefined stringency, are counted. A slight advantage in using the number of days is also the fact that number of days when the stringent measures were implemented is slightly less correlated than the initially considered quarterly average values. Additionally, specification, where days are counted if the variable is non-zero is also tested, inspired by Liu et al. (2021).

In most cases, only the values corresponding to a maximum stringency are sufficient for inclusion of the day into the variable. The exemptions are variables representing lockdown, where the second highest possible stringency was decided to be enough for inclusion and the order to wear face masks, where it was the third highest stringency. These choices were made, because these lower values do not correspond to only a recommendation and do not apply only to some groups (of workplaces, schools…), in contrast with the lower values of most other variables and thus are comparable to other variables maximum values.

In case of estimating effect of NPIs on the transmission of the virus, every day was assigned value 1 when the measures were implemented with sufficient stringency on it and 0 if not. The variable representing a measure is then a two-week average of these daily values. The sufficient stringencies for a day to be assigned value 1 are same as in the case of counting day into quarterly variable in estimation of effects of NPIs on the economic growth. The exact definitions of variables, corresponding to value 1 assigned to a day in the estimation of effect of NPIs on transmission of the virus and counting a day into the quarterly variable in the economic part of the analysis can be seen in the table 6.3.

Table 6.3: Minimum requirements for including days into the NPI quarterly variable

Measure	Day is counted in the variable when:	N.
C1	All levels and types of schools are closed	3
C2	All except essential businesses are closed	3
C3	Public events are required to be cancelled	2
C4	Gatherings of 10 or less people are prohibited	4
C6	Requirement to not leaving house with exceptions	2
C7	Internal movement restrictions are implemented	2
C8	Travelling to all regions prohibited/ Borders are closed	4
E1	At least 50% of income is replaced (flat sum paid is more than of 50% of states median salary)	2
H2	The testing is open to the public, even the asymptomatic people	2
H3	Contact tracing performed for all identified infected people	3
H6	Face masks are ordered to be worn outside of home, in public, in presence of other people, without exceptions	3

Note: N. refers to the number on the ordinal scale corresponding to the description of the stringency of the measure in the dataset. Source of the descriptions: Hale et al. (2020)

Because stringent restrictions on public transport were implemented in minimum states included in the study, the variable was excluded from the analysis and the variable for public informational campaign was left out because there was very little variation in their values in the sample. Additionally, similarly as in the case of estimating effect of NPIs on the economic activity, specification, where days are assigned value 1 if the NPI is in force with at least some stringency is also estimated, inspired by Liu et al. (2021).

6.3 Descriptive statistics

Given the fact that two different datasets are applied for effect of NPIs on economic activity and transmission of COVID-19, summary statistics in this chapter are also divided into two parts each dedicated to one part of the analysis. For each of these two, the statistics are available for two types of variables used in the analysis, in the first one only the days on which the maximum stringency measures in force, are counted, in the second one the days on which at least some level of NPIs were implemented are included. Additionally, because for each part of the analysis, the variables are constructed in a different way, as described in the previous section, even though they describe the same measures, they are assigned letter a in case of the economic part of the analysis and letter b in case of analysis of the effect of NPIs on the transmission of COVID-19 in the tables 5.4 and 5.5 with descriptive statistics.

Regarding the quarterly values used in the economic part of the analysis, for each variable, there is an observation in the sample in which NPI with maximum possible stringency was implemented both the whole period and 0 days. Further, the statistics are very affected by the first quarter of 2020, when the measures were not mostly implemented until the later part of the quarter. The overall statistics can be seen in the table 6.4.

The complete closing of schools (C1) was applied less than 19 days in a quarter in a half of the observations, on the other hand, in almost 80 of them, the total closure spanned the entire quarter. At least some actions regarding closure of schools were then taken more frequently, when in more than half of the observations, some level of measure was in force. The complete closing of workplaces (C2) were even more rarely applied across the sample, when in more than half of the observations, it was not implemented at all and in only 53 cases, it was in force at least 30 days in a quarter. When days with at least some level of stringency are considered, at least 30 days corresponds to 185 observations, in most of them, the implementation is spanning the whole period.

The cancellation of public events (C3) and prohibition of gatherings (C4) were more frequently implemented. In case of public events, in more than half of the observations, the measures with maximum possible stringency were implemented at least 46 days of the period if all levels of stringency are accounted for, at least the same number of days corresponds to 257 observations. In more than half of them, some level of the stringency of the measure was implemented the whole period. In case of prohibition of gatherings, in half of the observations, number of days, where the most stringent measures were implemented, was at most 17, in 68 observations the most stringent measure was not implemented at all.

The one of the more rarely implemented NPIs included in the dataset were the stay at home orders (C6) which when only stringent types of measure are counted were implemented 0 days in 178 observations and less than 6 in half of the sample. In 80 observations, even the mildest version of the NPI was not in force at all. The most stringent restrictions on the internal movement (C7) were implemented even in less cases than the stay at home orders, in 192 observations, they were not in force at all and only in 112 observations, it was more than 30 days. The least used NPI was the international travel restriction which, in half of the cases, was not implemented at all. It is caused mostly by the fact that in U.S. states, it was not in force in any of the states in any of the periods. If even the days with the milder versions of the measure are counted, the statistics are similar to the ones of other NPIs.

Table 6.4: Summary statistics – Effect of NPIs on economic activity

Year		Only days with max NPIs					Days with non-zero NPIs				
2020	**Variable**	**Mean**	**St.Dev.**	**Min**	**Median**	**Max**	**Mean**	**St.Dev.**	**Min**	**Median**	**Max**
	C1a	35,66	35,18	0	18,5	92	52,85	38,45	0	58	92
	C2a	11,55	19,32	0	0	92	45,54	40,00	0	26	92
	C3a	47,61	37,14	0	46,5	92	64,57	34,69	0	91	92
	C4a	34,44	34,80	0	17,5	92	51,89	38,62	0	61	92
	C6a	21,63	29,99	0	6	92	50,49	40,63	0	59	92
	C7a	23,37	33,55	0	0,5	92	52,21	40,01	0	65,5	92
	C8a	9,50	24,24	0	0	92	53,11	40,14	0	59	92
	E1a	39,98	40,61	0	30	92	52,98	41,04	0	76	92

Source: Author's estimates

In case of variables used in estimating effect of NPIs on transmission of the COVID-19, the statistics are very similar to the statistics of variables used in analysis of the effects of measures on economic activity. The values can be seen in the table 6.5.

Table 6.5: Summary statistics – Effect of NPIs on transmission of COVID-19

Year		Only days with max NPIs					Days with non-zero NPIs				
2020	**Variable**	**Mean**	**St.Dev.**	**Min**	**Median**	**Max**	**Mean**	**St.Dev.**	**Min**	**Median**	**Max**
	C1b	0,49	0,48	0,00	0,43	1,00	0,98	0,12	0,00	1,00	1,00
	C2b	0,16	0,34	0,00	0,00	1,00	0,96	0,18	0,00	1,00	1,00
	C3b	0,64	0,46	0	1	1	0,96	0,17	0	1	1
	C4b	0,46	0,48	0,00	0,21	1,00	0,91	0,27	0,00	1,00	1,00
	C6b	0,29	0,43	0,00	0,00	1,00	0,85	0,34	0,00	1,00	1,00
	C7b	0,32	0,45	0,00	0,00	1,00	0,83	0,36	0,00	1,00	1,00
	C8b	0,13	0,33	0,00	0,00	1,00	0,99	0,10	0	1	1
	H2b	0,36	0,47	0	0	1	1,00	0,05	0	1	1
	H3b	0,54	0,49	0	1	1	0,98	0,13	0	1	1
	H6b	0,46	0,49	0	0	1	0,87	0,33	0	1	1
	E1b	0,55	0,49	0	1	1	0,87	0,33	0,00	1,00	1,00

Source: Author's estimates

6.4 Estimated equations and expected effects

Same as in the previous chapter, on a panel data, several fixed effects models are estimated. The equation, describing effect of individual measures on the economic activity, looks as follows:

$$GDPg_{it} = \sum_{s=1}^{27} \beta_s Q_s + \sum_{u=28}^{34} \beta_u C_{it} + \beta_{35} E1_{it}\,;\; i = 1,2,\dots 96, t = 1,2 \dots 28$$

There are 96 observations for 28 periods included, each of them representing a quarter of a year. The GPDg is quarterly year-over-year economic growth, Q_1 to Q_{24} are dummy variables representing quarters of the years between 2014 and 2020, one dummy variable is excluded because of the multicollinearity. C are then variables describing individual social distancing measures. Namely, these are closing of schools (*C1*) and workplaces (*C2*), cancellation of public events (*C3*), restrictions on gatherings (C4), internal movement (*C7*) and international travel (*C8*) and stay at home orders (*C6*). Additionally, there is also variable for the income support included (*E1*).
A similar equation with additional variables describing the NPIs is estimated in order to find out effect of the measures on the transmission of the COVID-19:

$$ngrc_{it} = \sum_{s=1}^{19} \beta_s Q_s + \sum_{u=20}^{26} \beta_u C_{i(t-1)} + \sum_{v=27}^{29} \beta_v H_{i(t-1)} + \beta_{30} E1_{i(t-1)}\,;$$
$$;\, i = 1,2,\dots 96, t = 1,2 \dots 20$$

Each time period represents two weeks. There are 96 observations for 20 time periods. NPI variables are included with one lag, because they do not affect transmission immediately. The social distancing measures variables included are the same ones as in the case of estimation of effect on the economic growth. Additionally, variables for testing policy (*H2*), contact tracing (*H3*) and mask wearing orders (*H6*) are also in the equation.

Again, there is variable for income support (*E1*) included and dummy variables for 10 two-week periods (Q_1 *to* Q_{19}). One dummy variable for time period is again excluded, because of the multicollinearity. The procedure in estimating the equation is same as described in the section 5.5.

The effect of closing of schools was explored by some studies in the past (Smith et al. 2009; Keogh-Brown 2010). Otherwise, studies for individual effect of NPIs are not really available, nevertheless studies dealing with the cumulative effect of the measures, find negative relationship between implemented NPIs and economic activity (König and Winkler, 2021; Demirguc-Kunt et al., 2020). So, the coefficients of variables representing individual measures are all except E1, representing income support, also expected to have negative signs.

Regarding the effect of the measures on transmission of COVID-19, all the coefficients of variables representing measures are also expected to have negative sign. Many of the variables implemented were found to have significant effect on transmission of COVID-19 in the studies preceding this thesis, Haug et al. (2020), finds strong evidence for the effect of school closures, lockdowns and border restrictions, Brauner et al. (2021) for testing policy and school closure. Thus, in this thesis, stay at home orders, restriction on gathering, testing policy and closing of schools are expected to have the highest effect on the transmission.

7 Results

The following chapter is divided into two parts each describing results of one part of the analysis, described in the chapters 4 and 5. The first one deals with effects of voluntary lowering of the economic activity in the face of the pandemic and the influence of NPIs. In the second one, the effect of individual NPIs are estimated. The abbreviations of the variables can be found in the table A.4 in the Appendix, more detailed explanation of the variables is then available in sections 5.1, 5.2 and 5.3 for the first part analysis and in the sections 6.1 and 6.2 for the second part. The results are further commented in the chapter 8.

7.1 Voluntary lowering of the consumption versus the effect of NPIs

In attempt to estimate effects of NPIs and voluntary lowering of the consumption, 6 different equation was estimated, following König and Winkler (2021). All the models were tested for heteroskedasticity, serial correlation and for cross sectional correlation. The null hypothesis of both Breusch-Pagan test for heteroskedasticity and Breusch-Godfrey test for serial correlation were, in case of all 6 models, rejected at p-values close to 0. At the same time, the null hypothesis of Psara's test for cross sectional correlation was not rejected at p-value smaller than 0,4 in any of the cases, so the Newey-West robust standard errors were applied to all the models. In the table 7.1, can be seen the results with the robust standard errors, the original error estimations are then available in the Appendix in the table A.5. The VIF test shows values around 1 for all variables in the models in which SI and its lag are not included at once. When they are both present at once, they both attain values of VIF around 4, suggesting that countries which implemented more restrictive measures in one period, tended, generally, enforce more stringent NPIs even in the following quarter.

All the models show very similar R^2 adjusted with all values around 0,7. The high values can be partially explained by the inclusion of dummy variables representing quarters of years included in the analysis. The results show that the Stringency Index (*SI*) variable, proxy for the stringency of social distancing measures, is significant, with p-value smaller than 0,01 in every of the specifications. The deaths per 100 000 inhabitants (*dp100t),* proxy for the voluntary lowering of the economic activity, is not significant in any of them, not even when it is included with one period lag. Notable is also the effect of the lagged SI variable, which is statistically significant in both specifications, when it is included with SI variable with no lag. If included together the SI variable has negative sign and coefficient -0,1 signaling that with every toughening of the measures, corresponding to increase in Stringency Index number by 1 unit, is in the sample, on average, connected with lowering of the GDP by 0,1 percent. On the other hand, lagged SI variable seems to have opposite effect on the economic growth and increase in its value by 1 relates to 0,05 higher GDP growth in the next period. Notable is also the fact that in specifications in which SI variable is included, dummy variables for the first and the fourth period are not statically significant, compared with models where it is missing in which the dummies for all quarters of 2020 are significant.

Following, König and Winkler (2021), robustness check was also performed in which SI, dp100t variables and their one-period lags were included in logarithmic form ln(1+x). The results are very similar to the original estimations, although dp100t variable is now significant, in one specification with both lagged variables and SI variable with one period lag is not statistically significant in any of them.

Table 7.1: Results of the estimations - robust standard errors

	Dependent variable: GDPg (standard errors in parenthesis)					
	(1)	(2)	(3)	(4)	(5)	(6)
SI	-0,08***	-	-0,08***	-0,10***	-	-0,10***
	(0,02)		(0,02)	(0,02)		(0,02)
dp100t	-	-0,01	0,0003	-	-0,01	0,004
		(0,01)	(0,01)		(0,01)	(0,01)
SI_1	-	-	-	0,05*	-0,004	0,05*
				(0,02)	(0,02)	(0,02)
dp100t_1	-	-	-	0,01	0,01	0,01
				(0,01)	(0,01)	(0,01)
Quarter1_2020	-0,38	-1,89***	-0,38	0,01	-1,89***	0,05
	(0,42)	(0,26)	(0,43)	(0,47)	(0,26)	(0,49)
Quarter2_2020	-5,89***	-11,42***	-5,88***	-5,39***	-11,36***	-5,35***
	(1,34)	(0,46)	(1,35)	(1,36)	(0,53)	(1,37)
Quarter3_2020	-0,29	-4,76***	-0,28	-2,83*	-4,75**	-2,90*
	(1,14)	(0,30)	(1,16)	(1,39)	(1,52)	(1,38)
Quarter4_2020	0,60	-3,81***	0,59	-1,15	-3,73**	-1,29
	(1,17)	(0,39)	(1,16)	(1,25)	(1,27)	(1,22)
Observations	2,688	2,688	2,688	2,688	2,688	2,688
R^2	0,68	0,68	0,68	0,69	0,68	0,69
Adjusted R^2	0,67	0,66	0,67	0,67	0,66	0,67
F Statistic	197,36*** (df = 28; 2564)	190,69*** (df = 28; 2564)	190,48*** (df = 29; 2563)	186,19*** (df = 30; 2562)	178,16*** (df = 30; 2562)	180,17*** (df = 31; 2561)

Notes: Fixed effects model. Newey-West robust standard errors. In the model, there are included dummy variables for every quarter in the sample not only the ones mentioned in the results. *p<0.1; **p<0.05; ***p<0.01

7.2 Effect of individual NPIs on economic activity and transmission of the virus

The effect of individual NPIs is estimated with two different specifications for transmission of COVID-19 and one for economic growth. The variables are constructed differently for each part of the analysis, more detailed description of them can be found in the chapter 6.2. The time periods used in two parts of the analysis also differ, effect of NPIs on the economic growth is estimated on quarterly data from between 2014 and 2020, in case of analysis of the effect of measures on the transmission of COVID-19, the data are two-week periods spanning approximately later three quarters of 2020.

In case of estimating effect of NPIs on economic activity, the NPI variables represent only the days when the measures were implemented with high stringency in the quarter. Originally, second specification, the days in which at least some level of measure was implemented, were to be counted but because of high collinearity of several of the variables, the results are not included.

At first, the Breusch-Pagan test for heteroskedasticity and Breusch-Godfrey test for serial correlation were applied. In both specifications, the null hypotheses of both tests were rejected at p-value very close to 0. Pesaran's test for cross sectional was negative, as it was expected, given the fact that time dummy variables were included in the estimation, and thus the Newey-West heteroskedasticity and auto correlation robust errors were applied. The highest VIF value, 4,2, attains variable C3, values of other variables range between 1,3 and 2,5.

R^2 adjusted of the model is 0,67. 3 of the variables were statistically significant if original standard errors were applied, but only one of them, C3 variable representing cancellation of public events stayed significant when the robust errors were implemented. According to the variable, with every additional day on which the public events were cancelled, the quarterly GDP decreased by 0,1 percent, although the magnitude of the effect needs to be taken with caution, because relatively high collinearity of the variable.

Table 7.2: Results of the estimation - Effects on the economic activity

	Dependent variable: GDPg (standard errors in parentheses)	
	Days with the most stringent measures	
	Normal	N-W
C1	0,004	0,004
	(0,004)	(0,01)
C2	-0,01	-0,01
	(0,01)	(0,01)
C3	-0,01**	-0,01**
	(0,004)	(0,004)
C4	-0,01	-0,01
	(0,004)	(0,01)
C6	-0,01**	-0,01
	(0,004)	(0,01)
C7	-0,005	-0,005
	(0,004)	(0,01)
C8	-0,01**	-0,01
	(0,004)	(0,01)
E1	0,002	0,002
	(0,003)	(0,01)
Observations	2,688	2,688
R^2	0,69	0,69
Adjusted R^2	0,67	0,67
F Statistic (df = 35; 2557)	159,30***	159,30***

Notes: Fixed effects model. Additionally, there are dummy variables for each time period, included in the estimated equation. *p<0.1; **p<0.05; ***p<0.0

In estimation of effect of NPIs on transmission, in both specifications, the day null hypotheses, stating that there is not an autocorrelation and heteroskedasticity in the model, were rejected at p-values close to 0. The null hypothesis of Pesaran's test was not rejected at values smaller than 0,3, so the Newey-Weston robust standard errors were applied. The VIF shows values between 1 and 2 for all variables in all the specifications. The R^2 adjusted is smaller than in case of the estimating effects of NPIs on the economic activity, at approximately 0,3 in both specifications.

In the model where days are assigned value one only if a sufficiently stringent measure is in force, there are 5 statistically significant variables. The first of them, C1, representing closure of schools, seems to have the highest negative effect on the growth of the new cases, when according to the estimated coefficient, the whole two weeks in which all the schools were closed, were associated with 0,29 percent lower growth rate of the new cases in the next period, in comparison with places where the most stringent measure was not in force at all. Second highest coefficient has the cancellation of public events (C3) and closure of workplaces (C2) where the same effect is 0,21 and 0,19 percent respectively. The last two variables which seems to have statistically significant negative effect are the restrictions on gatherings (C4) and wearing mask orders, where the difference, between full two weeks of implemented measure with high stringency and lower or no levels of stringency, is 12 percent and 10 percent lower growth of new cases in the next period respectively. Surprisingly, the income support policy (E1) seems to have positive relation with growth of the new cases. The significant positive effect is preserved even when the variable is included with two-period lag.

In the model with milder specification, the only two variables with statistically significant effect are stay at home orders and cancelation of public events, where difference, between no measure and any level of it implemented in two-week period, is 0,42 lower growth rate of the new cases, in case of stay-at home orders, and 0,24 lower growth rate in case of cancellation of public events.

Additionally, robustness checks were performed by estimating all equations on subsamples, containing either only U.S. states or world countries. In case of effect of NPIs on economic growth, the estimation performed on the U.S. states confirms the results of original regression and cancellation of events is negatively significant, on the other hand, in the subsample composed of world countries, no variable is significant.

In case of effect of NPIs on the transmission when only the stringent measures are accounted for, of the variables that were significant in the original equation, closing of work place, restriction on gatherings and cancellation of public events, were significant in both the subsamples, school closing only in the one composed of world countries and income support and orders to wear mask in neither of them. Additionally, from the variables that were not significant in the original equation, contact tracing and testing policy were significant with positive sign in the world countries subsample and stay at home orders with a negative sign and international movement restrictions with a positive sign in U.S. states subsample. When all levels of measures are accounted for, equation can be estimated only on the data with world countries, because in case of U.S. states, values of some variables do not vary at all. On this subsample, only stay at home orders variable is significant and its coefficient has a negative sign, same as in the case of the original equation.

Table 7.3: Results of the estimation- Effects on the transmission of COVID-19

	Dependent variable: ncgr (standard errors in parentheses)			
	Days with most stringent measures		Days with at least some level of measure	
	Normal	N-W	Normal	N-W
C1_1	-0,28***	-0,28***	0,004	0,004
	(0,04)	(0,05)	(0,13)	(0,20)
C2_1	-0,20***	-0,20**	-0,16	-0,16
	(0,05)	(0,06)	(0,09)	(0,13)
C3_1	-0,20***	-0,20***	-0,24**	-0,24*
	(0,04)	(0,04)	(0,09)	(0,10)
C4_1	-0,11**	-0,11**	-0,12	-0,12
	(0,03)	(0,04)	(0,06)	(0,06)
C6_1	-0,05	-0,05	-0,41***	-0,41***
	(0,04)	(0,05)	(0,05)	(0,06)
C7_1	0,002	0,002	-0,10	-0,10
	(0,04)	(0,05)	(0,05)	(0,06)
C8_1	-0,09	-0,09	0,27	0,27
	(0,05)	(0,07)	(0,15)	(0,24)
H2_1	0,01	0,01	0,03	0,03
	(0,04)	(0,05)	(0,26)	(0,27)
H3_1	0,06	0,06	0,15	0,15
	(0,04)	(0,04)	(0,11)	(0,13)
H6_1	-0,10**	-0,10*	0,16**	0,16
	(0,04)	(0,04)	(0,06)	(0,09)
E1_1	0,23***	0,23***	-0,04	-0,04
	(0,04)	(0,05)	(0,04)	(0,05)
Observations	1,920	1,920	1,920	1,920
R^2	0,30	0,30	0,29	0,29
Adjusted R^2	0,26	0,26	0,24	0,24
F Statistic (df = 30; 1794)	26,16***	26,16***	24,84***	24,84***

Notes: Fixed effects model. Additionally, there are dummy variables for each time period included in the estimated equation. *p<0.1; **p<0.05; ***p<0.01

8 Discussion

In this chapter, results of the regression analyses from the previous section are discussed and compared with results from the previous studies, described in sections 2.1 and 2.2.

In the first part analysis, dealing with the effects of the NPIs versus voluntary reduction of the economic activity, the results suggest that only the stringency measures were significant in determining economic growth of these two 2020. The variable serving as a proxy for severity of the measures implemented, Stringency Index, is statistically significant in all four models in which it is included, on the other hand, deaths per 100 000 inhabitants serving as a proxy for voluntary lowering of the economic activity is not significant in any specifications in which it is present.

The reason for this could be the fact that, over most of the year, the measures were so stringent in the states that are included in the sample that it took option from the people to change their behavior depending on the epidemiological situation. As it can be seen in the section describing descriptive statistics in table 6.1, in the later 3 periods of 2020, in every country in the sample, quarterly average value of Stringency Index were larger than 20 (on the scale from 0 to 100), and in a half of the countries it was higher than 50 in all 3 periods. The second possible explanation is that although severity of the pandemic seem to be strong determinant of the economic activity in the beginning of the pandemic as indicated, for example, by paper of Goolsbee and Syverson (2021), in the long run the risk-aversion could be play a smaller role as the population gets used to the new situation. Additionally, stringency of the measures from the previous period seems to have positive effect on the economic growth which could maybe be explained by better adaptation to the situation, because of necessity to deal with more stringent NPIs previously.

Lastly, statistical significance of fixed effects representing quarters of 2020 indicate that differences in economic growth are fully explained by NPIs in the first and the last quarter on the year, but in the second quarter, there seems to be other factors at play which generally affected the economic growth. In overall, results confirm findings of König and Winkler (2021), from first three periods of 2020 in which, using panel data analysis, the dominant effect of NPIs was identified both negative in simultaneous period and positive from the previous one. On the other hand, other studies from the beginning of the pandemic reached opposite conclusions and identified voluntary lowering of the activity as the driving force of the decline in economic activity (Goolsbee and Syverson, 2021; Maloney and Taskin, 2020).

In the second part of the analysis, two equations were estimated in order to find relationship between individual NPIs and transmission of COVID-19 and, one, between economic growth and individual measures. Generally, it seems that NPIs explain decline in economic growth more than the differences in transmission rate of the COVID-19, because R^2 adjusted is twice as high in the models with quarterly growth rate as a dependent variable.

As for the effect of NPIs on the economic growth, only one variable seems to have significant effect on the regression and that is the cancellation of public events. The relationship is negative as expected and it can be explained by both direct effects, such as losing income from ticket sales from sport events and concerts and indirect ones as it is the loss of income for various hospitality industry in the proximity of the bigger events.

In case of estimating effect of NPIs on the transmission, the same variable was the only one that showed statistical significance in both specifications. In specification which estimates effect of the stringent measures other 5 variables are statistically significant. The strongest effects seem to have closing of schools and income support, followed by closing of workplaces and cancellation of public events and the weakest prohibition on gatherings and orders concerning wearing masks. The coefficients of all of them, except income support, had negative signs as expected. The positive sign of the income support could be explained by that people who have guaranteed income do not have to act as cautiously and thus expose themselves to more risk contacts resulting in higher transmission of the virus. Another possible explanation is that they are more likely to admit that they have symptoms and get tested or not prevent people with which they came in risk contact to report them to the health department, which could again result in a higher number of cases.

In model where the differentiation was between no measures and at least some measures, except for the cancelation of public events, only variable describing the stay at home orders is significant. The interpretation of the fact that there are different significant variables in two specifications is that stay at home orders and public events restriction had strong effect, when they were initially implemented but, only in case of public events cancellation, the effect became greater as the two NPIs were becoming more stringent. On the other hand, in case of school closing, restriction on gatherings, income support, mask wearing and closing of workplaces, there seems to be effect on transmission only if they were implemented with a sufficient stringency. Surprisingly, testing policy and contact tracing do not seem to be significant in any of the two specifications. The reason could be, as noted by Liu et al. (2021), in both of them, there are two effects working against each other, on one hand, they prevent transmission, on the other hand, they can cause more cases to be reported. Another possible explanation is that the variables do not take into account the real number of performed tests and contacts that are traced.

The paper of Liu et al. (2021) which also worked with the OxCGRT dataset and included two specifications in which all the measures and only the stringent ones were taken into account, shows some similarities with the results of this thesis. School closing, prohibition and cancellation of public events were identified to be significant when only stringent measures were accounted for. There was also some evidence for stay at home orders when all levels of measures were accounted for and contact tracing and testing policy and international travel restrictions did not seem to have much of an effect. Otherwise the results differ. That could partially be caused by that the study was using data only from the early period of the pandemic or by the differences in modeling. The high effectivity of school closing and prohibition of gatherings can be further found in Brauner et al. (2021) and Haug et al. (2020).

There are several limitations in this thesis, one of them being, in the model estimating effect of individual NPIs on economic growth, correlation between variables, which even though VIF of any of the variables did not exceed value 5, could prevent extracting the statistically significant influences of other variables on the economic activity. Other problem lies in the construction of the original ordinal scale variables form the OxCGRT dataset that were used in the creation of the variables in this thesis. Sometimes, they do not describe situation in the whole state but only in some specific regions, describe measures, in some cases, rather vaguely, so the same value on the ordinal scale, can mean quite different measures in different settings.

This seems to be especially problem in case of variables describing testing policy and contact tracing. Variables describing number of tests performed and contact traced would be probably more helpful in estimating effect of testing and contact tracing on the transmission. The solution for other variables could be using different dataset or creating own data on the stringency of NPIs. The problem with correlation of the variables could then maybe be solved with excluding initial period of the pandemic from the analysis, because it seems that it is the main source of the collinearity between different variables describing NPIs.

9 Conclusion

There are two subjects of the analysis in this thesis. The first one is comparing effects of voluntary lowering of consumption and implemented non-pharmaceutical measures on the economic growth in 2020. The second one is then comparing the effects of individual measures on the economic growth and transmission of COVID-19. In order to examine these influences, several panel data regressions are estimated, on the sample of 96 countries, U.S states and the District of Columbia, all of them utilizing fixed effects with Newey-West robust standard errors because of the presence of heteroskedasticity and auto correlation in all the models.

In the regressions which concern itself with effect of NPIs and voluntary lowering of the consumption and the one identifying effects of individual measures on the economic growth, quarterly time periods ranging between first quarter of 2014 and the last quarter of 2020 are included in the analysis. In case of estimating the effect of the measures on transmission of COVID-19, observations are two-week periods from between the 29th of March 2020 and 2nd of January 2021. The variable representing economic growth is quarterly GDP year-over-year growth rate and, in case of estimating effect of NPIs on the transmission of COVID-19, it is new cases growth rate in the two-week period.

The results of the regression estimating effects of voluntary lowering of economic activity and NPIs indicate that only the measures, represented by Stringency Index from the OxCGRT dataset, had significant effect on decline of economic growth in 2020. Voluntary lowering of consumption, represented by deaths by 100 000 inhabitants, based on the presumption that higher death tolls are connected with bigger fear of the virus resulting in lower economic activity, do not show significance in any of the models. The more stringent measures from previous quarter also seem to be significantly positively related to economic growth, which could maybe be explained by better readjustment to more stringent NPIs in states in which they were implemented with more strength before. In overall, the results comply with findings of König and Winkler (2021). Additionally, VIF values of the models imply that the states which implemented stringent measures in one period, tended to enforce them more strictly even in the following one.

In case of estimating the effect of individual NPIs on the economic growth, the variables are represented by days in quarter in which only the most stringent measure was implemented. Only the cancellation of public events, with a negative sign, is statistically significant in the model. The additional variables which are no significant in the model, are closing of schools and workplaces, prohibition on gathering, stay at home orders, internal movement restrictions, international movement restrictions and income support. Coefficients of all of them, except closing of schools and income support have a negative sign. In combination with results of previous part of the analysis, in which the stringency of all the measures was included in one variable, has statistically significant effect, there seems to be some evidence for that the measures have statistically significant effect mainly when they are implemented together, although some statistically significant results could be prevented by the collinearity between the variables.

In order to analyze the effect of NPIs on transmission, there are two models estimated. Every day is assigned either value 1 or 0 depending on that if a condition for a stringency of the measure was fulfilled on it. The variables, representing individual NPIs, are then two-week averages of these values. In the first specification, a day is assigned value 1, only if sufficiently stringent measures are implemented on it, in the second, it is when, at least some level of the measure is in force. In a specification with only stringent measures, the closing of schools seems to have strongest negative effect on the growth rate of the new cases, followed by closing of workplaces, cancellation of public events, prohibition on gatherings and order to wear masks. One of the variables seems to have a positive effect on the growth of the new cases, income support, which could maybe be explained by lower caution of people that do not have to be afraid of losing income or bigger probability that person admits symptoms of the disease or a risk contact, which then results in a higher number of the new cases.

In the specification with all levels of stringency only two variables are significant, both with negative signs, stay at home orders and cancellation of public events. Four of the variables, representing testing policy, contact tracing, internal and international movement restrictions are not significant in neither of the specifications. The difference between results of the two models can be then explained by that some of the measures have an effect only if applied with a sufficient level of stringency (in case of the first specification) and some, on the other hand, are effective, even when they are implemented with lower levels of stringency but increasing their stringency does not help to further reduce the growth of the new cases.

Findings similar to the ones in this thesis can be found in some previous studies. Lie et al. (2021), comparing effects of only stringent and all levels of measures, using the same source of the data for the stringency of individual NPIs, also find evidence that school closures, prohibition on gatherings and cancellation of public events are mainly effective only if measures are implemented with high levels of stringency and, in case of stay at home orders, mainly, their initial levels of stringency seem to be effective. Also, in the study, the weakest evidence was found for effectiveness of testing and contact tracing policy and international movement restrictions. The differences between results of the study and this thesis could be caused by that the study implemented data only for first few months of the pandemic and, in time, the effects of the measures could change. Further comparison with other studies, Brauner et al. (2021) and Haug et al. (2020), is complicated, since the studies used different sources and specifications of the NPI variables, although school closing and public gatherings bans were also in both of them found to be significantly negatively associated with transmission of COVID-19.

In conclusion, the first part of the analysis builds on the study of König and Winkler (2021) dealing with the effect of stringency of the measures and voluntary lowering of the economic activity on economic growth. On a bigger sample of states with additional quarter included, it reproduces results of the study and adds to other existing literature on the topic (Goolsbee and Syverson, 2021; Maloney and Taskin, 2020). The second part then introduces one of the first attempts to identify individual effects of NPIs on the economic activity and extend the existing literature on effect of the measures on the transmission of COVID-19 by including data for later 3 quarters of 2020.

Both parts of the analysis could be further extended to more countries of the world in case of availability of their quarterly GDP data or by using a different variable to describe economic activity. This extension could add variation to values of the variables describing the individual NPIs. The analysis could also be performed on a longer time period after the data becomes available. Using daily data instead of two-weeks periods in estimation of effects of individual NPIs on transmission of COVID-19 would then enable choosing between variables with different time lags and thus possibly fitting the data better.

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Appendix

Table A.1: Correlation matrix of quarterly average values of NPIs var. – 2. Quarter

	C1	C2	C3	C4	C5	C6	C7	C8	H6
C1	1	0,35	0,15	0,13	0,24	0,53	0,36	-0,02	0,38
C2	0,35	1	0,52	0,53	0,2	0,47	0,42	-0,03	0,38
C3	0,15	0,52	1	0,42	0,16	0,38	0,3	0,02	0,3
C4	0,13	0,53	0,42	1	0,15	0,26	0,22	-0,04	0,17
C5	0,24	0,2	0,16	0,15	1	0,33	0,23	0,08	0,18
C6	0,53	0,47	0,38	0,26	0,33	1	0,55	0,08	0,41
C7	0,36	0,42	0,3	0,22	0,23	0,55	1	0,11	0,3
C8	-0,02	-0,03	0,02	-0,04	0,08	0,08	0,11	1	0,05
H6	0,38	0,38	0,3	0,17	0,18	0,41	0,3	0,05	1

Source: Author's estimates

Table A.2: Correlation matrix of quarterly average values of NPIs var. – 3. Quarter

	C1	C2	C3	C4	C5	C6	C7	C8	H6
C1	1	0,35	0,31	0,16	0,3	0,57	0,59	0,16	0,48
C2	0,35	1	0,5	0,5	0,41	0,53	0,45	0,21	0,41
C3	0,31	0,5	1	0,45	0,24	0,44	0,39	0,32	0,37
C4	0,16	0,5	0,45	1	0,25	0,33	0,4	0,19	0,34
C5	0,3	0,41	0,24	0,25	1	0,54	0,39	0,18	0,21
C6	0,57	0,53	0,44	0,33	0,54	1	0,6	0,27	0,34
C7	0,59	0,45	0,39	0,4	0,39	0,6	1	0,32	0,4
C8	0,16	0,21	0,32	0,19	0,18	0,27	0,32	1	0,15
H6	0,48	0,41	0,37	0,34	0,21	0,34	0,4	0,15	1

Source: Author's estimates

Table A.3: Correlation matrix of quarterly average values of NPIs var. – 4. Quarter

	C1	C2	C3	C4	C5	C6	C7	C8	H6
C1	1	0,27	0,32	0,26	0,16	0,22	0,39	-0,09	0,34
C2	0,27	1	0,61	0,52	0,32	0,41	0,42	-0,3	0,32
C3	0,32	0,61	1	0,49	0,18	0,37	0,28	-0,25	0,18
C4	0,26	0,52	0,49	1	0,26	0,15	0,22	-0,09	0,29
C5	0,16	0,32	0,18	0,26	1	0,33	0,33	-0,03	0,03
C6	0,22	0,41	0,37	0,15	0,33	1	0,5	-0,12	0,32
C7	0,39	0,42	0,28	0,22	0,33	0,5	1	-0,13	0,43
C8	-0,09	-0,3	-0,25	-0,09	-0,03	-0,12	-0,13	1	-0,28
H6	0,34	0,32	0,18	0,29	0,03	0,32	0,43	-0,28	1

Source: Author's estimates

Table A.4: Variables used in the models

Cumulative effects of NPIs and voluntary reduction of the consumption on the ec. growth	
SI	Stringency Index
dp100t	Deaths per 100 000 inhabitants
SI_1	Stringency Index with 1 lag
dp100t_1	Deaths per 100 000 inhabitants with 1 lag
Quarter1_2020	Fixed effect for the 1. Quarter of 2020
Quarter2_2020	Fixed effect for the 2. Quarter of 2020
Quarter3_2020	Fixed effect for the 3. Quarter of 2020
Quarter4_2020	Fixed effect for the 4. Quarter of 2020
Effects of individual NPIs on both the economic growth and transmission of COVID-19	
C1	Closing of schools
C2	Closing of workplaces
C3	Cancellation of public events
C4	Prohibition on gatherings
C6	Stay-at-home orders
C7	Internal movement restrictions
C8	International travel restrictions
E1	Income support
Effect of individual NPIs on only the transmission of COVID-19	
H2	Testing policy
H3	Contact tracing policy
H6	Orders to wear face masks

Table A.5: Estimations of the regression - original errors

	Dependent variable: GDPg (standard errors in parenthesis)					
	(1)	(2)	(3)	(4)	(5)	(6)
SI	-0,08***		-0,08***	-0,10***		-0,10***
	(0,01)		(0,01)	(0,01)		(0,01)
dp100t		-0,01	0,0003		-0,01	0,004
		(0,005)	(0,005)		(0,01)	(0,005)
SI_1				0,05***	-0,004	0,05***
				(0,01)	(0,02)	(0,01)
dp100t_1				0,01	0,01	0,01
				(0,01)	(0,01)	(0,01)
Quarter1_2020	-0,38	-1,89***	-0,38	0,01	-1,89***	0,05
	(0,33)	(0,27)	(0,33)	(0,34)	(0,27)	(0,35)
Quarter2_2020	-5,89***	-11,42***	-5,88***	-5,39***	-11,36***	-5,35***
	(0,77)	(0,29)	(0,77)	(0,77)	(0,54)	(0,77)
Quarter3_2020	-0,29	-4,76***	-0,28	-2,83**	-4,75**	-2,90**
	(0,64)	(0,28)	(0,64)	(0,90)	(1,59)	(0,91)
Quarter4_2020	0,60	-3,81***	0,59	-1,15	-3,73**	-1,29
	(0,65)	(0,33)	(0,65)	(0,79)	(1,33)	(0,82)
Observations	2,688	2,688	2,688	2,688	2,688	2,688
R^2	0,68	0,68	0,68	0,69	0,68	0,69
Adjusted R^2	0,67	0,66	0,67	0,67	0,66	0,67
F Statistic	197,36*** (df = 28; 2564)	190,69*** (df = 28; 2564)	190,48*** (df = 29; 2563)	186,19*** (df = 30; 2562)	178,16*** (df = 30; 2562)	180,17*** (df = 31; 2561)

Fixed effects model. In the model, there are included dummy variables for every quarter in the sample not only the ones mentioned in the results. *p<0.1; **p<0.05; ***p<0.01

Table A.6: Estimations of the regression – robustness check

	Dependent variable: GDPg (standard errors in parenthesis)					
	(1)	(2)	(3)	(4)	(5)	(6)
log (1+SI)			-3,34***	-3,78***		-3,64***
	(0,87)		(0,98)	(0,94)		(1,06)
log(1+dp100t)		-0,26	-0,05		-0,36*	-0,08
		(0,18)	(0,20)		(0,14)	(0,17)
log(1+SI_1)				1,20	-0,21	1,07
				(1,42)	(1,41)	(1,40)
Log(1+dp100t_1)				0,14	0,29	0,18
				(0,24)	(0,21)	(0,21)
Quarter1_2020	8,22**	-1,76***	8,02**	9,30***	-1,71***	8,93**
	(2,56)	(0,27)	(2,84)	(2,74)	(0,27)	(3,07)
Quarter2_2020	3,01	-10,90***	2,80	0,94	-10,17*	0,90
	(3,68)	(0,65)	(3,92)	(4,37)	(3,97)	(4,40)
Quarter3_2020	8,93*	-4,29***	8,72*	4,93	-3,89	4,98
	(3,52)	(0,48)	(3,78)	(5,44)	(5,65)	(5,39)
Quarter4_2020	9,82**	-3,17***	9,67**	6,17	-2,59	6,31
	(3,56)	(0,67)	(3,72)	(5,25)	(5,35)	(5,14)
Observations	2,688	2,688	2,688	2,688	2,688	2,688
R^2	0,68	0,68	0,68	0,68	0,68	0,68
Adjusted R^2	0,67	0,66	0,67	0,67	0,66	0,67
F Statistic	195,97*** (df = 28; 2564)	191,28*** (df = 28; 2564)	189,16*** (df = 29; 2563)	183,59*** (df = 30; 2562)	178,89*** (df = 30; 2562)	177,66*** (df=31; 2561)

Notes: Fixed effects model. Newey-West robust standard errors. In the model, there are included dummy variables for every quarter in the sample not only the ones mentioned in the results.
*p<0.1; **p<0.05; ***p<0.01