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A thesis presented by

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Analysis of Costs Associated with COVID-19 Mitigation Strategies in Selected European Countries

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Acknowledgments

Time flew by so fast. I still remember how excited I was when I received the admission letter from ETH Zurich and how fascinated I was when I first saw the country's elegance. Despite the Covid-19's influence, these two years in Switzerland were the happiest of my life. I enjoyed the classes and events at ETH Zurich, and I also cherished people I met during the Master program. Now, after one year and eight months, almost at the end point of this Master program, I am sincerely grateful to have this unique and valuable experience at ETH Zurich.

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Last and but not least, I would like to thank my parents, who have always been unconditionally understanding, consoling, supporting me. I especially thank my parents for fully loving but respecting me and giving me enough freedom to choose my life.

List of abbreviations

Covid-19: Coronavirus disease 2019
DHSC: The Department of Health and Social Care
DNA: Deoxyribonucleic acid
ECDC: The European Centre for Disease Prevention and Control
EU: The European Union
E&W: England and Wales
FHM: Folkhälsomyndigheten, The Public Health Agency of Sweden
GDP: Gross domestic product
IATA: The International Air Transport Association
ICAO: The International Civil Aviation Organization
IMF: International Monetary Fund
MERS: Middle East respiratory syndrome
NFER: The National Foundation for Education Research
NICE: The National Institute for Health and Care Excellence
NO_2: Nitrogen dioxide
NPI: Non-pharmaceutical intervention
NRS： National Records of Scotland
ONS: The Office for National Statistics
$PM_{2.5}$: Particulate Matter 2.5
PPE: Personal protective equipment
QALY: The quality-adjusted life year
RCEM: The Royal College of Emergency Medicine
RNA: Ribonucleic acid
SAGE： The Scientific Advisory Group for Emergencies
SARS: Severe acute respiratory syndrome
SARS-CoV-2: Severe acute respiratory syndrome coronavirus
SE: Standard error
UNCTAD: The United Nations Conference on Trade and Development
VSL: The value of a statistical life
WFP: The World Food Program
WHO: World Health Organization
YLL: Years of life lost

Contents

Abstract

Since the outbreak of Coronavirus disease 2019 (Covid-19), many countries in Europe have been severely affected. Different countries have adopted different strategies to try to control the pandemic. The aim of this research is to analyze the costs and benefits associated with Covid-19 mitigation strategies in European countries. In section 1, we first provide a brief introduction to the Covid-19 and the current situations about Covid-19 in several European countries. Then, we go through the three main mitigation strategies including non-pharmaceutical interventions (NPIs) by governments, vaccines, and the "Swedish styles". Following that, we discuss the debate over the implementation of NPIs. Since it is unclear if the benefit of NPIs is worth the high cost, we perform a cost-benefit analysis to assess these measures. In the second section, we conduct a literature review following by a sensitivity analysis of existing cost-benefit analysis about NPIs, especially lock-downs. The third section begins with an introduction to the methodology of cost-benefit analysis. Then, we focus on the UK, choosing gross domestic product (GDP) losses and school closures' related costs as the main costs, net lives saved from NPIs and reduction of deaths from other causes as the main benefits, and translating the costs and benefits into monetary value to compare them. In the fourth section, we address the unevenly distributed effects on different industries and we also discuss the unquantifiable costs in fields of health, education, society, environment and others. In the last section, we give the conclusions of this study.

1. Introduction

1.1 A brief introduction to Coronavirus disease 2019

In December 2019, a novel coronavirus disease (Covid-19) was identified in Wuhan, China. This is a disease caused by a kind of coronavirus that has not been previously discovered in humans. Afterwards, Covid-19 spread within China rapidly and then to the rest of the world. On 30th January 2020, the World Health Organization (WHO) declared the outbreak of a public health emergency of international concern. Covid-19 is a contagious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [19]. As of February 2021, more than 104 million Covid-19 cases and 2.2 million deaths have been reported [77]. Until March 30, 2021, the Covid-19 is still rampant around the world and shows no sign of easing - with approximately over 400,000 daily new cases every day for several months.

SARS-CoV-2 belongs to the broad family of viruses known as coronaviruses [22]. It is a positive-sense single-stranded ribonucleic acid (RNA) virus, with a single linear RNA segment. Most common symptoms include fever, dry cough and tiredness, while aches and pains, sore throat, diarrhea, conjunctivitis, headache, loss of taste or smell, a rash on skin and discoloration of fingers or toes are also possible symptoms. More serious symptoms include acute difficulty breathing or shortness of breath, chest pain or pressure and loss of speech or movement [74]. Also, there could be asymptomatic infections where infected people don't know they have the disease but could transmit it to others. It is this feature that makes Covid-19 harder to contain. Notably, unlike previous pandemics in which a large proportion of deaths were teenagers and young people, such as Spanish flu, this disease is more dangerous for the elderly and people with preexisting medical conditions, such as high blood pressure, cardiovascular disease, diabetes or cancers [26].

1.2 Current situation about Covid-19 in Europe

The first wave of Covid-19 hit Europe in January 2020, leading to large-scale lock-downs in many European countries. Since April and May 2020, the lock-downs and restrictions have been partially relaxed as a result of the improving situation. However, from October 2020 onwards, European countries were confronted with the resurgent second wave of the Covid-19 outbreak. As reported by Mike Ryan, the WHO's top emergencies expert, on October 25, 2020, Europe accounted for 46% of new cases and one-third of Covid-19 deaths worldwide. This compared with Europe (746 million) having around 10% of the global population (7.9 billion).

Though most European countries are hit by the second wave, the present situations among them are different. Basically, we divide them into two groups. It is worth noting that here we make this division only based on the numbers of Covid-19 cases and deaths, regardless of the influence of testing capacity. We will include the tests conducted per new confirmed cases for each country afterwards. The first group is countries with the worse second wave than the first one in terms of daily new cases and new deaths. The UK is an example of this. As shown in Figure 1, the daily new cases in the second wave from October 2020 to January 2021 are significantly higher than in the first wave, regardless of the testing capacity's difference in the two waves. The highest is 68,053 new cases (January 8, 2021), which is about 8.6 times the highest daily new cases during the first wave (7860 new cases on Apr 4, 2020). In Figure 2, the daily new deaths in the second wave are also considerably higher than in the first wave, with the highest daily deaths of 1820 on January 20, 2021, while the highest during the first wave was 1166 (April 21, 2020).

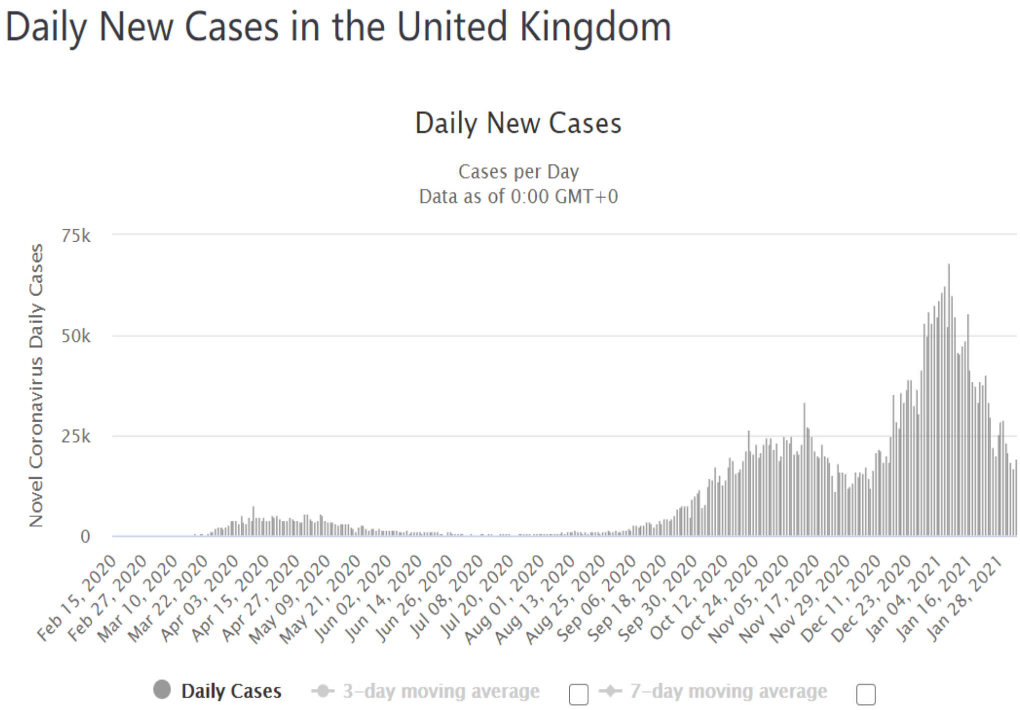


Figure 1: Daily new Covid-19 cases in the United Kingdom as of February 4, 2021

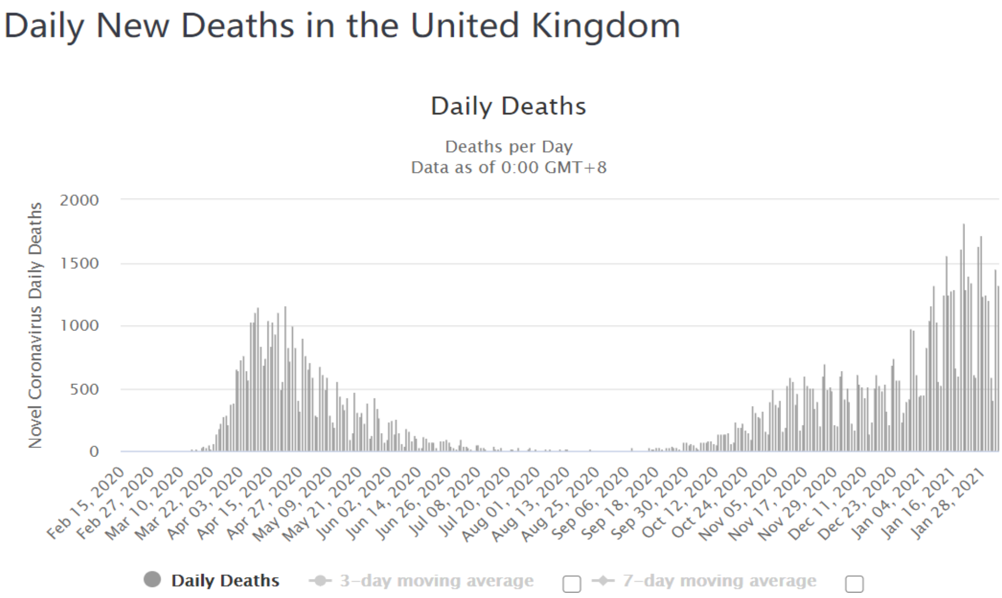
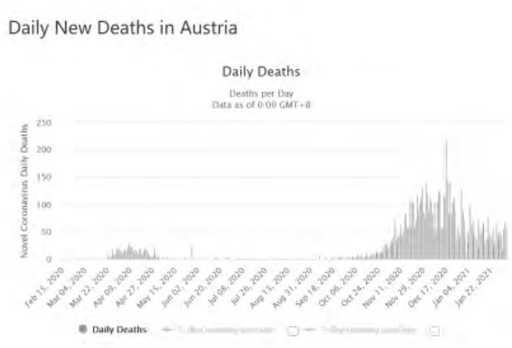


Figure 2: Daily new Covid-19 deaths in the United Kingdom as of February 4, 2021
Source: Worldometers [77]

All graphs of daily new cases and daily new deaths come from this source. (https://www.worldometers.info/coronavirus/#countries)

In addition to the UK, there are also countries now experiencing worse second waves (at the time when this section was written, which was Jan. 2021). They see higher daily new cases and new deaths in the second wave. These countries are Austria, Czechia, Germany, Poland, Portugal, Sweden and Switzerland, as shown from Figure 3 to Figure 16. Notably, Czechia successfully prevented an enormous outbreak during the first wave but is attacked extremely hard during the second wave. Czechia ranked 4th in the total number of cases per million people (94,522) and 6th in the total number of deaths per million people (1,569) on February 4, 2021 [77]. One of the possible explanations is that it imposed strict measures early in the first wave when they were only mildly affected but eased these measures later and was reluctant to reintroduce similar stringent measures as they did in the first wave.

Figure 3



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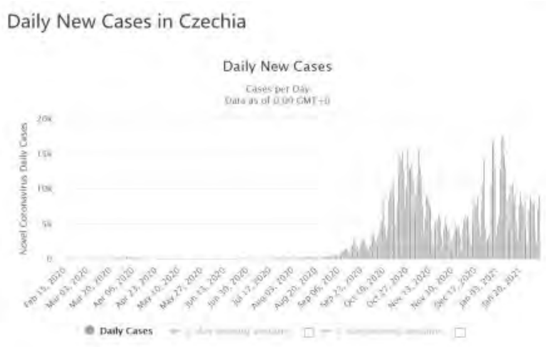

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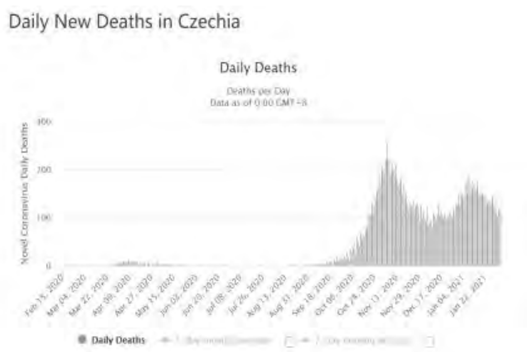

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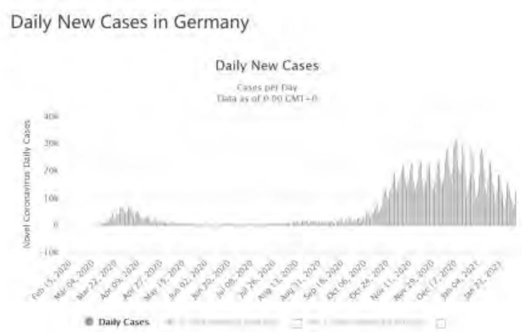

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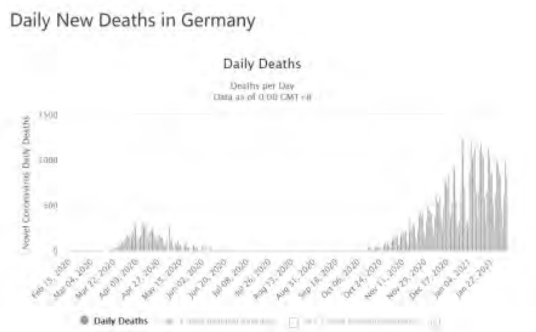

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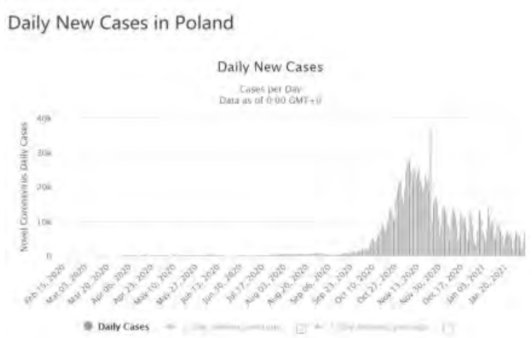

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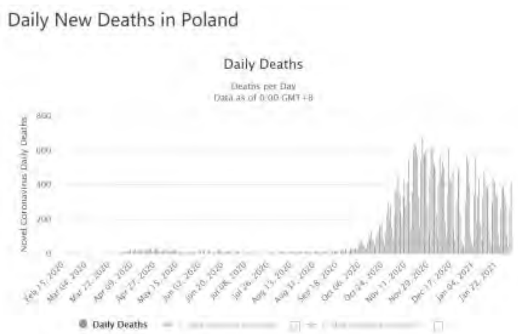

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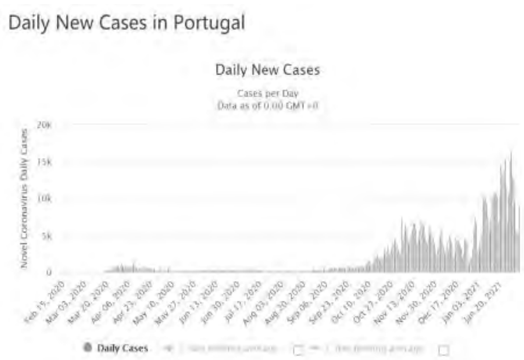

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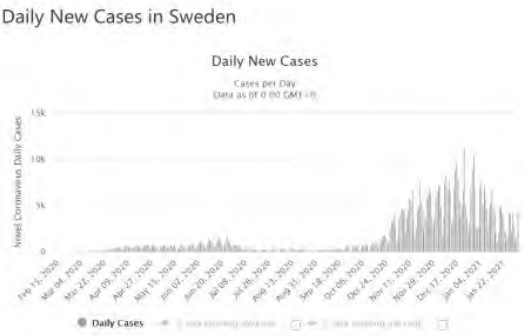

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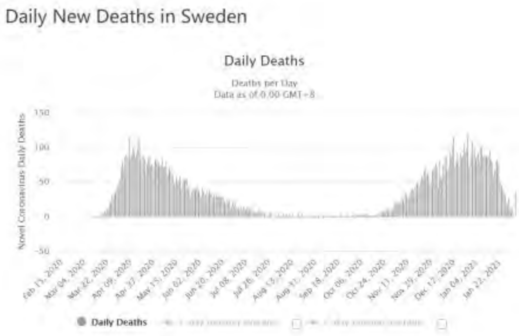

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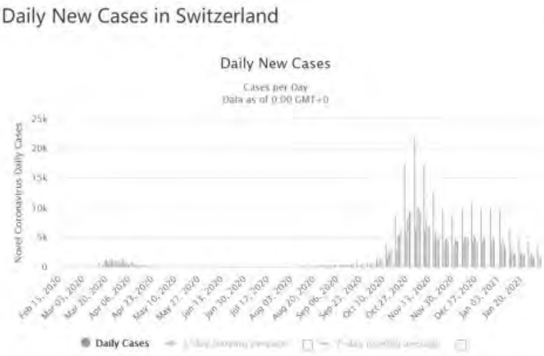

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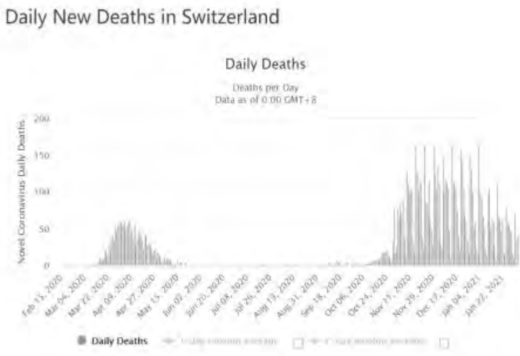


Figure 16

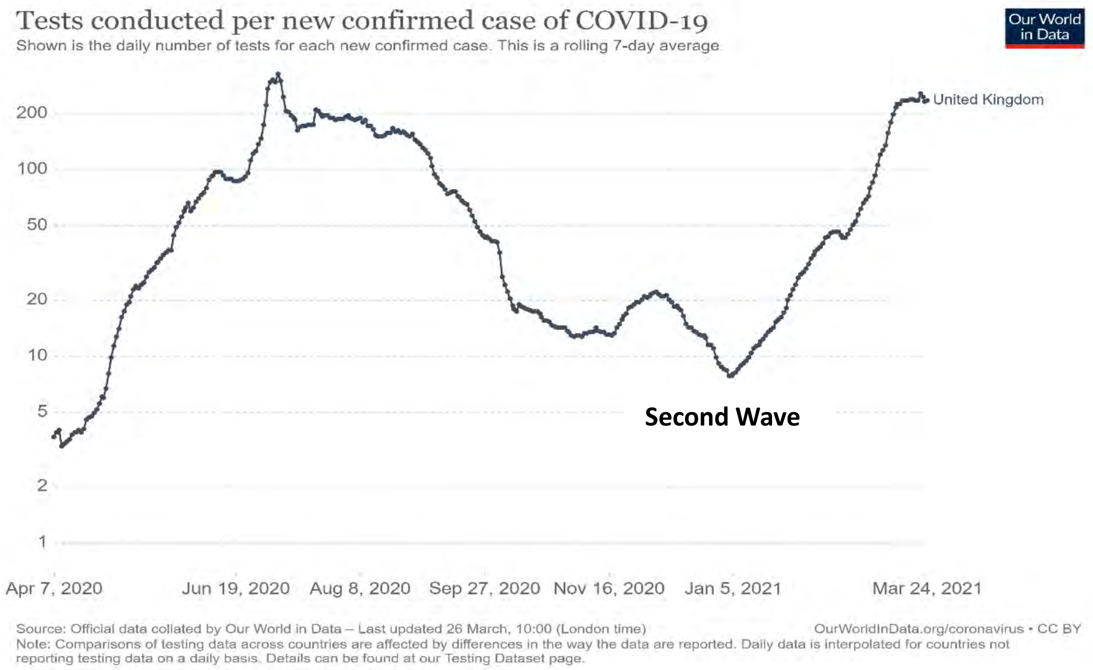
Figure 3, 5, 7, 9, 11, 13, 15: Daily new Covid-19 cases in Austria, Czechia, Germany, Poland, Portugal, Sweden and Switzerland as of February 4, 2021

Figure 4, 6, 8, 10, 12, 14, 16: Daily new Covid-19 deaths in Austria, Czechia, Germany, Poland, Portugal, Sweden and Switzerland as of February 4, 2021

Source: Worldometers [77]

(https://www.worldometers.info/coronavirus/#countries)

However, considering the fact that the lower daily new cases and daily new deaths in the first wave may be because of the lower testing capacity at the beginning of the outbreak, which means there might be more cases and deaths in the first wave than the figures represent, we also compare the tests per confirmed cases in the first and second wave for the UK, Austria, Germany, Portugal, Sweden and Switzerland, as shown Figure 17 to Figure 22. Since data for Czechia and Poland in the first wave are not available, we do not present graphs of tests per confirmed cases for these two countries here. Charts of daily tests per million versus daily new confirmed cases per million for each country are provided in the Appendix.



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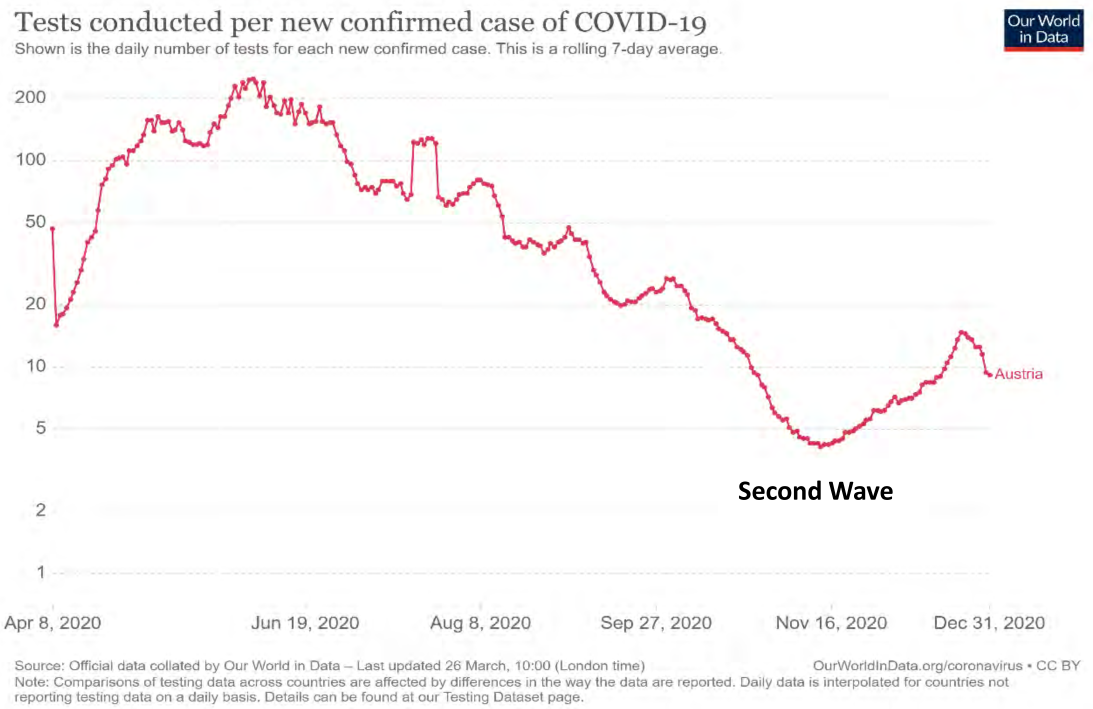

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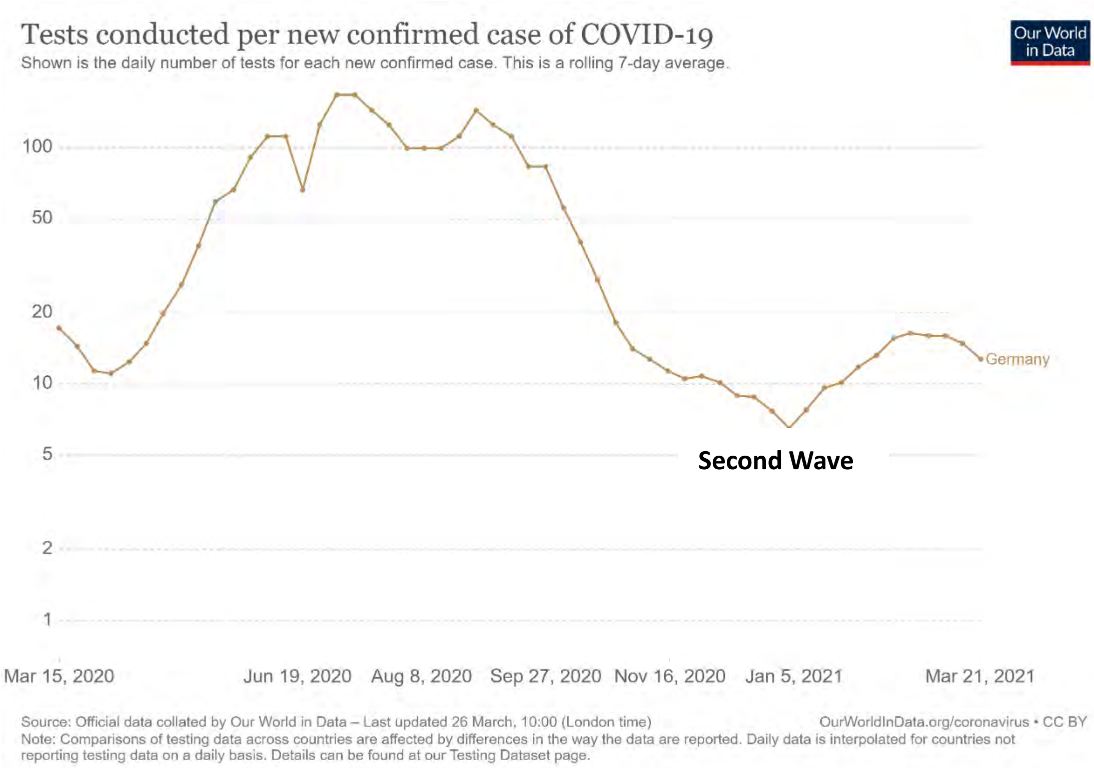

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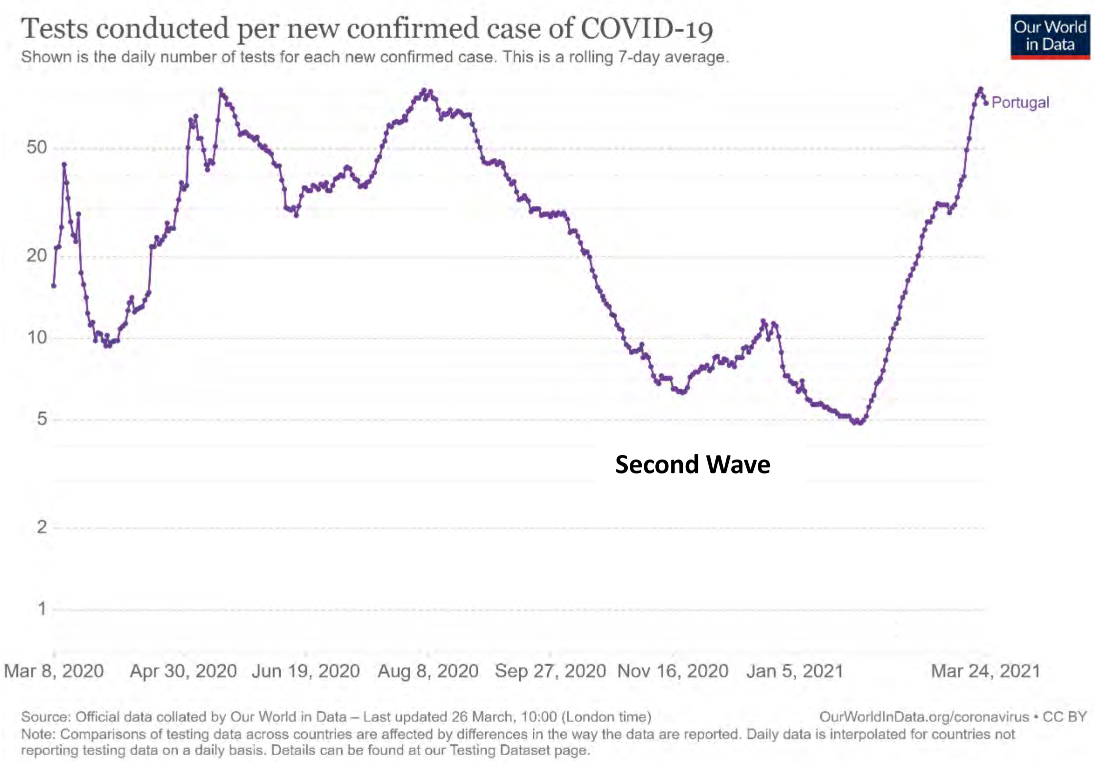

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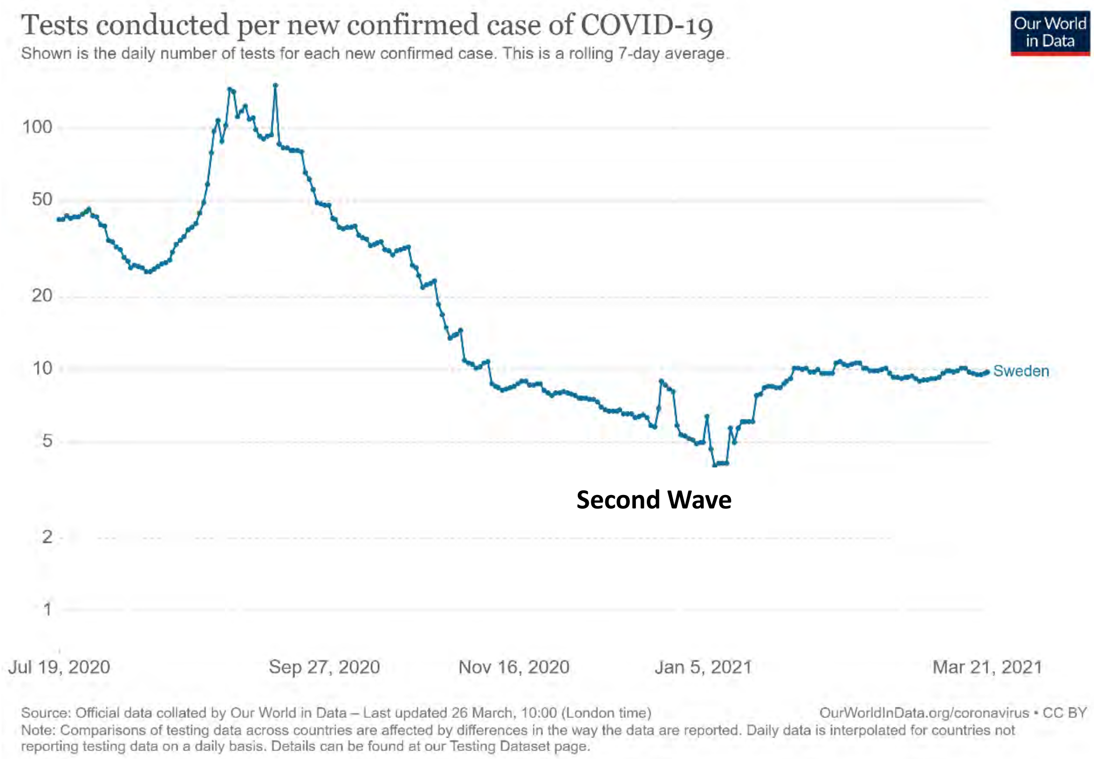

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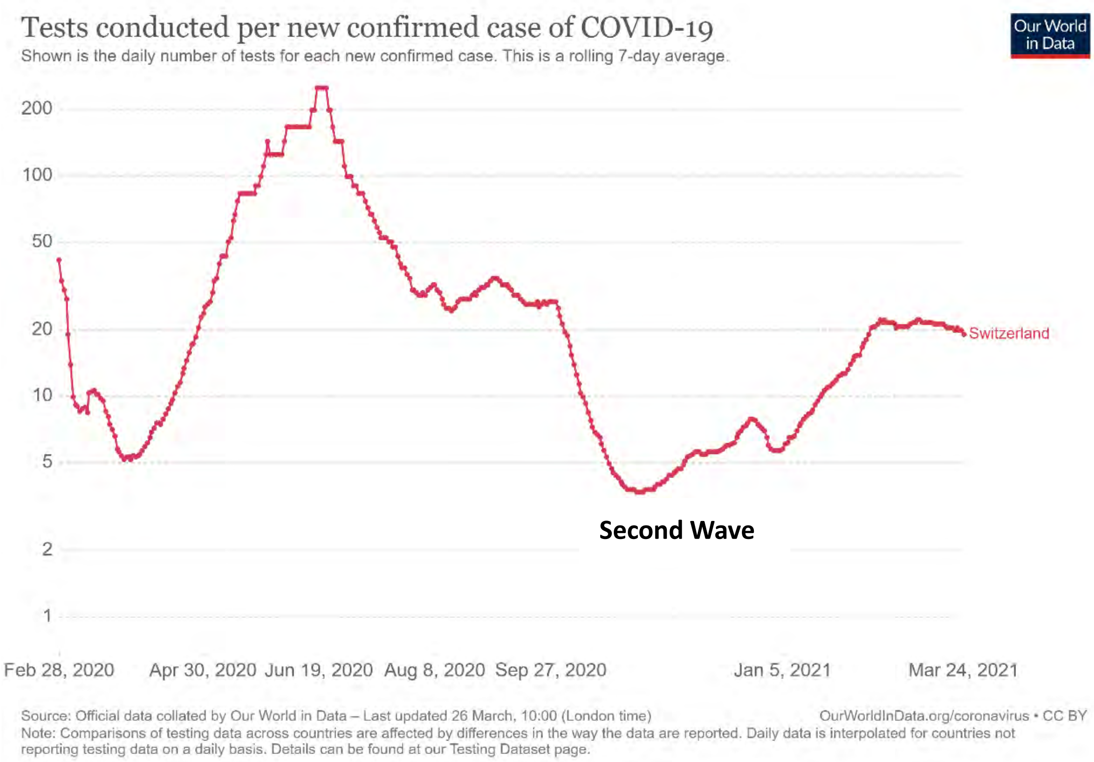


Figure 22

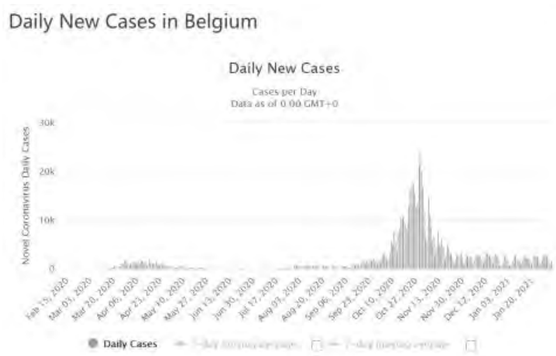
Figure 17-22: Tests conducted per confirmed cases of Covid-19 for the UK, Austria, Germany, Portugal, Sweden and Switzerland as of March 26, 2021.

Source: Our World in Data [55]

All graphs of tests per confirmed cases come from this source. (https://ourworldindata.org/coronavirus-testing)

As we can observe from Figure 17 to Figure 22, except for the UK and the two countries with unavailable data, all countries including Austria, Germany, Portugal, Sweden and Switzerland show lower tests per confirmed cases in the second wave than in the first wave, indicating that, despite the possibility that the testing capacity influenced the comparison, for these countries, the second wave is still worse than the first one. For the UK, we can see that while the daily new cases and deaths in the second wave are higher than those in the first one, the tests per confirmed cases of Covid-19 rate is lower in the second wave than in the first wave. This might make it hard to judge which wave is worse. One potential reason could be that the UK is testing a large number of people in the second wave and some testing might be unnecessary (untargeted testing).

Another group of countries, including, Belgium, France, Italy, Netherlands and Spain, were hit roughly equally in the second wave as in the first. They had similar or slightly higher daily new cases from October 2020 than in the first wave from January to April 2020, but approximately equal or lower daily new deaths than in the first waves, as shown from Figure 23 to Figure 32.



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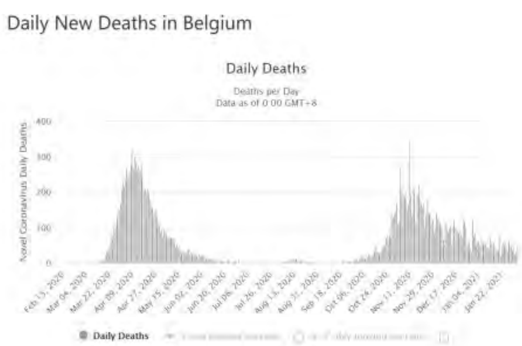

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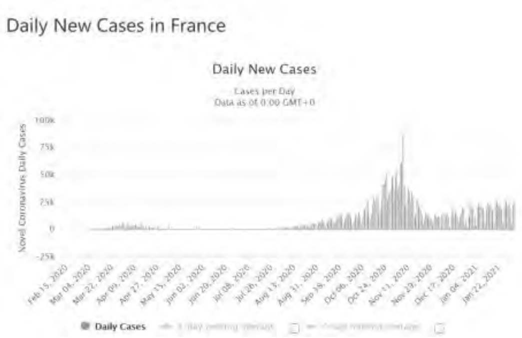

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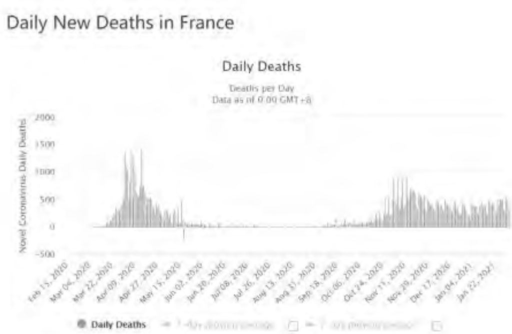

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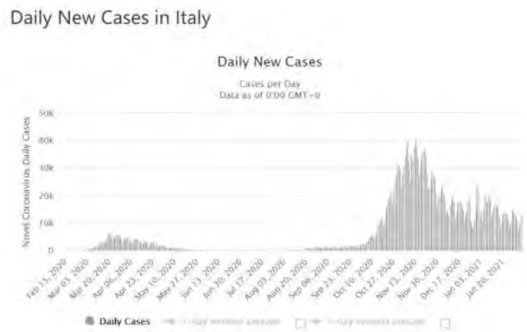

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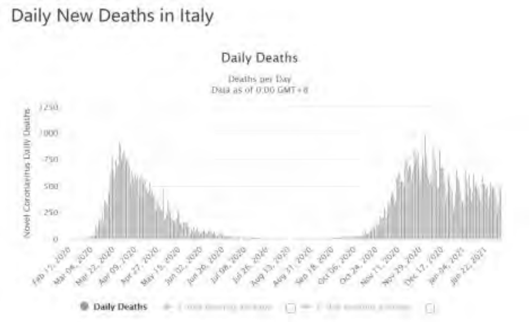

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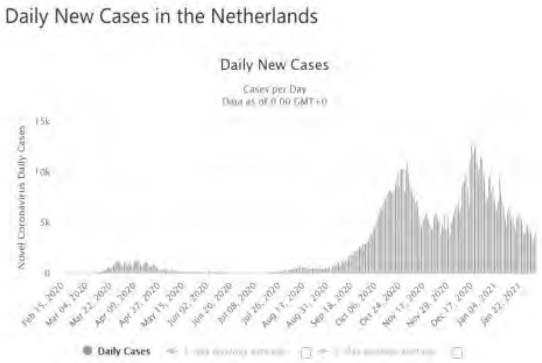

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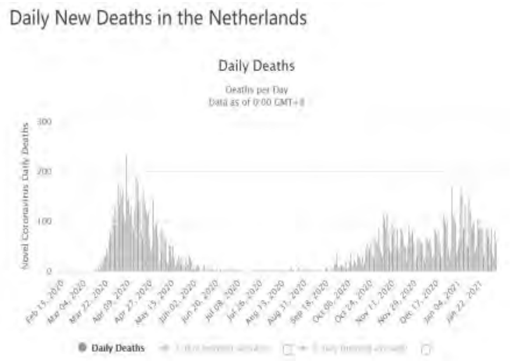

Figure 30

Figure 31

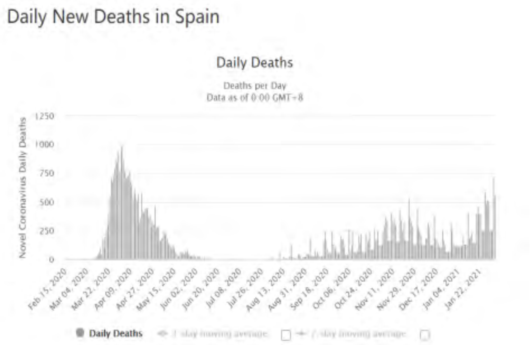

Figure 32

Figure 23, 25, 27, 29, 31: Daily new Covid-19 cases in Belgium, France, Italy, Netherlands and Spain as of February 4, 2021

Figure 24, 26, 28, 30, 32: Daily new Covid-19 deaths in Belgium, France, Italy, Netherlands and Spain as of February 4, 2021

Source: Worldometers [77]

(https://www.worldometers.info/coronavirus/#countries)

Similarly, in order to eliminate the influence of testing capacity on the comparison of two waves, we also present tests per confirmed cases for these countries, as shown in Figure 33-35. For France and Spain, since the data are unavailable from the first wave, we do not present the graphs for these two countries here. Charts of daily tests per million versus daily new confirmed cases per million for each country are provided in the Appendix.

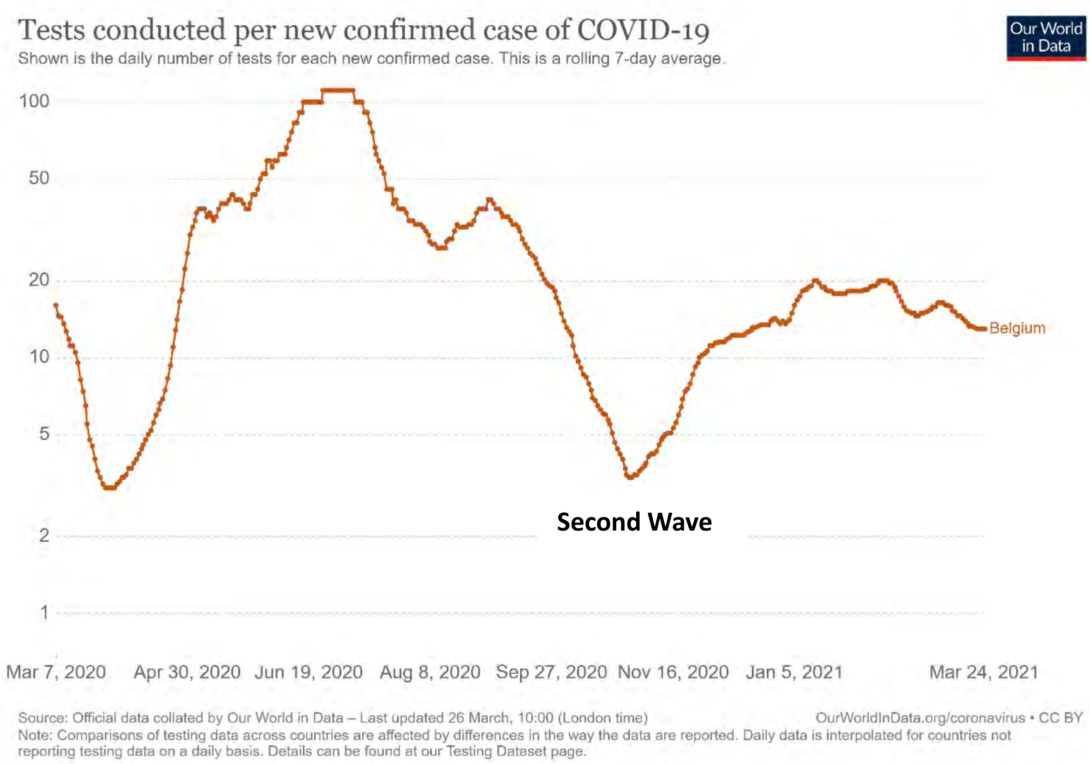

Figure 33

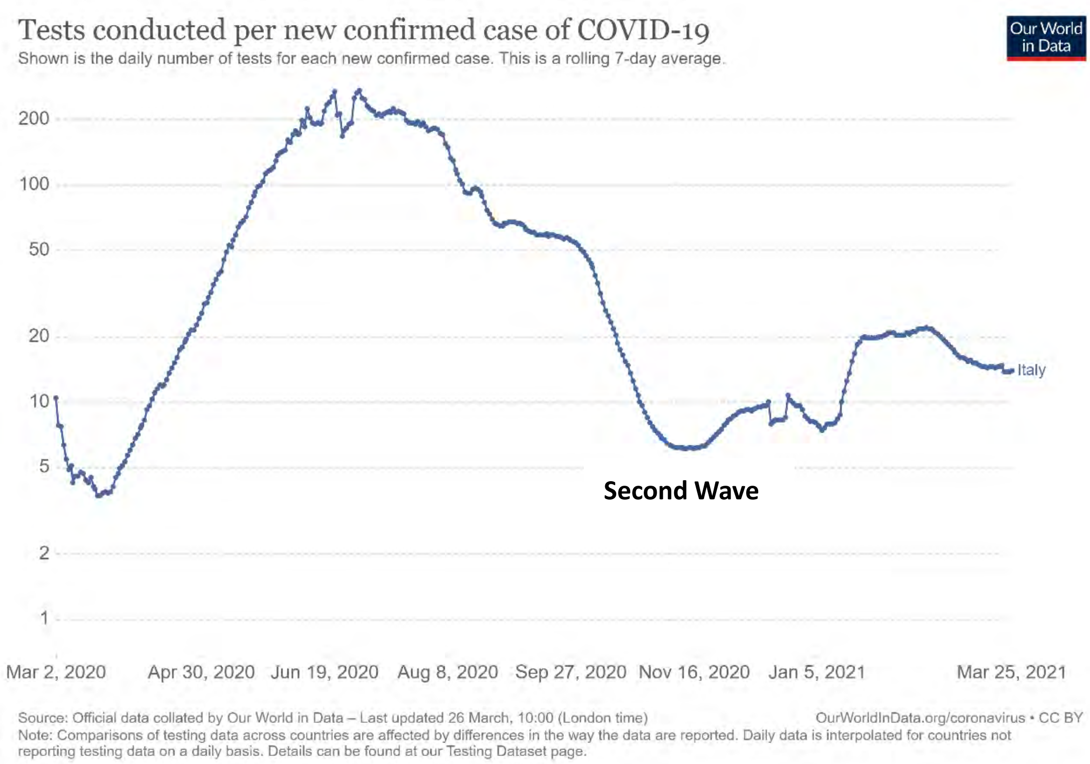

Figure 34

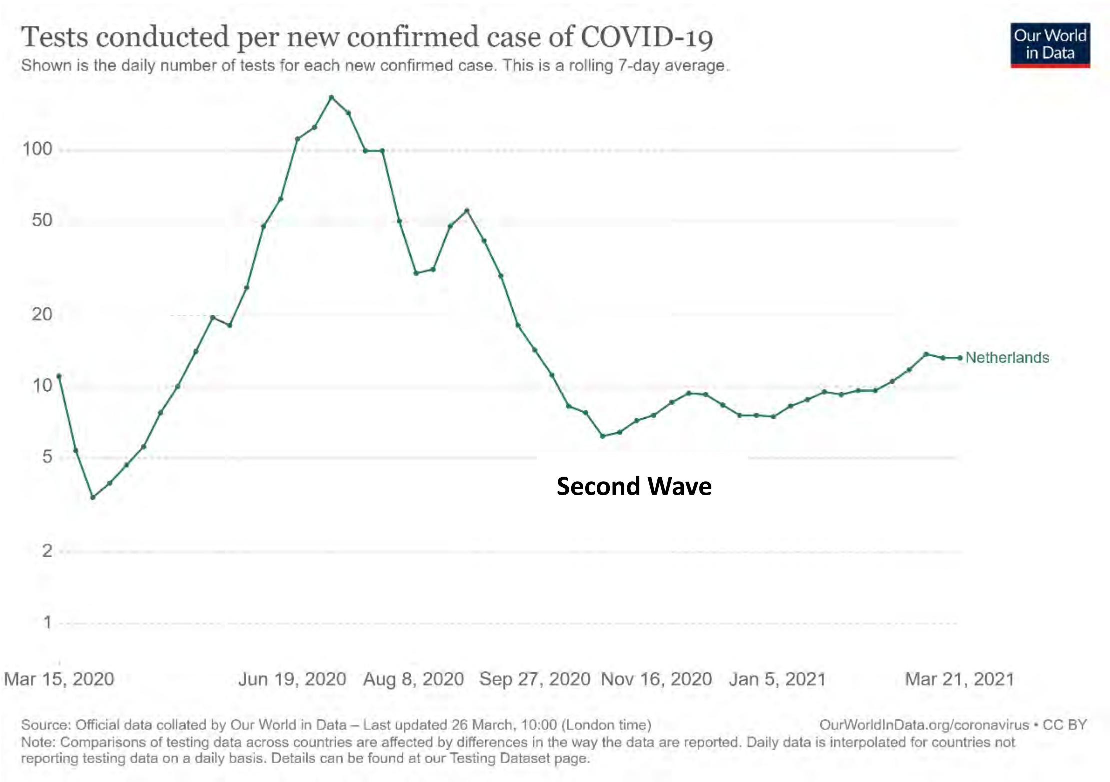

Figure 35

Figure 33-35: Tests conducted per confirmed cases of Covid-19 for Belgium, Italy and Netherlands as of March 26, 2021.

Source: Our World in Data [55]

(https://ourworldindata.org/coronavirus-testing)

We can observe from Figure 33 to Figure 35 that for Belgium, Italy and Netherlands, the tests per confirmed cases in the second wave is higher than that in the first wave, which indicates that after accounting for the probability of lower test capacity in the first wave, the second wave for these countries are better or at least not much worse than the first one.

In general, most countries in Europe have had a very tough time since October 2020, while the holiday season of Christmas and New Year with family gatherings and vacations could have contributed to a worse situation, reflected by higher daily new cases and deaths in weeks following these holidays. Moreover, new variants could be another reason for the serious second wave.

1.3 Different measures taken by European governments

Since the beginning of this pandemic in January 2020 in Europe (first case on January 24, 2020, in France), governments have taken a number of different measures to try to suppress the pandemic or at least "flatten the mortality curves" to prevent an uncontrolled outbreak. Generally, there are three types of measures：(1) Non-pharmaceutical interventions (NPIs) (2) Vaccines and (3) “Swedish style” measures also followed in countries like Japan and South Korea. Unlike most European countries, Sweden did not have a hard lock-down and made every effort to keep society as open as possible. The disciplined Swedish public did, however, engage in behavioral changes such as practicing social distancing and other measures designed to avoid or to minimize transmission. Sweden has been roundly criticized for this approach, even by those living in countries with far worse mortality statistics than Sweden. The Swedish approach is discussed in greater detail in section 1.3.3.

1.3.1 Non-pharmaceutical interventions (NPIs)

Non-pharmaceutical interventions (NPIs) are actions, apart from getting vaccinations or taking medicines, that ordinary people and the community can take to prevent infections and to slow down the spread of illnesses among people. They are also referred to as community mitigation strategies, which are particularly helpful when effective vaccines are not available. Since at the beginning of a pandemic, the virus is new and there is low level of immunity among people, allowing the virus to spread quickly from person to person and around the world. In such situations, these NPIs may physically reduce the possibility of people getting infected. Although specific measures vary across countries, typical interventions are similar including strict lock-downs (in epidemics and pandemics, lock-down mainly refers to stay-at-home order), social-distancing (such as keeping a certain distance, for example, 1.5 meters, in shops), voluntary and mandatory use of masks, border-closures, closure of schools, closure of public spaces, including restaurants, entertainment venues, non-essential shops, partial or full public transports, “stay-at-home” and “work-from-home” recommendations, isolating symptomatic patients and their close contacts and canceling unnecessary travels nationally and internationally. These measures were taken on a large scale throughout the world by governments.

From April to July 2020, as the situations of Covid-19 improved in Europe with trends of declining daily new cases and deaths, most countries gradually relaxed these strict restrictions. For example, shopping centers and large stores in Austria reopened on May 1, 2020. In Italy, most businesses including bars and restaurants reopened in May after more than two months of national lock-downs. In April 2020, Spain greenlighted part of on-site construction work. In the same month, Denmark reopened daycare centers and schools. Most European countries have enjoyed a relatively peaceful summer season.

However, in October 2020, the Covid-19 came back with a worse second wave or even a third wave, forcing governments and policy makers to adopt the same level or stricter NPIs. Spain and France led the way by imposing the second lock-downs in October. France has since come out of lock-down and switched to an early national curfew supplemented by restaurant closures, which was also adopted by Belgium and Luxembourg. Spain adhered to the national curfew and local lock-down system. Italy, where the number of cases has risen rapidly since October, also implemented the same system. At the same time, the restaurant closing early at 6 pm was added. Immediately after the acceleration of the spread of Covid-19, Germany imposed a national lock-down on November 2, 2020 and closed non-essential shops from mid-December. The UK returned to a national lock-down since the beginning of November and the government required that from February 15, 2021 onwards, everyone who enters England from a red-listed country must quarantine in hotels for 10 days and take tests twice on day 2 and day 8 if they have visited or passed through a country where travel to the UK is banned. Switzerland returned to a second lock-down on January 15, 2021 as well. Nevertheless, it kept schools open and allowed ski resorts to operate. Other restrictions not implemented during the first wave are also adopted, such as restrictions on the frequency of shopping in Greece.

It is worth noting that some Asian countries implemented these NPIs as well, but with targeted policies and tended to be more successful than measures taken in these European countries. In particular, SE Asian countries recognized early on that the disease was an airborne aerosol and that good ventilation was essential to suppress the spread of the disease. Meanwhile, Europe continues to obsess with hand washing, as recommended by the WHO. Since the first Covid-19 case was discovered in Wuhan, China could be a unique case. Taking advantage of the national Spring Festival holiday, China has shut down the entire city of Wuhan, enforcing tight controls on people movement between cities and provinces, imposing strict quarantines on serious and asymptomatic patients, and introducing a contact-tracing policy. Unlike the strategy taken in European countries of flattening the cases and deaths curves and slowing down the spread, China has adopted the "zero-Covid" strategy which seemed to be effective in containing the epidemic, as demonstrated by the lifting of lock-down of Wuhan on April 8, 2020. Other East Asian countries and regions have also implemented stringent measures to effectively control the spread, as shown the comparatively low Covid-19 cases and deaths rates compared to European countries. For example, South Korea tested early, extensively and frequently, using walk-in centers and drive-throughs. In March 2020, the testing once reached a high of over 10,000 per day, equivalent to a half-month's number of testing in the USA. Moreover, it also decided to monitor and confine patients with milder cases in special supervised centers, which is much better than keeping them at home, considering that people are tempted outside by the need of earning a living. Meanwhile, most Asian countries and regions concentrated heavily on contact-tracing, including interviewing patients, monitoring videos in public places and public transportations. For instance, in Vietnam, a "third-degree" sweep of personal data was used, and in Hong Kong, geofencing wristbands were used.

1.3.2 Vaccines

Vaccine research has been conducted around the world since the beginning of the Covid-19 outbreak. Even prior to the outbreak of Covid-19, there were researches on the vaccines against coronaviruses such as severe acute respiratory syndrome (SARS) and the Middle East respiratory syndrome (MERS). This knowledge of coronaviruses provided some basis for the research on Covid-19 vaccines and may have accelerated the progress. As reported by the European Centre for Disease Prevention and Control (ECDC), there are 175 vaccines in pre-clinical development and 65 vaccines in the clinical phase and 10 vaccines are authorized by at least one government for public use, as of February 2021. From the end of 2020, many countries had initiated vaccination programs and are relying on this strategy to largely establish immunity to the virus or stop the transmission of Covid-19, and to make vulnerable individuals more resistant to the disease. [23]

There are four main categories of vaccines against Covid-19, namely whole virus, protein subunit, viral vector and nucleic acid (RNA and DNA) [28]. Whole virus vaccines are conventional vaccines used to trigger an immune response. They may be either inactivated vaccines or live-attenuated vaccines as a weakened form of the virus. Protein subunit uses pieces of the pathogen - often fragments of protein to trigger the immune response. Nucleic acid vaccines use genetic material – either RNA or DNA – to provide cells with the instructions to make the antigen. In the case of Covid-19, this is usually the viral spike protein. The Comirnaty (the Pfizer-BioNTech Covid-19 vaccine) and the COVID-19 Vaccine Moderna, widely used in Europe are of this type. Viral vector vaccines also work by giving cells genetic instructions to produce antigens. But they differ from nucleic acid vaccines in that they use a harmless virus, different from the one the vaccine is targeting, to deliver these instructions into the cell [28].

The Comirnaty vaccine and the Moderna vaccine are widely authorized in European countries and have been used since December 2020. Exceptions are Cyprus, Greece, Hungary, Italy, Luxembourg, Malta, Slovakia and Slovenia using only the Comirnaty vaccine [23]. Nevertheless, though these vaccines are authorized and procured, the vaccination rate is not as high as previously anticipated and varies widely across Europe. Figure 36 illustrates the vaccination rate in Europe as of Feb 2, 2021, with the highest rate of 14.94% (UK) and the lowest of 0.66% (Bulgaria). One reason that most European countries have a low vaccination rate is that the European Union (EU)’s medical regulator gave approval to the Comirnaty and the Moderna later than the US (with 8.34% vaccination rate), the UK and Israel (with 38.95% vaccination rate) [55]. Another problem might be the capacity to administer and deliver the vaccines they received. For example, in Madrid, Spain, only 6% of the vaccines were used in the first week of vaccination. While in Asturias and Galicia, Spain, over half of the doses received were used as of January 5, 2021. Starting at the end of January 2021, supply shortages may be the biggest challenge facing most of the EU countries to implement vaccination. Many regions in European countries including France, Spain, Portugal and Netherlands have to delay or cancel part of the vaccination as initially planned owing to a shortage of supplies [17]. It is worth noting that as of April 18, 2021, 48.51% of people in the UK have received at least one dose of the Covid-19 vaccine [55], indicating that the vaccination program has been a success in the UK so far.

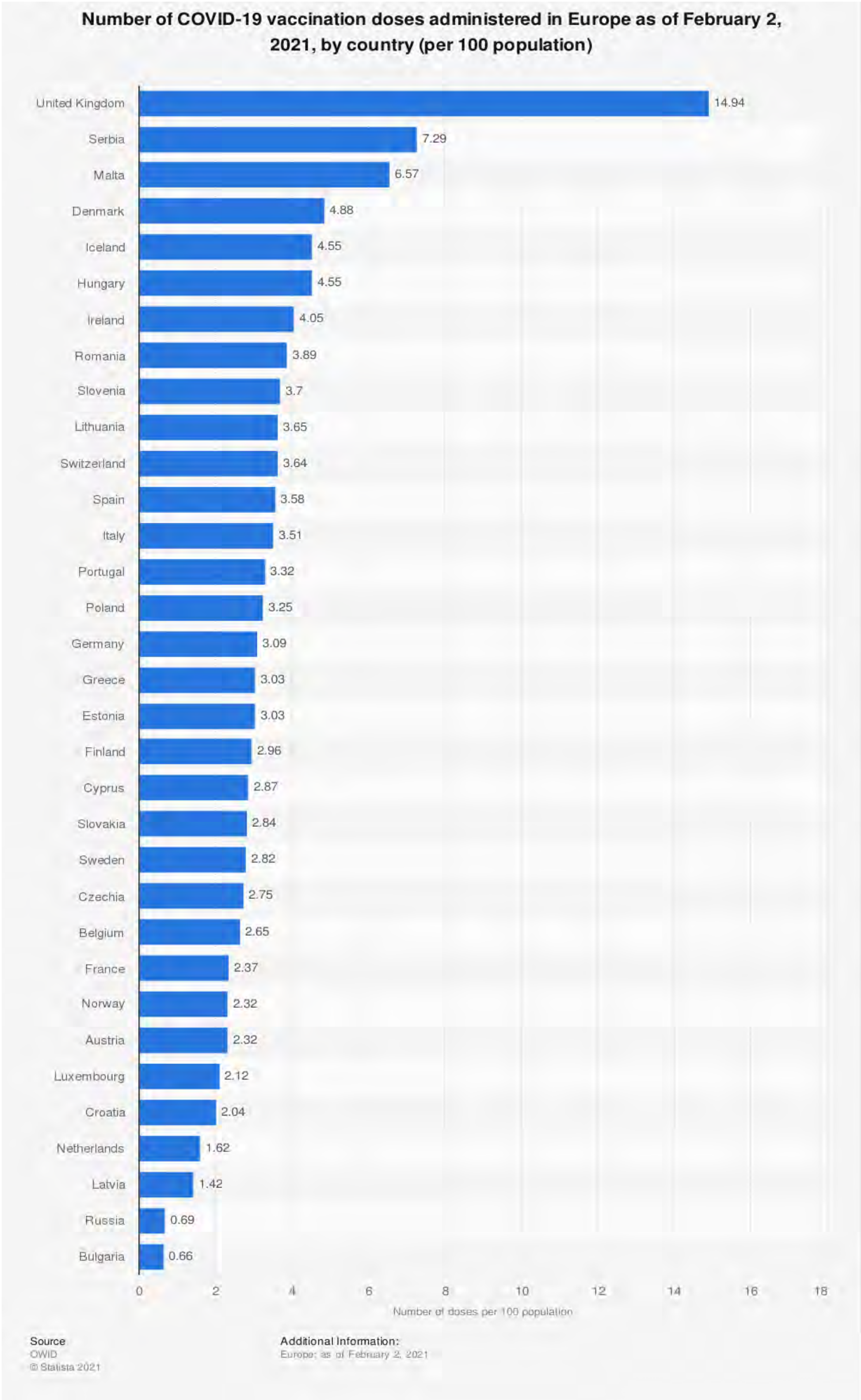

Figure 36: Number of Covid-19 vaccination doses administered in European countries as of February 2, 2021

Source:Statista(https://www.statista.com/statistics/1196091/covid-19-vaccination-doses-in-europe-by-country/)

1.3.3 "Swedish style" measures

While most European countries implemented strict lock-downs and other restrictions to control the pandemic of Covid-19, the Swedish government has chosen a different route. In general, the country has adopted mainly voluntary measures to limit the spread, this could be partly as the government has lacked wide-reaching legal powers to act. It wasn't until January 2021 that the parliament granted the government power to act more forcefully such as restricting the number of people in shops, businesses and public places.

From the onset of the Covid-19 pandemic, the Public Health Agency, Folkhälsomyndigheten (FHM) opted for a herd-immunity approach though they denied this was the strategy of rapid herd immunity, but claimed that they were aiming to slow the virus enough for health services to cope with the situation and to prevent the shortage of medical resources, and they hoped to have fewer cases in the second wave because of the higher level of immunity. Unlike many countries which have imposed strict lock-downs on shops, bars, restaurants and gyms, Sweden allowed these facilities to be open during the pandemic, and not officially recommended people to wear masks apart from in hospitals. No mandatory measures have been taken to avoid the crowds in the public spaces. They also refused to officially recommend wearing masks outside hospitals. It wasn't until November 11, 2020 that face masks were introduced in care homes and health-care facilities in Stockholm. From January 7, 2021, masks were recommended on public transports at certain times [10]. In addition to the lack of sufficient NPIs and directive recommendations, the Covid-19 testing, source identification and reporting were limited and inadequate as well [65]. This gradual approach led to a peak of daily deaths of 115 on the 8th and 15th of April during the first wave, which is relatively high compared to the data of its Nordic neighbor Finland (43 deaths on April 21, 2020) and Norway (16 deaths on April 20, 2020) [77].

However, from the beginning of December 2020 onwards, the Swedish governments gave up its resistance and announced its toughest measures to date, including recommending to use of masks on public transports, closure of secondary schools and many municipal services for a month and restrictions on the entrance to shops, shopping centers and gyms. In addition, the size of gathering in restaurants and bars was set to 4 people, and the serving of alcohol is prohibited after 8 pm. They also introduced a one-month "work-from-home" for workers in non-essential businesses [27].

1.4 Controversy about NPIs

With the increasing number of new daily cases and deaths that seemed uncontrollable at the onset of the pandemic, many European countries took the strategy of implementing NPIs. Although it is found by Yacong, B. et al [5] that the implementation of compulsory masks, quarantine, distance and traffic restrictions has been associated with a reduction in the transmission rate of Covid-19 compared to those without the implementation of corresponding measures, the implementation of such measures has been continuously accompanied by a wide range of criticism. The well-being of people has declined for multiple reasons such as deprivation of social contact, worry over loss of employment and lost income, forced into permanent co-habitation with all other family members, etc. It has made it difficult for students who do not have access to computers or the Internet to study online. Among all these disputes, the biggest controversy is around the national lock-downs. The cost-effectiveness of implementing long-term regional or national lock-downs is uncertain, since it is clear that this measure would have an immense cost to the national economy and would cause other social problems as a consequence. Thus, whether the cost of implementing these NPIs is worth the benefit of reduced infection is a matter that deserves detailed investigation.

2. Literature Review

2.1 Existing cost-related analyses on NPIs against Covid-19

The large number of deaths caused by Covid-19 and the seemingly unstoppable pattern of global spread through most countries at the beginning of 2020 stimulated decision makers to make efforts to reduce fatality. Similar NPIs have been implemented in most high-incidence countries. However, these NPIs have inevitably had some impacts on national productivity and the economy. It is crucial to understand whether these NPIs had positive effects on the control of the epidemic and which interventions were worth the economic and social costs. Not only does it help us to better understand the impact of these decisions, but it also provides insights into the next action to be taken against the subsequent waves of Covid-19, and what could be optimal measures for the government to take against potential similar epidemics in the future.

Cost-effectiveness ratios are widely used in the assessment of NPIs costs. Wang, Q. et al [73] conducted a modelling study to assess the effectiveness and cost-effectiveness of various response public health measures. They applied a stochastic agent-based model to simulate the process of Covid-19 outbreak in two different scenarios, each with a series of NPIs, including self-protection, isolation-and-quarantine, community containment and gathering restrictions. Both scenarios are with 2000 humans simulated as the community. One case or four cases were introduced in two scenarios respectively. They discovered that the isolation-and-quarantine measure is the most cost-effective NPI among all interventions they introduced, as it can avert 1696 and 1990 humans infected respectively at the cost of US$12,428 and US$58,555, in two separate scenarios. However, since their model only simulated a local area with 2000 people, it might be difficult to extrapolate the results of cost-effectiveness to a national level. Furthermore, the model didn't account for the flow of people, which could be a critical factor affecting the effectiveness and cost-effectiveness of NPIs and their associated costs.

Nonetheless, the cost-effectiveness analysis avoids evaluating the economic benefit of the interventions and the cost-effectiveness ratios are based on different metrics, making it difficult to directly observe the net economic benefits or costs and to compare the interventions. To address these weaknesses, the cost-benefit analysis technique was also used.

Dutta, M. et al [16] made a cost-benefit analysis of lockdown in India, estimating the benefit as Covid cases prevented plus net deaths averted, and the cost as unemployment plus loss in production. They generated scenarios with different percentages of growth in income and different proportions of loss in production and found that the net costs of lock-down ranges from 6455.69 to 10038.69 billion Indian Rupee in all scenarios. However, they measured the value of deaths averted by multiplying the number of deaths averted by the amount of money these people might have earned for the next 20 years. The age stratification of Covid-19 deaths was not taken into account. In addition, using future income in 20 years to reflect the value of life is dubious, and the actual net cost results could be less accurate and less reliable.

Thunström, L. et al [68] also performed a cost-benefit analysis to assess the net present value of social distancing in the United States. They included lives saved by social distancing as the benefit and the value of GDP lost due to social distancing as the cost and found that the net benefit of social distancing is about $5.2 trillion when compared to their uncontrolled benchmark. They did, however, implement the value of a statistical life (VSL) to quantify the value of saved lives, but according to the study of Robinson, L. et al [58], the relationship between age and VSL is unclear, and assigning different monetary values to different types of VSL could lead to conflicting conclusions.

Miles, D. et al [43] also adopted a cost-benefit analysis to assess lock-down policies in the face of Covid-19 in the UK. They compared the value of net lives saved and the value GDP loss and created different scenarios of the potential value of GDP loss and possible net lives saved and they discovered that the lock-down from March to June in the UK could result in net costs ranging from GBP 68 billion to 547 billion, depending on their assumed scenarios. However, there are still limitations of this study. For example, as the GDP loss is the combined result of many factors, including Covid-19, lock-down policies, fears of people, etc., using the entire GDP loss to represent the cost of lock-down policies is not scientific.

Though a number of studies regarding the economic costs and social costs of NPIs have been conducted, they use different methodologies such as cost-effectiveness analysis, cost-utility analysis and cost-benefit analysis, applying different metrics, e.g. the value of a statistical life (VSL), the quality-adjusted life year (QALY), and years of life lost (YLL), and focus on different countries including the Unites States, European countries and Asian countries, and based on their own assumptions. Moreover, since the situations of Covid-19 and the measures taken are changing rapidly, the published studies may already be obsolete and therefore limited. As yet, there is no clear consensus to emerge from the existing cost-benefit scenarios. Thus, there is still enough room for later NPIs assessment.

2.2 Analysis of the existing cost-benefit analysis

As stated in section 2.1, cost-benefit analyses are conducted in different countries using different metrics, including VSL, QALY and YLL. Meanwhile, different assumptions were made and the authors also assigned different monetary values to the metrics. For example, in the study of Schonberger R., et al [60], $125,000 is allocated to 1 QALY, while in the study conducted by Miles D., et al, £30,000 is used [43]. All these factors would have an impact on the final result of the net economic costs/benefits and different monetary values of metrics could lead to conflicting conclusions. To testify the influence of different assumptions on the final result, a sensitivity analysis is carried out on the paper investigating the cost and benefit of lock-down in the UK by Miles D., et al [43], the calculation framework of which is most similar to that used in this thesis.

Miles D., et al [43] have found that the 3-month restrictive lock-down from mid-March to late June is not economically effective and should be eased sooner because the economic costs are relatively high compared to the benefits. However, in this calculation, there is uncertainty as to the inputs from the monetary value of QALY to the life expectancy. Controversies also arise with regard to the estimation of the number of net lives saved (lives not lost), given the different models used to predict potential deaths due to Covid-19. In order to understand the effects of such uncertainties on the result of economic value combining costs and benefits, sensitivity analysis is used to determine the factors that influence the outcomes most and to what extent the changes in the inputs would result in the variation of the final value.

The formulas used in the paper are as Equation 1. There are five inputs, namely percentage of GDP loss, net lives saved (or lives not lost), life expectancy (or YLL), quality-adjusted life year (QALY) and a utility factor. They assumed that the percentage loss of GDP could range from 9% to 25%. As there is a high level of uncertainty regarding the net lives saved, which is equal to the potential deaths less the actual Covid-19 deaths, the number of lives not lost is expected to range from 20,000 to 440,000. The authors applied the life expectancy to the actual Covid-19 deaths and calculated an average life expectancy of 10.1 years, which means that saving a life from Covid-19 deaths could have an average net gain of 10.1 years. GBP 30,000 was allocated to the monetary value of QALY. Considering that the Covid-19 deaths are potentially in poor health conditions before they are dead, the authors also introduced a life utility factor in their calculation. The utility factor ranges from 0 (death) to 1 (healthy). Shi, J. et al found that the utility score for patients with breast cancer at stage IV is estimated to be 0.69 (0.65-0.72) and the utility score for individual patients with 6 different cancers ranges from 0.60 to 0.62 [61]. An average utility factor of 0.8 is used in the paper to simulate the health condition of a Covid-19 patient prior to death.

To simplify the calculation, the authors combined life expectancy and the utility factor together and set two scenarios as an average of 5 QALY lost or 10 QALY lost for each Covid-19 death in their calculation. Thus, the total benefit would equal to the net lives saved (lives not lost) multiplied by 5 or 10 QALY in monetary value. Their results suggest that the lowest loss of GBP 68 billion can be achieved if 440,000 lives are saved, 10 QALYs are applied and only 9% GDP is lost. If there are only 20,000 lives are saved, 5 QALYs are applied and there is a 25% GDP loss, an enormous loss of GBP 547 billion can be the result.

$$Net\ Cost = Total\ Cost - Total\ benefit$$

$$Total\ Cost = Percentage\ of\ GDP\ loss * GDP_{2019,UK}$$

$$Total\ benefit = Net\ lives\ saved * Life\ expectancy * QALY * Utility\ factor$$

Equation 1: Cost-benefit calculation model. GDP2019, UK means the GDP value of UK in the year 2019.

In the sensitivity analysis, the simplification is restored and the adjusted-QALY (combining life expectancy and utility factor) is split. Five inputs are examined separately. Figure 37 shows the result of the sensitivity analysis.

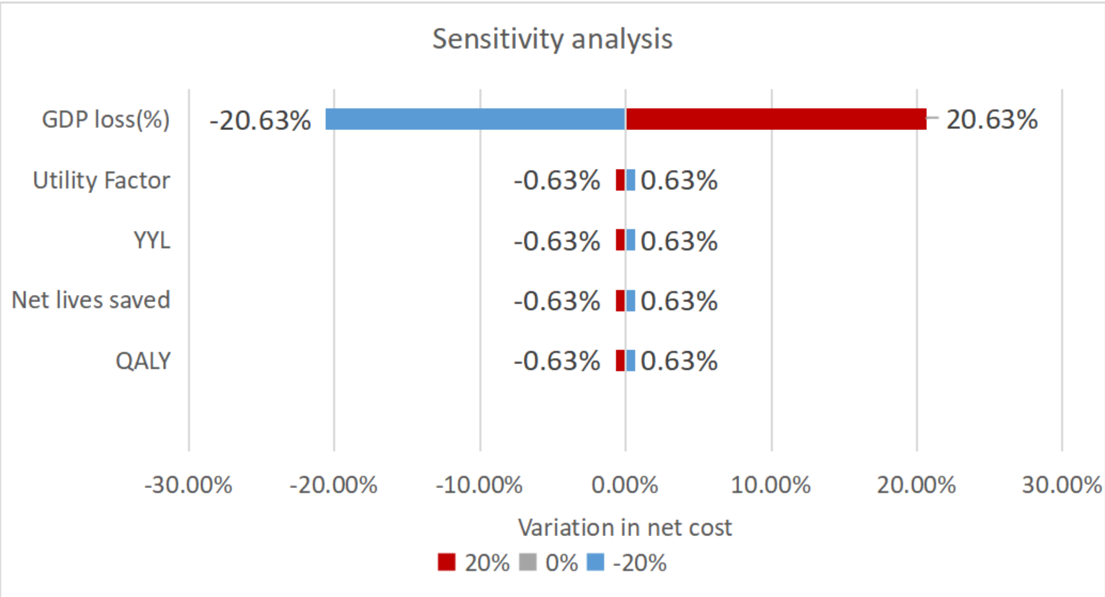

Figure 37: The Tornado diagram presenting the impact on the final net cost.

The tornado diagram reflects the variation in the final net costs if changing a single input while keeping other inputs fixed. The blue bars show the change in the final net cost if decreasing a single input to a 20% degree. For example, if the percentage of GDP loss decreases by 20%, the final net cost would be 20.63% lower. If the monetary value of QALY decreases by 20%, the final net cost would be 0.63% higher. Similarly, the red bars show how final net costs would change if a single variable increases by 20%. If the net lives saved increases by 20%, the final net costs would decrease by 0.63%. According to this sensitivity analysis, the assumption of the value of percentage GDP loss could be the key factor affecting the net economic costs/benefits when compared to other variables.

3. Cost-benefit analysis

Since the outbreak of Covid-19 in early 2020, there has always been controversy about whether it is rational for governments to introduce the NPIs, especially lock-downs, which have had significant impacts on countries, populations and economies. Lock-downs have been linked to social and economic costs, but studies also indicate that they were successful in flattening the infection and mortality curves and in preventing the uncontrolled spread of the disease. As a result, conducting a cost-benefit analysis to compare the costs and benefits of NPIs and determining if they are worthwhile to implement is meaningful.

3.1 Introduction to cost-benefit analysis

Cost-benefit analysis is a systematic and analytic approach often used by economists to identify the strengths and weaknesses of a given strategy and to judge the net social benefit or costs of a given policy or project [14]. It measures the change in well-being to people living within the relevant population - typically in a country. The basic cost-benefit analysis approach entails identifying all of a project's or policy's impacts on social well-being in terms of "costs" and "benefits”, discounting these impacts to the present value using the value of time, and comparing the amount of discounted benefits to the sum of discounted costs to determine if a policy should be adopted or rejected. The principle is shown in Equation 2.

$$Social\ benefit = Present\ value\ of\ benefits - Present\ value\ of\ costs$$

Equation 2: The equation represents the basic cost-benefit analysis method, which takes into account the importance of time [72].

There are two forms of cost-benefit analyses [4]. The first is the “ex-ante” cost-benefit analysis, which is conducted prior to making decisions. It assists in deciding whether a project or strategy should be followed. However, it is worth noting that the result of a cost-benefit analysis is only a recommendation for decision-makers in terms of monetary value; other factors that are not quantifiable or cannot be monetized are also taken into account, and they may lead decision-makers to take a different course of action as suggested by an “ex-ante” cost-benefit analysis. The second is the “ex-post” cost-benefit analysis, which is performed after the project has been completed. It is retrospective and evaluative, aiding decision-makers or governments in being more informed and making better choices in the future in similar circumstances.

As discussed in the previous section about NPIs, a number of high-incidence countries with Covid-19 introduced lock-downs at the beginning of 2020, some of which may be arbitrary without rational and comprehensive thinking in those emergent circumstances. Furthermore, a range of uncertainties about the SARS-CoV-2 obstructs a systematic and reliable analysis. For example, how fierce would the SARS-CoV-2 be and to which range would it spread, or whether the medical system for the specific country could withstand the attack of the pandemic. All of these issues can cause policymakers to become too panicked to make the best decisions. Thus, in this thesis, we conduct an "ex-post" cost-benefit analysis, aiming to assess the benefits and costs of implementing such measures. This cost-benefit analysis might provide some insight into what policymakers can do to make better decisions and pursue better options to avoid such large costs in the event of a potential pandemic.

3.2 Costs

Covid-19 has resulted in a large number of deaths. As of April 4, 2021, there are nearly 2.84 million Covid-deaths worldwide and approximately 127 thousand Covid deaths in the UK. Meanwhile, NPIs have caused a slew of economic and social costs as well. Closure of schools, for example, forces parents to stay home to accompany their children, lowering the productivity of the economy and the country. Furthermore, the school closures could have less influence on students who have access to online remote courses than on students in poor families who do not have access to computers or the internet, potentially increasing the inequality between children from the rich and the poor families. In addition, "stay home" directives largely reduce social contacts for ordinary people, which may lead to an increased rate of mental illnesses and suicides. Aside from these examples, there are numerous costs in various fields such as health, education, society, environment and others.

3.2.1 GDP losses

One of the most significant costs would be the GDP loss. According to the data from The International Monetary Fund (IMF) [38], the real GDP growth of UK in 2020 is around -9.9%. Figures from The Office for National Statistics (ONS) [51] show that the UK GDP in 2019 was GBP 2.17 trillion. Thus, the gross GDP loss in 2020 will be GBP 255 billion, assuming a not realized growth rate of 1.84 percent, which is the geometric mean of GDP growth over the ten years from 2010 to 2019. Equation 3-5 depicts the method of estimating the UK GDP loss in 2020.

$$g_{expected,2020} = \sqrt[10]{\prod_{i=2010}^{i=2019}(1+g_i)} \quad (3)$$

$$GDP_{expected,2020} = GDP_{2019} * \left(1 + g_{expected,2020}\right) \quad (4)$$

$$GDP\ loss_{2020} = GDP_{2020} - GDP_{expected,2020} \quad (5)$$

Equation 3-5: These three equations present how the monetary value of GDP loss of 2020 in the UK is calculated. $g_{expected,2020}$ is the expected GDP growth in 2020, calculated by the geometric mean of g_i. g_i $(i = 2010, 2011, 2012 \ldots 2019)$ is the GDP growth from 2010 to 2019. $GDP_{expected,2020}$ is the monetary value of the expected UK GDP in 2020. $GDP\ loss_{2020}$ is the monetary value of the estimated GDP loss in year 2020. GDP_{2020} is the real GDP value in

2020.
Data source: ONS [51]
(https://www.ons.gov.uk/economy/grossdomesticproductgdp)

However, since the overall GDP loss is a combined effect of the Covid-19 disease and NPIs, to conduct the cost and benefit analysis of NPIs, the economic costs of Covid-19 should be omitted. To assign a rough proportion of the GDP loss to the NPIs, we look at the major industries that contribute to the UK's total output, make assumptions and set different scenarios, and analyze which industries would be more affected by NPIs rather than Covid-19.

The industry sectors of the UK

According to the statistics stated by ONS [50], the main economy of the UK is based on the services industry, comprising many industries including financing, retail, and entertainment, etc., accounting for over three quarters of the UK's GDP, whereas manufacturing and production contribute to around 20% of the total output, and agricultures only contribute about 1%. Figure 38 depicts the GDP composition of the UK in 2018. Figure 39 describes the percentage of different industry sectors of the total UK GDP in 2018.

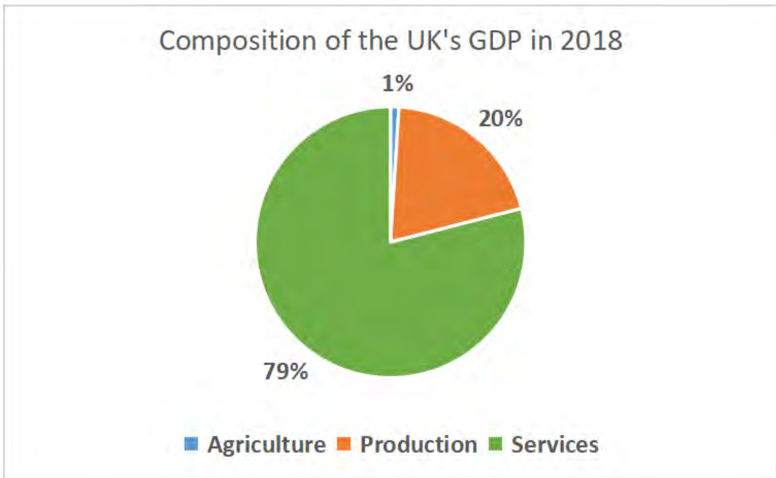

Figure 38: The pie diagram presents the composition of the main industries of the UK contributing to GDP in 2018.
Data source: ONS [50]
(https://www.ons.gov.uk/economy/economicoutputandproductivity/output/articles/fivefactsabouttheukservicesector/2016-09-29)

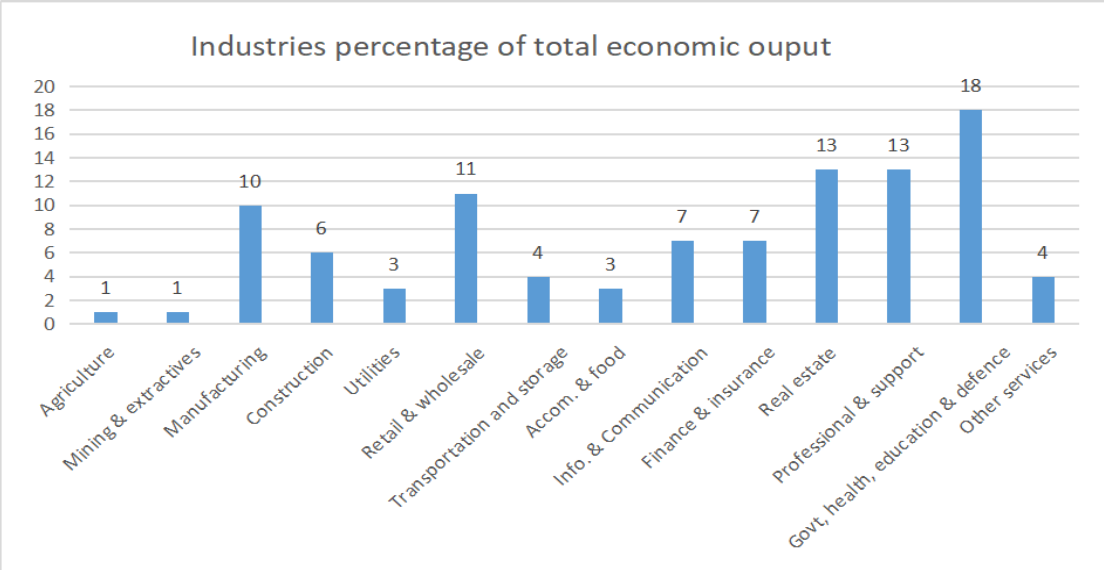

Figure 39: The bar chart illustrates the detailed composition of the UK GDP in 2018. Data source: ONS [51] (https://www.ons.gov.uk/economy/grossdomesticproductgdp)

Transportation and storage, as well as accommodation and food, are the two industries with the greatest impacts caused by NPIs of all industry groups. Based on the UK's Standard Industrial Classification (2007), the accommodation and food section primarily include accommodation and food and beverage services activities, excluding food and beverage retailing [54]. According to the ONS [51], the productivity index for the air transport, accommodation, and food and beverage decreased to 7%, 20% and 35%, respectively, in Q2 compared to Q1 of 2020. The index figures also show that the productivity of accommodation and food & beverage in 2020 Q3 are higher than that in 2020 Q1, which means the loss of productivity in this sector were mainly in Q2, implying that the impact on this industry primarily last during the first lock-down (from mid- March to June). Assuming that different industries contribute to the GDP equally in four quarters, combing the contribution of 3% GDP in total for accommodation and food as Figure 39 suggests, and taking an average of the productivity index 20% and 35%, the contribution to the total GDP loss of these two industries (accommodation and food & beverage) in Q2 would be approximately 0.54% (3%/4*[(1-(20%+35%)/2] = 0.54%).

Unlike the accommodation and food & beverage industries, the strict border restrictions lead to the loss of productivity on the air transportation lasting for the whole year 2020 as the Covid-19 spreads. In the first three quarters, the productivity index for air transportation in 2020 is 81.17, 6.06 and 26.54, respectively (The productivity index of 2018 is 100). Here we assume that the transportation and storage industry remained an average of 25% productivity from 2020 Q2 to Q4 compared to that in Q1, and we also assume that 4% GDP contribution is evenly distributed to four quarters in 2018, the GDP loss would be around 2.25% (4%/4*3*(1-25%)). Thus, the NPIs' impact on industries of transportation & storage, accommodation & food would be around 2.79% (0.54% plus 2.25%) GDP loss in 2020.

We look at other industries that are less affected by NPIs as a whole and create four scenarios for productivity in 2020 Q2, which is primarily the duration of the first lock-down and when GDP began to plummet. We only consider the loss in Q2 as the result of lock-downs since other industries recovered to a substantial level in Q3 and Q4.

Scenario 1: we assume that the productivity of other industries in Q2 is 100% compared to the productivity before the lock-downs.

We made this hypothesis based on the fact that though the lock-downs restricted partial businesses, some industries thrived including e-commerce, pet-related business, online entertainment, etc. Meanwhile, the lock-down also effectively relieved some of the burdens on the health-care sector. It is possible among all the less affected industries, the downturn in some sectors is compensated by a rise in others, which results in no productivity loss in 2020 Q2. In this situation, the cumulative GDP losses attributed to NPIs would be around 2.79%.

Scenario 2: we assume that the productivity of other industries in Q2 is 95% compared to the productivity before the lock-downs.

Under this assumption, the NPIs impact on the other industries (except for transportation & storage, accommodation & food) would be about 1.16% ((1-3%-4%)/4*(1-95%) =1.16%). Then, the total GDP loss caused by the NPIs would be around 3.95% (2.79%+1.16%).

Scenario 3: we assume the productivity of other industries in Q2 is 90% compared to the productivity before the lock-downs.

In this case, the NPIs impact on the other industries (except for transportation & storage, accommodation & food) would be around 2.33% ((1-3%-4%)/4*(1-90%) =2.33%). Then, the total GDP loss due to NPIs would be around 5.12% (2.79%+2.33%).

Scenario 4: we assume the productivity of other industries in Q2 is 70% compared to the productivity before the lock-downs.
In this scenario, the NPIs impact on the other industries (except for transportation & storage, accommodation & food) would be around 6.98% ((1-3%-4%)/4*(1-70%) = 6. 98%). Under this scenario, the total GDP loss because of NPIs would be around 9.77% (2.79%+6.98%).

The total GDP loss in percentage is shown in Table 1.

		Productivity after lockdowns/ Productivity before lockdowns in Q2 (%)	Total GDP loss in industry sectors(%)	Total GDP loss (%)
Transportation & Storage		N/A	2.25	
Accom. & food			0.54	
Other industries	Scenario 1	100%	0	2.79
	Scenario 2	95%	1.16	3.95
	Scenario 3	90%	2.33	5.12
	Scenario 4	70%	6.98	9.77

Table 1: This table presents the approximate GDP loss due to NPIs in various industries under different assumed scenarios and the total GDP loss of the UK caused by NPIs in year 2020.

Combing the fact that the total GDP loss for the UK in 2020 is 9.9%, the GDP loss caused by Covid-19 itself under 4 scenarios are respectively: 7.11%, 5.95%, 4.78% and 0.13%. The GDP loss of Covid-19 itself under scenario 3 is comparable to Sweden's GDP loss in 2020 of 4.7% [37], nearly without any NPIs until the end of 2020. And the GDP loss of Covid-19 itself under scenario 4 is comparable to the world GDP loss of The Hong Kong flu in 1968-69 without NPIs [3]. The Hong Kong flu [20] was a global flu pandemic that began in Hong Kong in 1968 and spread worldwide in 1969. It killed between one and four million people worldwide, according to WHO estimates, when the world's population was 3.53 billion [13].

Using the GBP 255 billion calculated before, the GDP loss in monetary value caused by NPIs (excluding the impact of Covid-19) under four scenarios would be GBP 72, 102, 132 and 252 billion, respectively 28%, 40%, 52%, 99% of the actual GDP loss of GBP 255 billion. Based on these assumptions and calculations, the GDP loss caused by NPIs is estimated to be around GBP 70 to 250 billion.

3.2.2 School closure costs

Apart from the large impacts on national productivity and GDP, NPIs' impact on national the education system is significant as well. On March 23, 2020, there was a nationwide shutdown for schools in the UK [21]. Schools were closed except for children from key worker families, resulting in a substantial decrease in school attendance from late March to June. Except for the loss of the productivity for the education system which would lead to GDP loss, the missing education for children could affect their final educational attainment and increase the possibilities for them to become unemployed and poor, and eventually, resulting in a loss of life years in long-term for them as well as the country.

We use a three-stage estimation to measure the economic costs of school closures. In the first stage, we look at the missing school days. On March 3, 2020, schools in England, Wales, Scotland and Northern Ireland began to close as requested by the governments, with the exception of children who are from key workers families. From mid-June, secondary schools in England gradually reopened for specific year groups with conditions and secondary students returned in full at the start of the new academic year in September. Meanwhile, schools in Wales reopened on June 29, Scottish schools reopened between August 11 to 18, while schools in Northern Ireland reopened for "key cohorts" in August and other students in September [21]. Assuming that schools closed for an average of 5 months (150 days), the real missing school days, excluding the weekends, would be around 107 days, which is comparable to the results of the survey conducted by The National Foundation for Education Research (NFER) about "The challenges facing schools and pupils in September 2020" [45]. In the survey, the authors asked around 1500 teachers a series of questions about the curriculum learning and found that pupils were falling behind by 2.9 months on average compared to normal expectations in July 2020, with over 70% of teachers stating students were falling 2 to 4 months behind, as shown in Figure 40. The following factors might be able to explain the difference from 107 days and 2.9 months (87 days): (1) The estimation for an average of 5 months' school closures is not accurate due to the variance in schools reopening plans. (2) The estimation of 107 days doesn't take into account the productivity of home learning, which could be the substitution of schooling and result in less falling behind compared to the normal expected progress. (3) The survey was conducted in July 2020, when schooling wasn't compulsory and some parents chose to keep their children staying home due to concerns with the health issue. If the schooling attendance rate rises, and if the survey was conducted later than in July, the 2.9-months span of falling behind may be extended. Figure 40 illustrates the distribution of the time falling behind given by teachers' response.

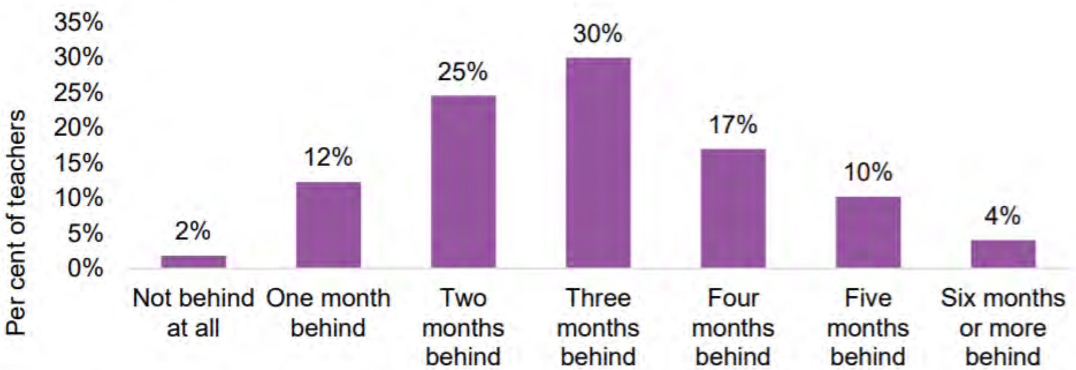

Figure 40：This chart presents the pupils' curriculum learning compared to normal expectations in July 2020. The result is from the NFER survey of 1782 classroom teachers and 1489 teachers gave at least one response.

Source: NEFR survey about 'The challenges facing schools and pupils in September 2020"[45] (https://www.nfer.ac.uk/media/4119/schools_responses_to_covid_19_the_challenges_facing_schools_and_pupils_in_september_2020.pdf)

In the second stage, we link the missing school days to the reduction of final education achievements. David Jaume and Alexander Willen [39] conducted a survey that provides a reasonable estimate of the association between missed education during primary schools and total years of educational attainment. The study is based on a carefully constructed econometric model that explores the quasi-random school closures triggered by teachers' strikes in Argentina. The findings of the analysis indicate that the 10 days of missed school is associated with the reduction in the number of years of education of 0.0262 (SE, 0.0064) years for boys and 0.0217 (SE, 0,0062) years for girls, with significance at 1%. Based on the data given by the UK government [24], as of January 2019, there are 4.52 million boys and 4.33 million girls in primary and secondary schools or in alternative provisions. Using the estimation of 107 missed school days on average, we can calculate that the total reduction of years of education for boys and girls in the UK would be approximately 1.27 million years (4.52*107/10*0.0262=1.27) and 1.01 million years (4.33*107/10*0.0217=1.01), respectively.

At the final stage, the decline of years of education is connected to the loss of life years (YLL). According to the findings of Lleras-Muney, A.'s research [41], an additional year of education increased life expectancy at age 35 by as much as 1.7 years. Based on this result, the cumulative loss of life years for both genders will be about 3.876 million years ((1.27+1.01) *1.7=3.876). As described in the sensitivity analysis section 2.2, if a QALY of GBP 30,000 as stated by The National Institute for Health and Care Excellence (NICE) is used [46], the overall monetary cost of school closures on reduced life expectancy for the country would be around GBP 116 billion. However, this number is undiscounted. Assuming that the average age of pupils is 10 and considering the life expectancy of UK is 81.26 years stated by the ONS [52], a discounted period of around 70 years should be considered in this calculation. If 0.5% is used as the annual discount rate, the monetary value of YLL for the country would be roughly GBP 82 billion (116/ $(1+0.5\%)^{70}$=82). If 3% is used as the annual discount rate, the monetary value would be approximately GBP 15 billion (116.28/ $(1+3\%)^{70}$=15). If 5% is used as the annual discount rate, the monetary value would be approximately GBP 4 billion (116/ $(1+5\%)^{70}$=4). Thus, the present value of school closure costs may range approximately from GBP 4 to 80 billion.

This estimation does, however, have some limitations. First, the estimation of 107 days on average of school closures is not very accurate, given the wide range of reopening plans for schools in the UK. It also ignores the children from key workers' families who continued to attend schools throughout the school closure period. Second, the estimation of 107 days, though comparable to the average of 2.9 months falling behind from the survey by NFER [45], excludes the effect of home learning efficiency, which could have a substitution effect on schools. Third, the 1.7-year rise in life expectancy is a general figure for people aged 35; it does not take into account the various increases in life years for people of different ages. Last but not least, the estimate also ignores the fact that the British government has set aside GBP 3.4 billion in total as a "catch up" fund [30], which will be used in the near future to make up for the falling behind period. However, this "catch up" fund could come from government tax revenue, potentially jeopardizing social welfares for other groups of people.

3.3 Benefits

Despite the fact that NPIs have a range of drawbacks, they do have some advantages. Lock-downs, for example, may reduce traffic accidents, resulting in fewer traffic injuries and deaths. Furthermore, lower national productivities can reduce various types of pollutions, such as air pollution, light pollution, water pollution, and so on. It is also worth noting that during the lock-downs, certain types of businesses also prosper, such as e-commerce businesses, like Amazon, online entertainment including online games and videos, vendors of net-based communications like Zoom and MS Teams, and pet-related industry, etc.

3.3.1 Net lives saved from NPIs

Of all the advantages of NPIs, the largest one, which is also the main purpose of enforcing such policies, is the net lives saved from Covid-19. To roughly determine how many lives are saved, we use Equation 6.

$$Net\ lives\ saved = Estimated\ potential\ deaths - Actual\ Covid\ deaths$$

Equation 6: This equation presents the main theory of how the net lives saved from NPIs are estimated in this section.

The estimate is divided into two stages. In the first stage, we look at models that forecast the potential Covid-19 deaths in the UK. One of the widely used model to estimate the potential death at the beginning of the pandemic is the Ferguson, N. et al's research [63], which indicates that if nothing was done, the total potential deaths over the whole pandemic course would be between 410,000 to 550,000, with the reproduction rate (R_0) ranging from 2.0 to 2.6. This estimation is based on the hypothesis that if nothing was done, over 81% of people in the UK may have become infected over the whole course of the epidemic.

This prediction could be overestimated based on what occurred in the UK in 2020 for the following reasons. First, according to the current statistics as of March 10, 2021, there are 4,228,998 cases of Covid-19 in the UK [77] that have been confirmed by a test, accounting for 6% of the total population in the UK, which is significantly lower than the estimated figure of over 81%. The number of Covid-19 cases in Sweden as of the same day is 695,975 [77], accounting for nearly 7% of Sweden's total population. Given that the Swedish government didn't implement strict lock-down orders during the first wave, we can suppose that even there were no NPIs in the UK during the first wave, the infection rate might be higher than the current rate of 6%, but not be as high as over 81%. Another reason is that Ferguson's research is based on the scenarios of R_0 ranging from 2.0 to 2.6. According to the data provided by the Department of Health and Social Care (DHSC) and Scientific Advisory Group for Emergencies (SAGE) [33], even during the fierce second wave that could lead to a more serious situation than in the first wave, the reproduction rate (R_0) has never been above 1.8, as shown in Figure 41. As this is under the scenario of NPIs including lock-downs, we also take the R_0 figure of Sweden, which nearly took no NPIs in 2020. According to the data provided by the Public Health Agency of Sweden [25], Sweden's R number reached a peak in March 2020 with 1.69, then dropped for a while before stabilizing around 1.0 between early April to mid-June, 2020. Therefore, the estimation of R_0 to be between 2.0 to 2.6 may be overestimated. Even if the R_0 reaches 2.0 without NPIs, it will not last long, and the government will take measures to regulate it, as the Swedish government did during the second wave. As a result, the number of possible deaths will be lower than predicted by Ferguson's model [63]. Another explanation that this model could be overestimated is that it is unlikely that nothing would have been done to counteract Covid-19. Even if there were no NPIs implemented and suppression strategy is not adopted, people would take individual precautions to protect themselves. As a result of these factors, the model of Ferguson, N. et al [63] might overestimate the infection rate and the potential deaths. Given that there could be overestimation in Ferguson's model [63] and lack of accurate and reliable estimations, we use Neil Ferguson's model, but narrow down the potential deaths to 200,000 to 400,000, setting three scenarios of potential deaths without NPIs to be 200,000, 300,000, 400,000, and analyze the net lives saved under these different scenarios.

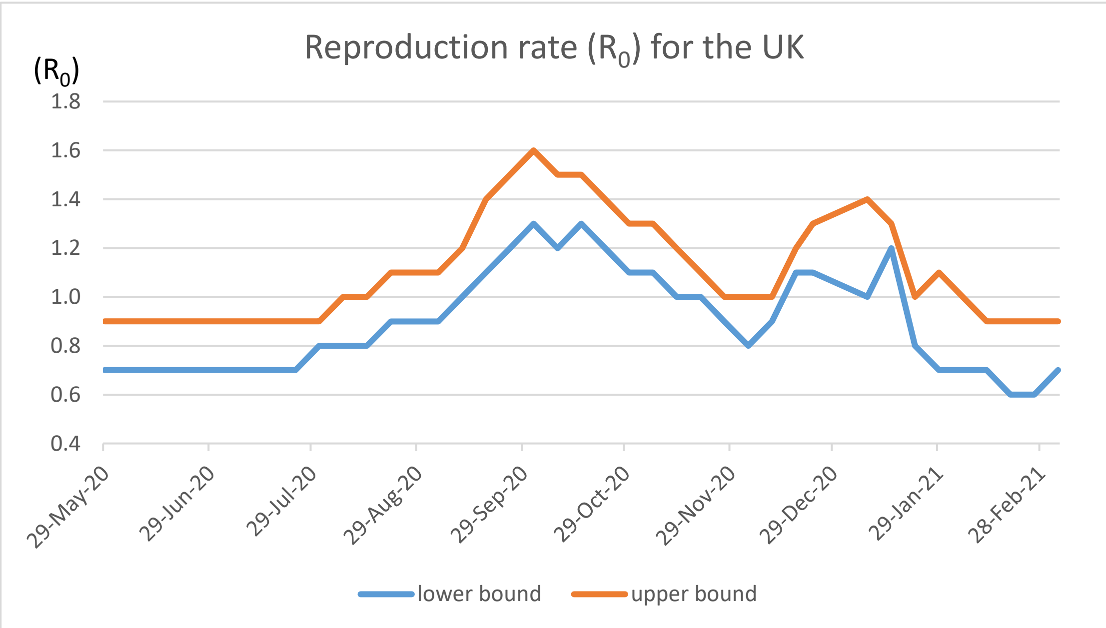

Figure 41: This chart depicts the lower and upper bound of the reproduction rate (R_0) since May 29, 2020 for the UK [33]. (https://www.gov.uk/guidance/the-r-number-in-the-uk)

In the second stage, we estimate the real Covid-19 deaths in the UK. To assess the real Covid-19 deaths, the concept of excess deaths needs to be introduced first. Excess deaths are typically defined as the disparity between the observed numbers of deaths and the expected numbers of deaths in particular time periods. For example, as shown in Figure 42, the total weekly deaths minus the Covid-19 deaths are higher than the expected weekly deaths from week 13 to week 20. This difference could be due to a variety of reasons such as change of reporting policies, lags in reporting time and the government's deliberate underreporting, etc. Therefore, examining the excess deaths would be useful in determining the true number of deaths that might differ from the reported number. To identify the excess deaths, three methodologies are used to calculate three different ratios, namely R_1, R_2, and R_3 for selected European countries. The definition of variables R_1, R_2, and R_3 will be described below. Weekly deaths figures for other countries and regions can be found in the Appendix.

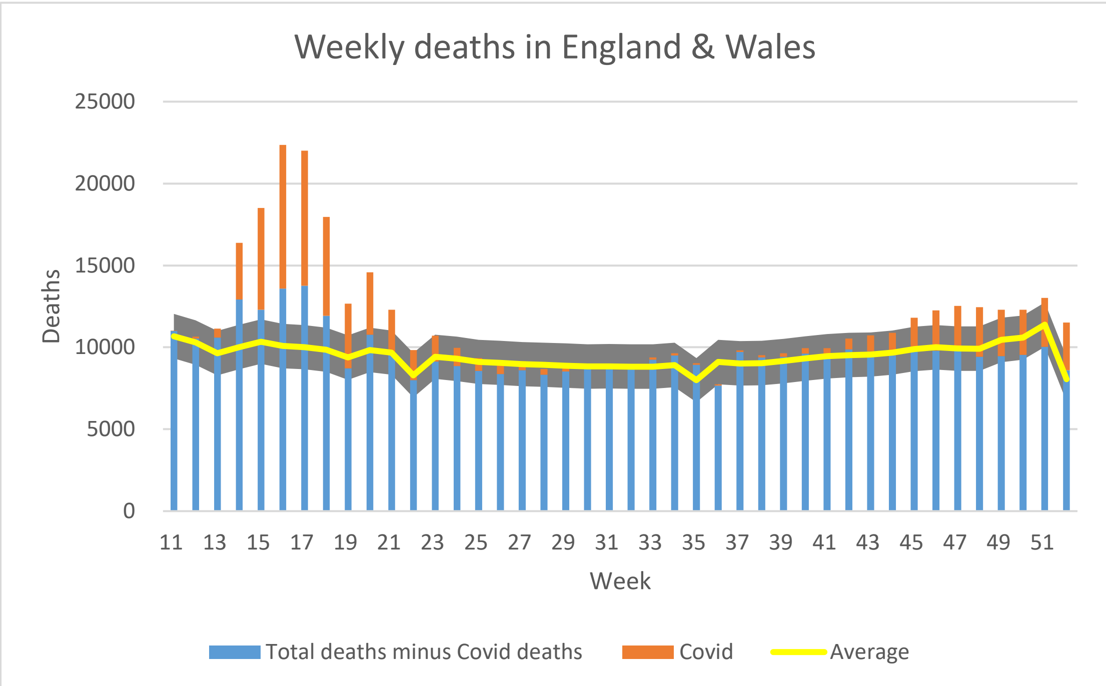

Figure 42: This graph represents the Covid-19 deaths and the weekly total deaths from week 11 to week 52 in England and Wales. The orange bars are weekly Covid-19 deaths, and the blue bars are weekly total deaths minus the weekly Covid-19 deaths. The yellow line is the 10 years' weekly average deaths which are calculated to represent the expected weekly deaths in 2020 without the pandemic. The grey band is the range that the expected death could be within, which also shows the upper and lower bound for expected weekly deaths.

Source: Data from ONS [48]

(https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/weeklyprovisionalfiguresondeathsregisteredinenglandandwales)

In general, R_1 measures the ratio of total Covid-19 deaths to the total weekly deaths minus the expected weekly deaths, which is represented by the 10 years' historical averaged. The basic steps for calculation are as followings. First, the 10 years average of the weekly deaths from year 2010 to year 2019 is calculated to be used as the expected death in 2020 without the pandemic. Then, the data of weekly Covid-19 deaths and the weekly total deaths are collected from the official data given by ONS [48]. The data are collected from the first week with Covid-19 deaths registration to the last week (week 53) in 2020. After that, the ratio (R_1) is the total Covid-19 deaths for the entire period divided by the total deaths in these weeks minus the sum of 10 years weekly average from 2010 to 2019 in the corresponding weeks, which is shown as Equation 7.

$$R_1 = \frac{\sum_{week_i}^{week_{53}} Weekly\ Covid\ deaths}{\sum_{week_i}^{week_{53}} (Weekly\ total\ deaths - 10\ years'average\ of\ weekly\ deaths)}$$

Equation 7: Equation 7 illustrates how the excess deaths ratio (R_1) is calculated. $Week_i$ is the first week in 2020 with Covid-19 deaths' registration. Week 53 is the last week of year 2020. Since not all years have 53 weeks, the 10 years' average of week 53 is represented by the weekly death of the 53rd week in 2015 instead.

Different from R_1, R_2 compares the Covid-19 deaths to the weekly total deaths over the upper bound of the expected weekly deaths (95% Confidence Interval). The following is the description of how R_2 is calculated. First, the 10 years average of the weekly deaths from year 2010 to year 2019 is calculated. Then, the 95% confidence interval is calculated of the historical average, and the lower bound and the upper bound is set according to the 95% confidence interval. Afterwards, the weekly total deaths are compared to the upper bound, and the weeks of which the weekly total deaths are higher than the upper bound are selected. For the selected weeks, the ratio (R_2) is calculated by using the sum of Covid-19 deaths in selected weeks divided by the sum of weekly deaths above the upper bound, which is illustrated by Equation 8.

$$R_2 = \frac{\sum Weekly\ Covid\ deaths_j}{\sum (Weekly\ total\ deaths_j - Upper\ bound\ of\ expected\ weekly\ deaths_j)}$$

Equation 8: Equation 8 illustrates how the excess deaths ratio (R2) is calculated. $Week_j$ represents the weeks when the weekly total deaths are larger than the upper bound of the expected weekly deaths calculated by 10 years' average.

Similar to R_2, R_3 compares the Covid-19 deaths to the weekly total deaths over the expected weekly deaths. The 10 years average of the weekly deaths from year 2010 to year 2019 is calculated first as the expected weekly deaths in 2020 without the pandemic. Then, weeks are picked if the weeks total weekly deaths are higher than the historical average. For the selected weeks, the excess deaths ratio (R_3) is calculated by using the sum of the Covid-19 deaths in selected weeks divided by the sum of weekly deaths above the historical average, illustrated by Equation 9.

$$R3 = \frac{\sum Weekly\ Covid\ deaths_k}{\sum (Weekly\ total\ deaths_k - 10\ years'averge\ of\ weekly\ deaths_k)}$$

Equation 9: Equation 9 illustrates how the excess deaths ratio (R3) is calculated. $Week_k$ represents the weeks when the weekly total deaths are larger than the expected weekly deaths calculated by 10 years' average.

To verify the calculations in this thesis, the results of R_1 for specific European countries are compared to the ratio and excess deaths calculated in Kontis, V. et al's research [40], which is shown in Table 2. To make it more comparable, R_1 is calculated using the data from Feb 10 to May 31, 2020. To make a more visual comparison, a scatter plot is made as Figure 43, ratios for Czechia and Denmark are excluded.

	Ratio calculated in Kontis V. et al's research			Ratio calculated in this thesis		
Time	Mid-Feb ~ End of May			Week 7-22 (Feb 10~May 31)		
	Both sex number of excess deaths	Assigned to Covid-19	ratio	Excess deaths over historical average	Covid-19 deaths	R1
Belgium	8600(6700~10400)	9487	1.10	8447	9358	1.11
Czechia	-510(-2880~1300)	319	-0.63	487	317	0.65
Denmark	530(-270~1300)	571	1.08	94	574	6.11
Finland	470(-360~1100)	316	0.67	952	318	0.33
France	23700(14900~32300)	28771	1.21	28949	28777	0.99
Italy	48700(38100~58900)	33340	0.68	47983	33508	0.70
Netherlands	8600(6100~10800)	5951	0.69	10877	5956	0.55
Portugal	2900(1000~4700)	1396	0.48	3040	1410	0.46
Spain	45800(39900~51700)	27127	0.59	49634	29050	0.59
Sweden	5500(4400~6500)	4395	0.80	4242	4629	1.09
Switzerland	1400(350~2300)	1656	1.18	1826	1831	1.00
E&W	57300(48900~65000)	47104	0.82	61186	45516	0.74
Scotland	4600(3700~5500)	3914	0.85	5171	3914	0.76

Table 2: This table compares the total excess deaths, the Covid-19 deaths, and the ratio of excess deaths in the Kontis, V.et al's research [40] and in this thesis by using the methodology for R_1. The number in the parentheses represents the range of excess deaths calculated using the author's methodology.

Data source: Eurostat and national official report [1,48].

(https://appsso.eurostat.ec.europa.eu/nui/show.do?query=BOOKMARK_DS-1166948_QID_-65C2C7D1_UID_-3F171EB0&layout=TIME,C,X,0;GEO,L,Y,0;UNIT,L,Z,0;SEX,L,Z,1;AGE,L,Z,2;INDICATORS,C,Z,3;&zSelection=DS-1166948INDICATORS,OBS_FLAG;DS-1166948SEX,T;DS-1166948UNIT,NR;DS-1166948AGE,TOTAL;&rankName1=TIME_1_0_0_0&rankName2=UNIT_1_2_-1_2&rankName3=GEO_1_2_0_1&rankName4=AGE_1_2_-1_2&rankName5=INDICATORS_1_2_-1_2&rankName6=SEX_1_2_-1_2&sortC=ASC_-1_FIRST&rStp=&cStp=&rDCh=&cDCh=&rDM=true&cDM=true&footnes=false&empty=false&wai=false&time_mode=ROLLING&time_most_recent=false&lang=EN&cfo=%23%23%23%2C%23%23%23.%23%23%2

https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/weeklyprovisionalfiguresondeathsregisteredinenglandandwales)

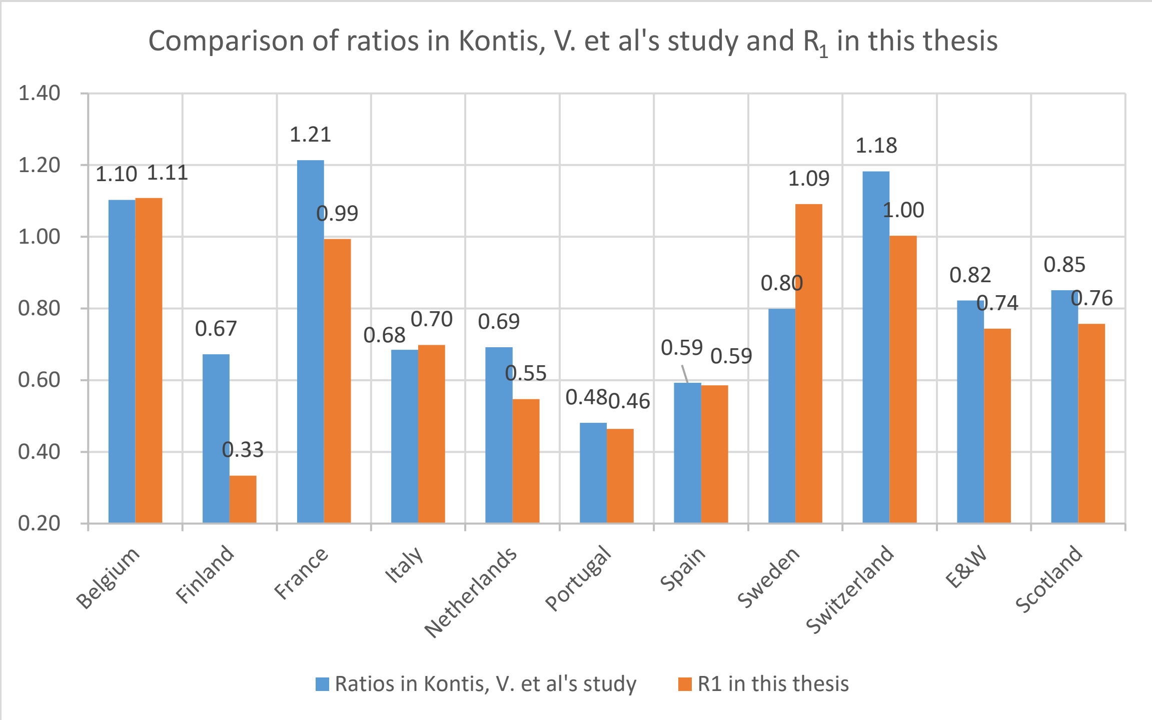

Figure 43: This scatter plot presents the comparison of ratios in Kontis, V. et al's study [40] and R1 in this thesis based on figures from Table 2.

Comparing these results, we come up with four main findings: (1) All excess deaths calculated in this thesis are within the range given in the research by Kontis, V. et al [40], implying that the results calculated in this thesis using R_1 are consistent with earlier papers. (2) For countries including Denmark, and less so for Czechia and Finland, the excess deaths and the ratios are not quite comparable, but for other countries, the excess deaths, Covid-19 deaths, and the excess deaths ratios are more or less similar. It is unclear why for Czechia, Denmark and Finland, the results in this thesis vary significantly from the result of Kontis, V. et al's research [40], one possible explanation is that for these countries, the weekly deaths are relatively low. As a consequence, a minor variation in the methods used of how data are collected and processed may result in an amplification of uncertainties producing a large difference in the final results. (3) Countries such as Belgium, Denmark, France and Switzerland may have less probability of underreporting than other countries. Since the ratios in either Kontis, V. et al's study [40] or this thesis are larger than 1.00, or very close to 1.00, indicating that the reported number of Covid-19 deaths are very close to or higher than the excess deaths. Therefore, the probability of under-reporting in these four countries is relatively low. (4) The ratios for England & Wales and Scotland are quite close. Considering these three nations represent the majority of the population of the UK, the ratio of England & Wales alone might explain the underreporting level in the UK.

We repeated the calculation of the excess deaths ratios as the Covid-19 epidemic continued to spread and the situation changed rapidly. The outcomes of the two different periods can also give insights into how the under-reporting levels change over time for different countries or nations. The first update of ratios was accomplished in mid-October, with the latest data updated to week 35 to 44. The second update was conducted at the beginning of 2021, when the whole year data of 2020 had been published. The data source for England & Wales and Scotland is The Office for National Statistics (ONS) [48] and National Records of Scotland (NRS) [47]. Data for other countries are collected from Eurostat [1]. The three ratios are calculated using the methods described previously. The three excess deaths ratios for the first and second update are shown as in Table 3.

	1st Update (~ Mid-October)			2nd Update (~ the end of 2020)		
	R1	R2	R3	R1	R2	R3
Austria	0.30	1.51	0.28	0.61	1.06	0.60
Belgium	1.00	1.15	0.89	1.01	1.25	0.94
Czechia	0.25	1.42	0.21	0.62	0.88	0.60
Denmark	0.63	3.51	0.51	0.64	2.29	0.56
Finland	0.21	1.14	0.18	0.22	0.90	0.18
France	0.78	1.13	0.76	0.83	1.35	0.82
Germany	0.50	1.18	0.43	0.59	1.28	0.57
Netherlands	0.45	0.65	0.45	0.49	0.77	0.49
Portugal	0.24	0.65	0.24	0.45	1.21	0.45
Spain	0.50	0.74	0.49	0.55	0.84	0.55
Sweden	1.56	1.35	1.00	1.42	1.57	1.13
E&W	0.79	0.98	0.76	0.88	1.24	0.84
Scotland	0.76	1.06	0.73	0.86	1.31	0.83

Table 3: This table presents the three ratios of R_1, R_2, R_3 calculated in mid-October and in the beginning of 2021. The results are based on the data collected from ONS, NRS, Eurostat [48,47,1].

To make Table 3 more visual, scatter plots of R_1, R_2 and R_3 between two updates are made as in Figure 44 - 46.

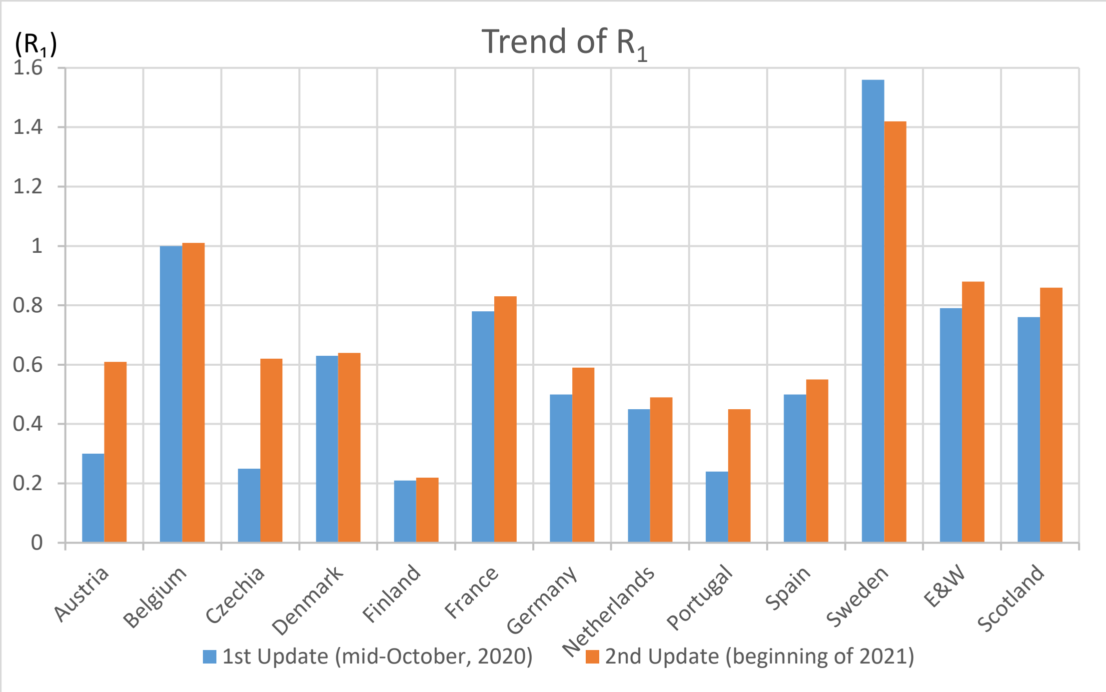

Figure 44: This graph presents the trend of R_1 between two updates. Data from Table 3.

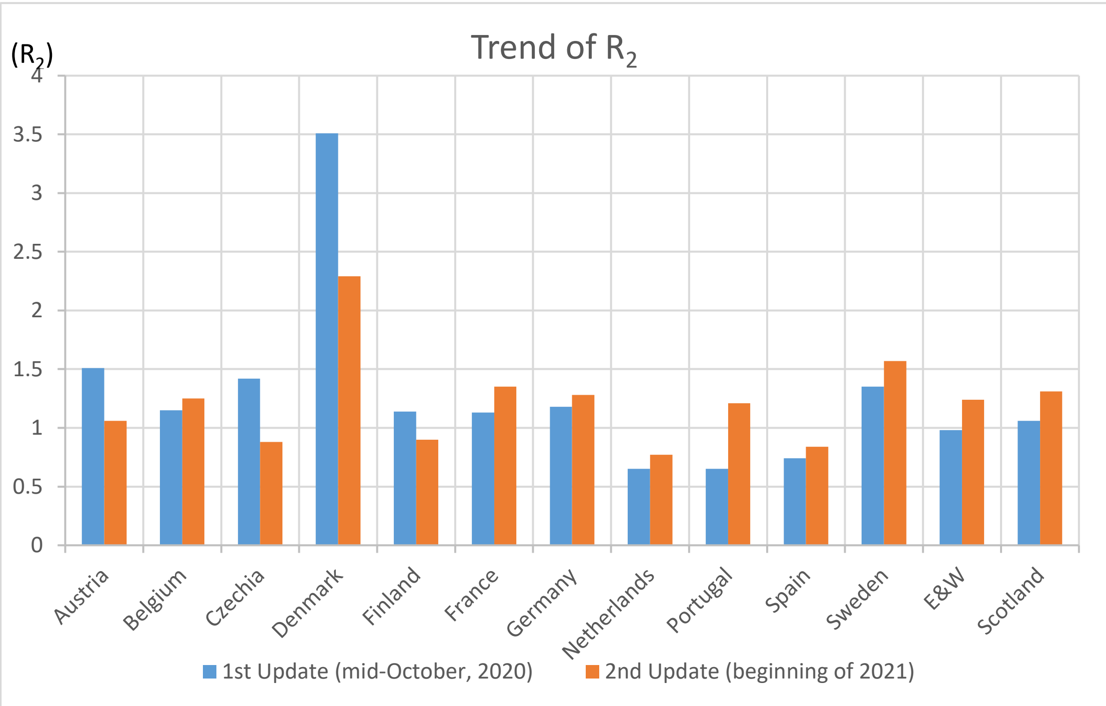

Figure 45: This graph presents the trend of R_2 between two updates. Data from Table 3.

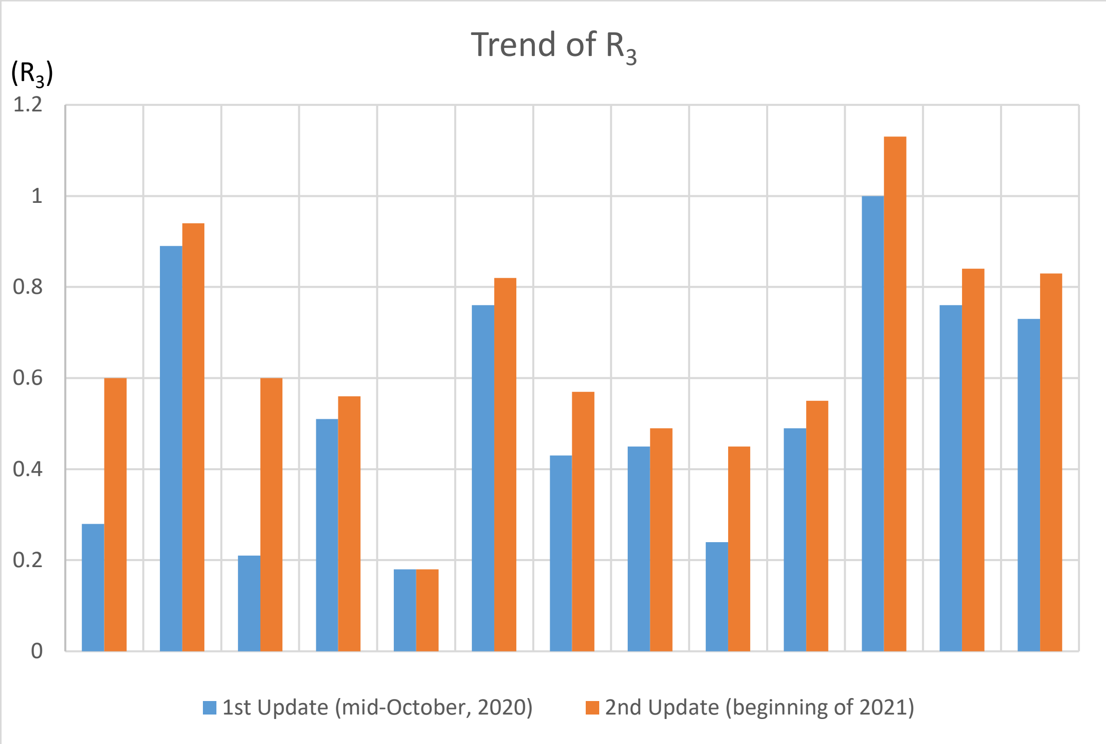

Figure 46: This graph presents the trend of R_3 between two updates. Data from Table 3.

Comparing the three ratios in the two updates, we can see that the changes of R_2 and R_3 are relatively greater than the change of R_1 over time. This is partly due to the fact that R_2 and R_3 only look at the data in weeks total deaths are above the upper bound or above the historical average, while R_1 measures the data of all weeks from the week with first Covid-19 deaths registration to the week 53, which makes it more comprehensive than the R_2 and R_3. Thus, in this thesis, the R_1 is chosen to represent the underreporting ratio of Covid-19 deaths.

From Table 3, we can see that the R_1 for England &Wales (E&W) and for Scotland rises over time, which means the gap between total Covid-19 deaths and the sum of total weekly deaths minus the sum of weekly expected deaths decreases and the under-reporting level narrows. This might be explained by a shift in reporting policy that at the beginning of the outbreak, the UK reported a Covid-19 death as it is within 28 days of a positive test. Later on, the reporting policy is modified to report a Covid-19 death if it is mentioned on the death certificate [31]. Another possible reason could be the increasing testing capacity of Covid-19. Based on this, we assume that until the end of 2020, the under-reporting level is ranging from 0.86 (the smaller of R_1 for E&W and Scotland) to 1.00, meaning that the result of the reported Covid-19 deaths divided by the "real" Covid-19 deaths ranges from 0.86 to 1. As the total Covid-19 deaths for the UK ending in December 2020 is 73,609 [77], we compute that the real Covid-19 deaths in the UK may range from 73,000 ($R_1 = 1.00$) to 86,000 ($R_1 = 0.86$) at that time.

Combining the results of the first stage and the second stage, we can get that the number of net lives saved ranges from 114,000 (Potential deaths =200,000, R_1=0.86) to 327,000 (Potential deaths =400,000, R1=1.00), as shown in Table 4.

		Potential deaths		
		200,000	300,000	400,000
R_1	0.86	114,000	214,000	314,000
	1.00	127,000	227,000	327,000

Table 4: This table presents the net lives saved under different assumptions. Net lives saved are defined as estimated potential deaths without NPIs minus actual Covid-19 deaths in Equation 5. For example, if the number of potential deaths without NPIs is assumed to be 200,000 and the R_1 is assumed to be 0.86, which means the number of real Covid-19 deaths is 86,000 until the end of 2020, the net lives saved by NPIs would be 114,000. The real Covid-19 deaths 86,000 is calculated when under-reporting ratio R_1 is 0.86.

After estimating the net lives saved, the life expectancy of the Covid-19 deaths is estimated too. To investigate the life expectancy of those Covid-19 deaths, we look at the age structure of Covid-19 deaths, multiplying the number of Covid-19 deaths at each age group with the average period expectation of life, and dividing it by the total number of Covid-19 deaths to get the average life expectancy of the Covid-19 deaths, which works out at 10.0 years. The age structure of Covid-19 deaths and their average period expectation of life is shown in Table 5.

	Male		Female	
Age group	Number of Covid-19 deaths (until Dec 25, 2020)	Average period expectation of life (years)	Number of Covid-19 deaths (until Dec 25, 2020)	Average period expectation of life (years)
<1	2	79.37	0	83.06
1-4	0	77.23	1	80.87
5-9	0	72.76	1	76.41
10-14	4	67.79	1	71.43
15-19	6	62.84	5	66.46
20-24	19	57.97	15	61.53
25-29	40	53.12	24	56.60
30-34	65	48.30	48	51.69
35-39	108	43.53	82	46.82
40-44	218	38.83	139	42.01
45-49	414	34.22	260	37.27
50-54	778	29.72	457	32.62
55-59	1385	25.35	720	28.07
60-64	2056	21.16	1070	23.68
65-69	2880	17.23	1532	19.47

70-74	4707	13.56	2625	15.46
75-79	6580	10.25	4079	11.78
80-84	8576	7.42	6237	8.56
85-89	8268	5.16	7574	5.92
90+	6860	2.89	9850	3.24

Table 5: This table presents the age structure of Covid-19 deaths and the average life expectancy for different age groups in England & Wales. The age structure of Covid-19 deaths is collected from The Demography of Covid-19 Deaths and the average life expectancy is given by the ONS [52].

Sources: ONS [52]
(https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/datasets/nationallifetablesunitedkingdomreferencetables)

Then, the monetary value of the net lives saved can be calculated by the multiplying net lives saved, the average life expectancy of Covid-19 deaths and the QALY, shown as in Equation 10. Applying the GBP 20,000 to 30,000 of QALY suggested by NICE [46], the result is shown as in Table 6. We can estimate that the benefit of NPIs in net lives saved is from GBP 23 billion to GBP 98 billion.

$$Monetary\ value\ of\ net\ lives\ saved = Net\ lives\ saved * Average\ life\ expectancy\ * QALY$$

Equation 10: This equation illustrates how the net lives saved by the NPIs are converted to monetary value.

GBP billion		QALY=20,000			QALY=30,000		
		Potential deaths			Potential deaths		
		200,000	300,000	400,000	200,000	300,000	400,000
R1	0.86	23	43	63	34	64	94
	1.00	25	45	65	38	68	98

Table 6: This table shows the monetary value of net lives saved when the potential deaths without the NPIs range from 200,000 to 400,000, the QALY monetary value equals GBP 20000 and 30000, and the excess deaths ratio is 0.86 and 1.00.

3.3.2 Reduction of deaths from other causes

Lock-downs may reduce deaths for several reasons. For example, people switch to healthier lifestyles and devote more time to personal well-being as a result of having more private time. Alternatively, there might be fewer traffic accidents and road injuries and deaths because people must stay home. Another explanation may be that people have been exposed to fewer emissions as a result of most factories working at a lower capacity and productivity and fewer cars on the road. Since data related to these issues are unavailable, here we only analyze the possible reduction of road deaths because of lock-downs.

According to the report released by the UK Department for Transport in September 2020 [32], there were 1752 reported road deaths in 2019, similar to the level seen since 2012. Due to the lack of data for 2020, we made hypotheses as to how many road deaths were reduced because of lock-downs and what is the monetary value of this reduction. To make an estimation of the monetary value of the reduction in road deaths, we use the following assumptions: (1) The road deaths in 2020 without the lock-down would be the same as in 2019, which is 1752. (2) The road deaths for a whole year are evenly distributed to 12 months. (3) As there is no available specific number of road deaths in 2020, we assume that the lock-down of the first wave, which lasted for approximately three and a half months, would result in 50% road deaths compared to the same timeframe in previous years. (4) As data given by the European Commission [44] shows that the children younger than 10 years old and adults aged 65 and above account for a high proportion of fatal accidents while it doesn't provide specific age distribution, we assume the average age of road mortality is around 40 years old. Using the same average period of life expectancy as shown in Table 5, the average life expectancy for these people would be around 40 years. Thus, the monetary value of the benefit of lock-downs in reducing road deaths would be shown as Equation 11. Using the monetary value of GBP 20,000 to 30,000 suggested by NICE [46], the gain from the reduction in road deaths would be GBP 204 million (QALY=20,000) to GBP 306 million (QALY=30,000), as shown in Table 7. Based on the calculation, the benefit of assumed reduction on road deaths would be range approximately from GBP 200 to 300 million, shown in Table 8 as GBP 0.20 to 0.30 billion, which is comparably low compared to other benefits or costs.

$$Benefit = \frac{Total\ road\ deaths_{2019}}{12} * T_{3.5} * 50\%(reduction\ ratio) * 40\ years * QALY$$

Equation 11: This equation demonstrates how the benefit of the reduction of road deaths is calculated based on assumptions. $Total\ road\ deaths_{2019}$ is the number of road deaths in 2019, which is used as the possible number of road deaths in 2020 without lock-downs, since the number didn't fluctuate dramatically since 2012. $T_{3.5}$ means the approximate period of the first lock-down in the UK is about 3.5 months, from mid-March to the end of June. 50% is based on the assumption that the road deaths during the lock-down period is about 50% compared to the normal period. And 40 is the average life expectancy for the road deaths.

GBP Million	QALY=20,000	QALY=30,000
Monetary value of reduction in road deaths due to lock-down	204	306

Table 7: This table presents the monetary value of assumed reduction in road deaths.

3.4 Conclusions and discussions

Combining the costs and benefits of NPIs analyzed in previous sections, we can get the balance sheet of costs and benefits shown in Table 8.

Costs (GBP billion)		Benefits (GBP billion)	
GDP losses assigned to NPIs	70 ~ 250	Net lives saved	23 ~ 98
School closure costs	4 ~ 80	Reduction in road deaths	0.20 ~ 0.30
Total	**74 ~ 330**	**Total**	**23.2 ~ 98.3**

Table 8: This table shows the balance sheet of implementing NPIs, which is the sum-up of costs and benefits discussed in previous sections.

According to the balance sheet, we have the following two findings: (1) Under most scenarios, the costs associated with NPIs (especially lock-downs) far outweigh the benefits, especially when GDP losses are largely assigned to the NPIs rather than Covid-19. (2) Under some circumstances, for example, when the productivity of industries during the lock-down periods are comparable to the productivity before NPIs are implemented, which means the main reason for GDP losses is Covid-19 instead of the NPIs, and when the school closures are discounted by 3% annually, the costs of NPIs are comparable to the benefits of NPIs. Considering the fact that the cost-benefits analysis only includes the main cost and benefits, there is the possibility that the benefits of NPIs exceed the costs when more factors are included. Conversely, we have not included the costs of keeping 65 million people under involuntary confinement that could be very substantial.

Summary

As previously mentioned, this cost-benefit analysis is a rough calculation based on a lot of assumptions and scenarios. The scope has been constrained by the limited 6-month duration of this work. Though it identifies the greatest cost of NPIs, which is the GDP losses, and the greatest benefit as the net lives saved, a variety of other factors could still affect the final result. For example, on the cost side, there could be an increase of deaths caused by non-Covid reasons. This can be true for a number of reasons. The compulsory lock-down, for instance, might increase the risk of people having mental illnesses, or even worse, increasing the rate of suicide. Another reason is that people have been denied to get routine medical care as they did before the pandemic, such as cancer care, hemodialysis, etc. Or people may have to postpone their operations because of a shortage of medical resources. However, as data for this issue is not available for detailed analysis, and it is not clear whether the lack of medical care is because of the physical lock-down, or is due to the “crowding out” effect of Covid-19, we don’t include this part in the quantitative analysis. Fear also plays a role in sick people coming forward for treatment. Furthermore, there are many costs and benefits of NPIs that can be analyzed qualitatively rather than quantitatively to translate them into monetary value, such as the decline in societal equality, the long-term or permanent effects of the economy, problems related to democracy or human rights when people are forced to isolate themselves, and so on. To summarize, the costs and benefits of NPIs are a complex subject. In this segment, we have attempted to determine the most significant costs and benefits, as well as provide comparisons to assess the worthiness of NPIs. Other social and economic costs and benefits that may exist but are difficult to include in the quantitative analysis will be discussed in the following section. Furthermore, due to the time constraint of this project, we only performed the cost-benefit analysis of the UK. As a result, we are unable to compare the net costs/benefits of countries taking different approaches, such as the UK and other European countries, Sweden or SE Asian countries. While, at the time of writing, strategies taken in SE Asian countries seemed to be more successful in containing the pandemic and may have lower costs, it is still unclear now which strategy is more cost-effective, as the Covid-19 is still ongoing, and we don’t know if these SE Asian countries will face a more serious resurgence of Covid-19. Therefore, an overview and a comparison of cost-benefit analysis of different strategies such as “flattening the curves”, “suppression” or the so-called “Swedish styles” in different countries would be useful and necessary in understanding the performances of governments against Covid-19 and preparing for the future similar epidemics.

4. Discussion

4.1 Discussion about heavily affected industries

Besides the large numbers of Covid-19 cases and deaths, the impact on the global economy is also massive though highly variable from one country to the next. As shown in Figure 47, the impact on the individual industries and the economy for the UK is larger than the 2008 banking crisis. These impacts, however, are not evenly distributed across all industries. Some industries, for example, the accommodation and food service industries, are affected heavily and would take longer to recover. Some industry losses are even permanent and irreversible. Other industries may be less influenced and can quickly bounce back, for instance, public administration and defense industries, as shown in Figure 47. To fully comprehend the impact on the economy, it is better to view it by industry. In section 3, we tried to isolate and measure the economic effect of Covid-19 and NPIs, but in this section, we don't explicitly allocate proportions to these two factors, instead of discussing how different sectors are affected by Covid-19 and NPIs together.

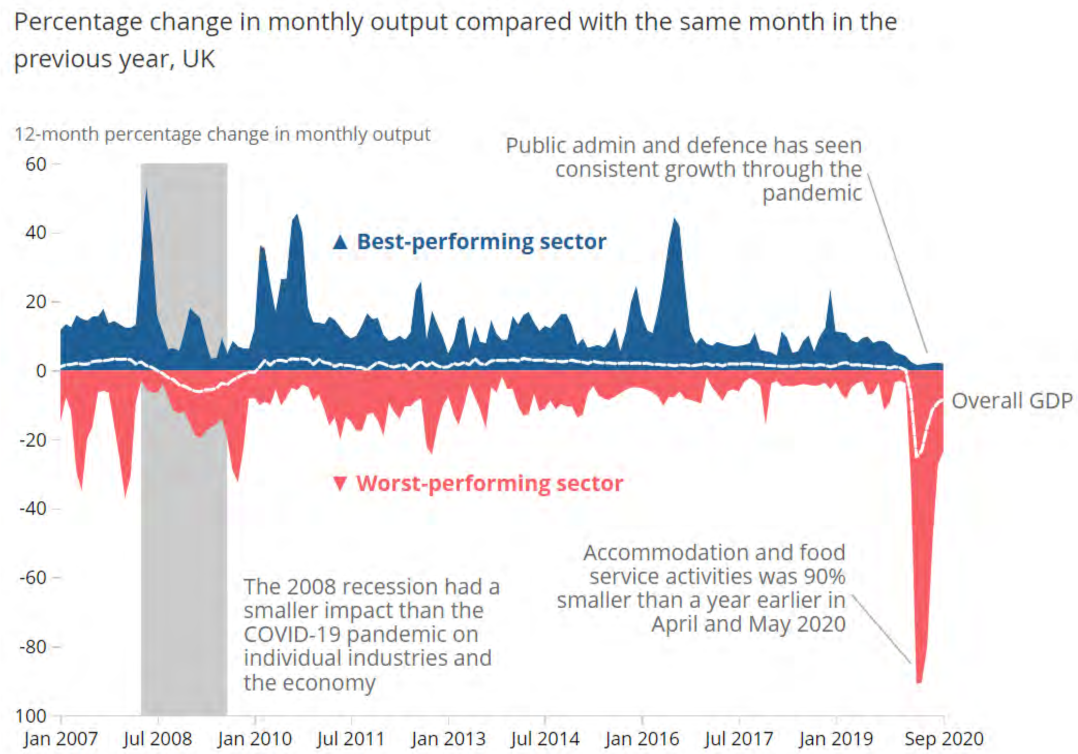

Figure 47: This figure presents how the monthly output changes when compared to the same month in the previous year. The data is collected by the ONS.
Source:ONS [50]
(https://www.ons.gov.uk/economy/economicoutputandproductivity/output/articles/theimpactofthecoronavirussofartheindustriesthatstruggledorrecovered/2020-12-09)

Figure 48 shows the global impact index by industry and dimension of personnel, operations, supply chain, revenue and overall.

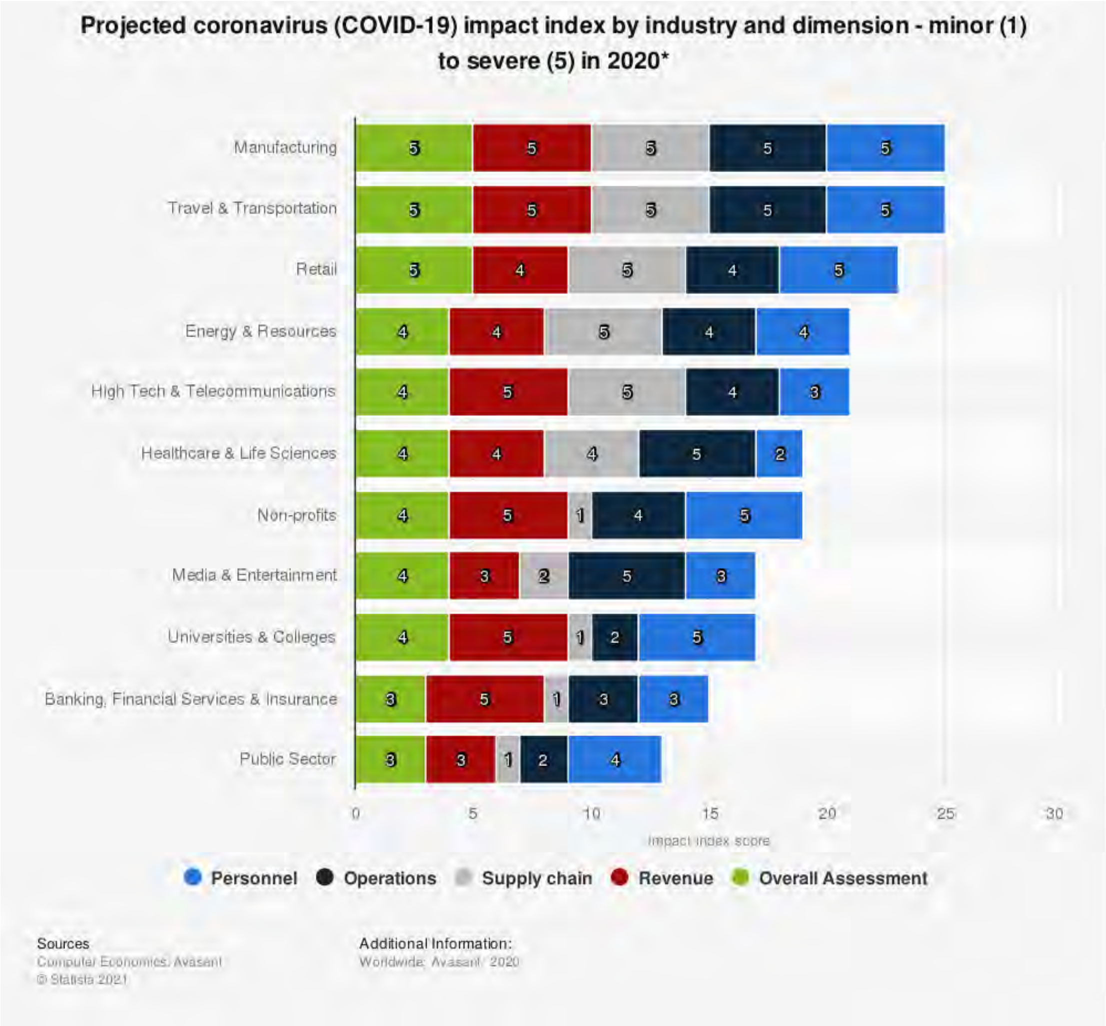

Figure 48: This figure presents the global impact by Covid-19 and NPIs for different industries and indifferent dimensions, including personnel, operations, supply chain, revenue and overall assessment. Score 1 means minor impact and score 5 means severe impact.
Source: Statista 2021; Computer economic; Avasant
(https://www.statista.com/statistics/1106302/coronavirus-impact-index-by-industry-2020/)

According to Figure 48, among all the industries, there are two that have been hardest hit, one is Manufacturing and the other is Travel & Transportation.

One of the key reasons for the severe impact on manufacturing could be the shutdown in China, which accounts for about 28 percent of the world output in 2018 as the data published by the United Nations Statistics Division suggests [15]. As a result, the shutdown in China contributes to a significant lag in revenue globally beyond manufacturing. In the meantime, since this industry is with strong supply chain relationship, its recession would also extend to other industries. To be more precise, the automobile, fast-moving consumer goods, and pharma sectors were hit badly because of the supply chain issues in China. Moreover, since many businesses in the manufacturing industry need on-site work, millions of workers are unable to attend work due to lock-downs and transportation restrictions or if they have symptoms or need to take care of their family members.

Another heavily hit industry is Travel & Transportation. Since the beginning of the outbreak in 2020, many countries took unprecedented measures to restrict domestic and international transportation. According to the data given by The International Civil Aviation Organization (ICAO) [36], seating capacity dropped by about 50 percent in 2020, and passengers totals dropped by 60 percent with just 1.8 billion passengers taking flights, compared to 4.5 billion in 2019. The International Air Transport Association (IATA) also released a full-year global passenger traffic results for 2020 showing that a 65.9% decrease in demand (revenue passenger kilometers) compared to the full year of 2019 [35]. As shown in Figure 49, the global weekly flight frequency decreased to about 32% compared to the previous year in April and May 2020. From June 2020, it slightly recovered but still stayed at about 50% to 60% level compared to the same week in 2019. By October 8, 2020, 43 airlines had declared bankruptcies and many more were expected to follow [11]. Furthermore, in late October 2020, ACI Europe also stated that 193 airports in Europe were also in danger of going bankrupt [59]. Based on the survey conducted by The International Air Transport Association (IATA) and The International Civil Aviation Organization (ICAO) [64], the loss in global commercial profit is expected to reach over 118 billion U.S. dollars, with North America, Europe and the Asia Pacific losing 45.8, 26.9 and 31.7 billion U.S. dollars respectively, followed by the Middle East, Latin America and Africa.

Figure 49: This figure depicts how the global weekly flight frequency changes year to year. The survey is conducted by OAG Schedules Analyser.
Source: Statista; OAG Schedules Analyser
(https://www.statista.com/statistics/1104036/novel-coronavirus-weekly-flights-change-airlines-region/)

Aside from these two industries, other industry sectors including Retail, Energy & Resources, High Tech & Telecommunications, etc. were also significantly affected.

However, within these industries, some sectors were positively affected. For example, online sales have comparatively increased as consumers are buying online rather than leaving the house to go shopping because either they are reluctant or not allowed to go out. On the other hand, in the Retail sector, grocery retail chains such as Walmart have seen an increase in revenues as people stocked up on groceries and personal care products. In the High Tech & Telecommunications industry, we can also observe an increased demand for software vendors and their products, such as Zoom, Slack, Microsoft Office Teams, which could increase companies' remote working capabilities. Share prices also reflect the positive effects on these businesses. Zoom Video Communications Inc. (NASDAQ: ZM)' stock, for example, surged 425% in 2020, from US$ 68.72 to US$ 342.5 per stock, despite cooling in the final months of the year. Amazon.com, Inc. (NASDAQ: AMZN)'s stock price increased by 74%, from US$1874.97 to US$3256.93. Microsoft Corporation (NASDAQ: MSFT)'s stock increased by 40% from US$158.62 to US$222.42. However, it is worth noting that the impact on the High Tech & Telecommunications industry is mixed. Though we see increases in stock prices for such companies, the manufacturer of computers, smartphones, and components are greatly impacted by the closure of factories in China and the quarantine of workers. For example, major players include Apple and Microsoft have issued warnings of shortage of components due to globalized supply chain issues.

To conclude, the Covid-19 along with NPIs have caused havoc on the global economy, though the losses are not evenly distributed in countries and in industries. Apart from this economic cost, there is also social cost in various fields that cannot be overlooked and need time to recover.

4.2 Discussions about unquantifiable costs and benefits

4.2.1 Health

As we have discussed in section 3 of the cost and benefit calculation, the greatest benefit of NPIs could be lives saved from Covid-19. Furthermore, it is likely that lives have also been saved from road accidents as a result of "stay at home" orders. On the cost side, there are mainly two types of costs in the health category: the first is the redeployment of medical resources and postponed treatment of more conventional illnesses such as cancer, the second could be increased mental illness.

During the first wave, millions of non-urgent elective operations were postponed by at least 3 months in England by request of The National Health Service in order to free up beds for Covid-19 patients [6]. As the second wave bounce back since October 2020, hospitals had to cancel routine operations across England due to the pressures from the resurgent Covid-19 despite the new lock-down measures [2]. According to the report by The Royal College of Emergency Medicine (RCEM), there was a nearly 44%

decline during March 2020 of Emergency Department attendance [57]. However, the reason for this decline is unclear, it could be people fear going to hospitals that could increase the chance of getting infected, or it might be due to the “stay at home” orders meaning that fewer people got injured and required emergency treatment.

Apart from the postponed or cancelled treatment and people voluntarily reducing the attendance to the hospitals, the mental disorder is another serious issue related to NPIs, especially for children and teenagers. According to a survey conducted by a mental health charity YoungMinds [78], involving 2111 participants up to age 25 years with a mental illness history in the UK, 83% said the pandemic had worsened their conditions. 26% said they couldn’t get mental health support; peer support groups and face-to-face programs have been cancelled, and support by phone or online can be challenging for some young people. Moreover, many countries cancelled university entrance exams, which would also bring pressure to students. According to a poll by the student counselling group Hok Yau Club in March [34], 2020, over 20% of the 757 candidates surveyed said their stress levels were at a maximum of 10 out of 10, even before the postponement was announced. Not only students and children experienced mental health problems, but adults have also struggled with mental health issues. Based on a longitudinal probability sample survey of the UK population about the mental health before and during the Covid-19 pandemic conducted by Pierce, M. et al [56], by late April 2020, mental health in the UK had deteriorated compared with pre-Covid-19 trends. In addition, policies emphasizing the needs for women, young people and children are very necessary to prevent a sharp increase of mental illness in the near future. However, as the actual mental health conditions worsened, the number of people seeking help for depression dropped by 43%, anxiety disorders by 48% and self-harm by 38% during the first lock-down in the UK [66]. One possible explanation may be that people were encouraged to remain at home to protect themselves and to relieve the burden on the National Health Service. This means they would receive less mental support than they would normally receive. This widening gap between actual mental illness and actual mental treatment may result in widespread mental problems in the post-Covid-19 era. Nevertheless, it is worth noting that despite the fact that the national mental health conditions deteriorated, there is no evidence that the suicide rates for the UK have increased during the pandemic. According to the figure of quarterly suicides deaths registration in England released by the ONS [53], the provisional quarterly suicides registrations for the first three quarters are 1262, 845 and 1334, respectively, while the statistics for the same time frame in 2019 were 1247, 1326 and 1330, separately. The lower number of suicides registered in Q2 2020 may be due to the Covid-19 pandemic’s impact on the coroner’s services resulting in delays to the inquest, implying that part of deaths registered in Q3 2020 should be registered in the second quarter of 2020. Making a simple calculation here, we can get that the number of suicides registered in the first quarters of 2020 is less than the number of suicides registered in the first three quarters of 2019. Thus, though it is still too early to conclude the impacts of Covid-19 pandemic’s impact on the trend of suicide rate, the data so far shows no evidence that Covid-19 has increased the number of suicide rates. One of the possible reasons that the suicides rates vary from the national mental conditions trend may be that there are still delays and gaps in coroner's services though a portion of this was compensated by the registrations in the third quarter. Another possible explanation could be that people may commit suicide (with a bad mental health condition) died because of other causes, such as Covid-19, influenza, or cardiovascular diseases, and so forth, and were recorded under these causes.

4.2.2 Education

Aside from the conjectured future monetary loss associated with the school closures which have been discussed in section 3.2.2, there are also other educational costs that may not be reflected in a monetized format. To begin with, due to unequally distributed resources, students would be impacted to varying degrees by school closures. The schooling-at-home strategy relies in part on the instructional skill of parents and family discipline as well as the use of technology solutions relying on tablets, computers, and internet access to remote teaching and online classes in the family home. This may be strongly affected by the family's financial status. As a result, students from poor families may not get fewer resources than the students from rich families, which might result in lower educational achievement, higher possibilities of being unemployed when they grow up. Eventually, this skewed distribution may widen the gap between the wealthy and the poor in society. However, since skewed distribution and inequality existed prior to the Covid-19, determining the causes of the possible widening gap between the rich and the poor would be challenging. Perhaps more difficult to assess is the degree to which school closures during the pandemic would exacerbate inequality decades later. Another issue could be the influence on the practical experiences for the undergraduate or graduate students. For instance, the education and research that need to be conducted in labs in the universities could be cancelled or delayed; students' chances to get internship or job opportunities from daily social activities or net-working would be greatly diminished, and so on. Furthermore, the target attainment levels of the students during the year 2020 have been lowered by the authorities. To illustrate, a lot of universities chose to give a pass or fail grade instead of a score to students. A number of written exams in universities have been replaced by remote exams, which could be less strict and allow for cheating. This lower requirement could have a negative impact on students and in turn, on society.

4.2.3 Society

The NPIs' impact on the society is also significant. A big issue is about the increase of inequality in the society, since the Covid-19 and NPIs are not benefiting people in a uniform way. According to a report by The United Nations Conference on Trade and Development (UNCTAD) [69], the impact has been seen asymmetric and tilted towards the most vulnerable, affecting disproportionately low-income households, migrants, informal workers and women. To illustrate, while men reportedly have a higher fatality rate, women and girls are affected in particular by the related economic and social crises. Across the 32 countries for which gender-disaggregated data are available, the countries with higher Covid-19 incidence have seen greater increases in female unemployment than male unemployment. According to a McKinsey's research [12], women's jobs are 1.8 times more vulnerable to the Covid-19 crisis than men's jobs. Women make up 39 percent of global employment but account for 54 percent of the overall loss of work. One of the explanations may be that the virus is rising the burden of unpaid care, which is borne overwhelmingly by women. Another possible reason could be that sectors dominated by women, such as tourism and hospitality, are more affected by the Covid-19 crises.

Another problem could be caused by the NPIs is the increase in domestic violence, as many governments announced stay-at-home guidelines. By implementing stay-at-home recommendations, victims and survivors of domestic violence were forced to be isolated with their abusers. According to the ONS's dataset [49], the police recorded 259,324 offences flagged as domestic abuse-related in the period March to June 2020 for England and Wales, which represents a 7% increase from 242,413 in the same period in 2019 and an 18% increase from 218,968 in 2018, as shown in Figure 50. Based on a United Nations' report [70], in Tunisia, calls to the helpline in the first days of confinement increased fivefold. Home is not heaven, and the stay-at-home orders make the situation more dangerous for those who are now or may become victims of domestic violence.

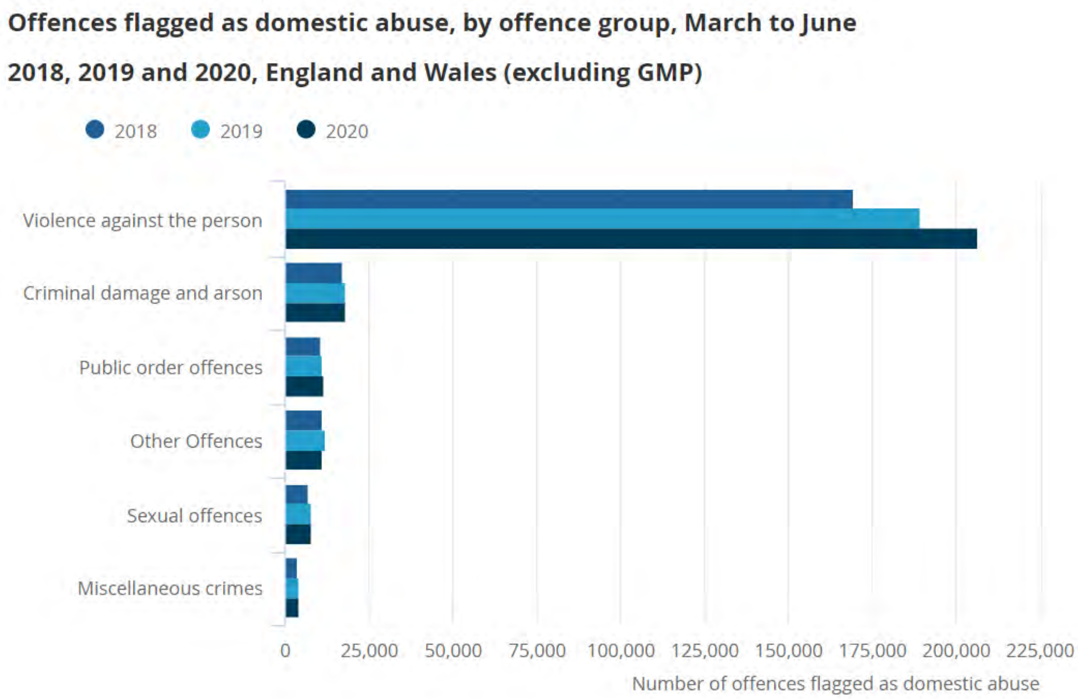

Figure 50: This figure presents the number of offences as domestic abuse for England and Wales from March to June 2020, excluding the data for Greater Manchester Police (GMP) which is unavailable.

Source: ONS [49]

(https://www.ons.gov.uk/peoplepopulationandcommunity/crimeandjustice/articles/domesticabuseduringthecoronaviruscovid19pandemicenglandandwales/november2020#domestic-abuse-during-the-coronavirus-covid-19-pandemic-data)

Besides, as the pandemic spread and the NPIs were implemented, the stability of the society was also affected. People may lose trust in their government and medical system. Processions and demonstrations happened because people were tired of the long-time NPIs that largely affected their normal lives. The pandemic also brought to light several previously unresolved issues. Racism emerges while the Covid-19 is still going on. For example, there were several violent incidents against black people and Asians in the United States, though this might not be completely because of the Covid-19 and NPIs, Covid-19 and NPIs may cause people to be fearful, panicked, and hostile in the meantime. During the pandemic, society became more agitated.

4.2.4 Environment

Environmental impacts are another area that should be considered. The vast amount of plastic-based, single-use personal protective equipment (PPE) such as masks could have a direct environmental effect. After sanitizing, there are usually two options for disposing of these discarded PPEs: landfilling or managed incineration, all of which have major disadvantages. The former could leak toxic pollutants to the ground water and the latter may spew millions of tons of carbon dioxide into the atmosphere, though a proportion of the gas emissions are recycled, for instance, producing electricity. Many people wear masks in their everyday lives because this is one of the most common and cost-effective forms of self-protection. A waste company indicated that only in the UK, people are throwing away 53 million masks each day in a waste mountain, let alone the global amounts of used masks [67]. As a consequence, we could predict that after the pandemic is over, there will be billions of used masks that need to be disposed of globally. Not only is the final stage of waste treatment of used PPEs could result in an environmental issue, but the intermediate steps, such as used PPEs' collection and classification, can also be problematic, particularly in countries where household waste is poorly managed. For example, people may litter used masks on the street. Besides, as people stay at home and increase their usage of online shopping, the increased waste of households from shipped package materials could also induce a serious environmental impact [62]. Meanwhile, many countries postponed the waste recycling activities to reduce the transmission of virus infection, though this mode of transmission is still under debate and not confirmed. For example, the UK, Italy and other European countries prohibited infected residents from sorting their waste, and the US also restricted recycling programs in many cities (nearly 46%), as governments worried about the risk of COVID-19 spreading in recycling facilities [62]. However, according to CDC [8], the risk of being infected through contacts with contaminated surfaces or objects (fomite transmission) is generally considered to be low.

However, although there are negative effects on the environment, there is still some good news. First, there were decreased concentrations of Nitrogen dioxide (NO_2) and Particulate Matter 2.5 ($PM_{2.5}$). The results of NO_2 and $PM_{2.5}$ emissions during 5 to 20 days before the Chinese Lunar New Year, minus the emission before this date, were compared in 2016-2019 and 2020, respectively, in a difference-in-difference study [9] aimed at removing the impact of the Chinese Lunar New Year. NO_2 levels were reduced by 22.8 g/m3 (1.1 g/m3 in 2016 - 2019 and -21.7 g/m3 in 2020) and 12.9 g/m3 (-2.7 g/m3 in 2016 - 2019 and -15.7 g/m3 in 2020) in Wuhan and China, respectively, due to strict traffic controls and self-isolation measures. $PM_{2.5}$ fell by 1.4 μg/m3 in Wuhan and decreased by 18.9 μg/m3 in 367 cities. The smaller reduction in $PM_{2.5}$ in Wuhan is because of a similar declining trend in Wuhan from 2016 to 2019. In addition, as there are fewer tourists during the pandemic and the lock-downs, beaches are much cleaner than before. For example, beaches of Acapulco (Mexico), Barcelona (Spain), or Salinas (Ecuador) now look cleaner and with crystal clear waters [79]. Moreover, as there is decreased usage of private and public transportation, as well as the partial cessation of commercial activities, there could also be a reduction in the noise level. However, these positive impacts may only be temporary, and they may be reversed in the immediate future during and after the recovery period.

4.2.5 Others

Apart from impacts addressed in fields such as health, education, society and environment, there are other costs that must be paid attention to. These costs could be global, long-term and catastrophic. For instance, the global starvation, is a potential disaster at the end or after the pandemic. According to David Beasley, Executive Director of the World Food Program (WFP), there is an alarm of global hunger and food insecurity, with the number of people marching towards starvation spiking from 135 million to 270 million since the beginning of the pandemic [71]. Though pre-Covid estimates of acute food insecurity in West and Central Africa predicted a conflict-induced increase of acute hunger in 2020, Covid-19's compounding impact could increase food insecurity by 135 percent [29]. Evidence suggests that Covid-19 has exacerbated the food security problem in countries that already have them. In Sudan, for example, an estimated 9.6 million people (21 % of the population) were experiencing a crisis or worse levels of food insecurity in the third quarter of 2020, which is the highest figure ever recorded for Sudan [29], though it is difficult to distinguish which proportion of this increase is because of Covid-19 and related factors such as delays in the farming season due to disruptions in supply chains and restrictions on the labor movement. Nevertheless, since the Covid-19 is still ongoing and data on hunger in all these countries is unavailable, we cannot predict to what extent the Covid-19 will exacerbate global food security.

A rise in inequality during the pandemic may also be a concern. Even though inequality is already a problem in many countries, Covid-19 can exacerbate the problem or expose it. Based on short-term projections conducted by the World Bank and the International Monetary Fund [76], global extreme poverty and income disparities for low-income and developing economies are expected to increase. In most countries, college-educated workers are less likely to stop working than less-educated workers and women survey respondents are more likely to stop working than men. Furthermore, previous disasters show that it is often more costly for poor households to recover, as they lose human capitals and assets to cope with pandemics, which would also make the welfare disparities larger and increase inequality in the long run if the government did not intervene. Therefore, policy making with an equity lens is necessary, critical and urgent.

5. Conclusions

Since the beginning of 2020, many European countries have been affected by Covid-19. In order to control and pandemic, countries have implemented NPIs, for example, rounds of lock-downs, social distancing, quarantines, etc. These measures may help prevent potential infections and save deaths from Covid-19, but they come at a high price. This study aims to evaluate the cost and benefits related to NPIs. In order to compare the costs and benefits, we adopted the cost-benefit analysis methodology, to compare the monetary value of main costs and benefits. Furthermore, we also discuss the costs and benefits that are hard to be precisely converted into monetary values.

As previously mentioned in section 3, we have two main findings based on the calculation part. The first finding is that, under most scenarios, the costs associated with NPIs (especially lock-downs), far outweigh the benefits, particularly when the GDP losses are largely attributed to NPIs rather than Covid-19 itself. This finding may imply that, based on cost-benefit analysis, it is preferable not to introduce lock-downs in many countries.

Another finding could be, under certain circumstances, for example, when the productivity of the country during the lock-down periods is comparable to the productivity before NPIs were implemented, implying that the GDP losses are primarily due to Covid-19 instead of NPIs, the costs of NPIs are comparable to the benefits, which suggest that implementing NPIs, especially lockdowns could be a suitable choice. However, it is worth noting that we performed a rough cost-benefit analysis including several assumptions. Meanwhile, several costs discussed in section 4 that cannot be accurately translated into monetary values are not involved in the cost-benefit analysis, which suggests that the true costs of adopting NPIs could be higher than the monetary value calculated in section 3. Therefore, implementing lock-downs could have been a wrong decision for many countries.

Nevertheless, as mentioned before, this is a rough cost-benefit analysis, and there are several costs and benefits that we did not consider in the calculation, leaving space for future improvements. Furthermore, there are some long-term effects of NPIs that we cannot predict exactly at this moment, such as how rapidly the economies will recover, what proportion of the businesses will permanently vanish, whether new opportunities will emerge except for what we have seen with the software vendors' success. All of these uncertainties could be factored into the cost-benefit analysis after the pandemic is over and the uncertainties getting apparent. The more accurate and thorough the cost-benefit analysis is, the more useful recommendations it can have for policymakers to make the right decisions in similar circumstances in the future.

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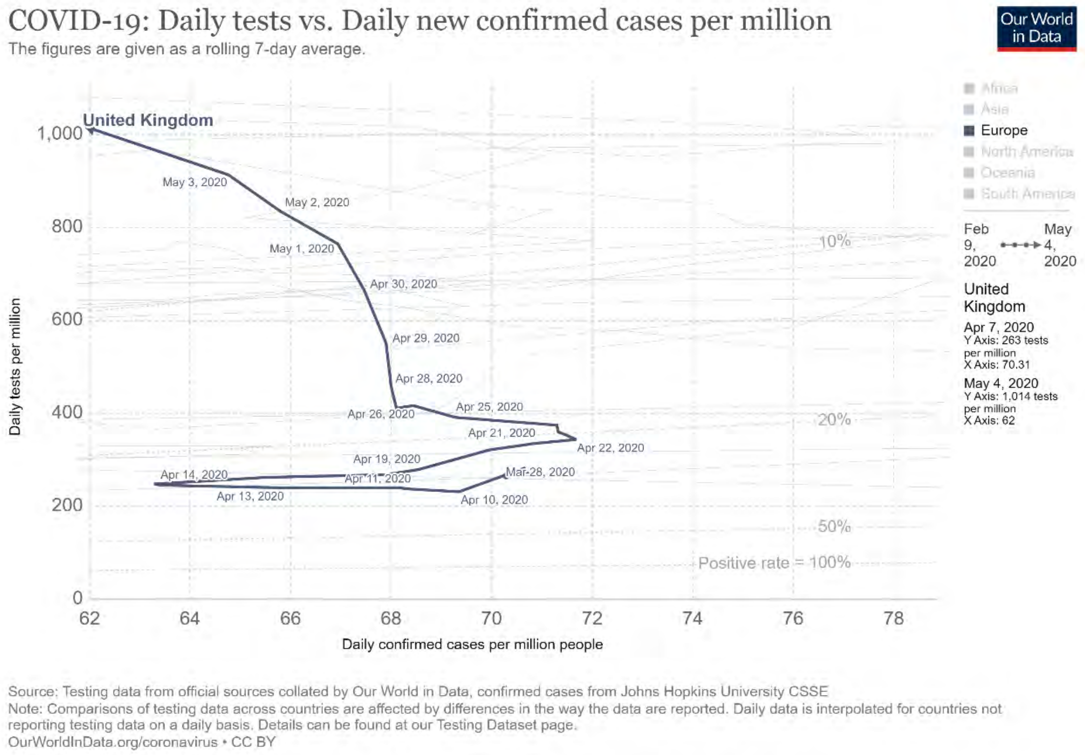
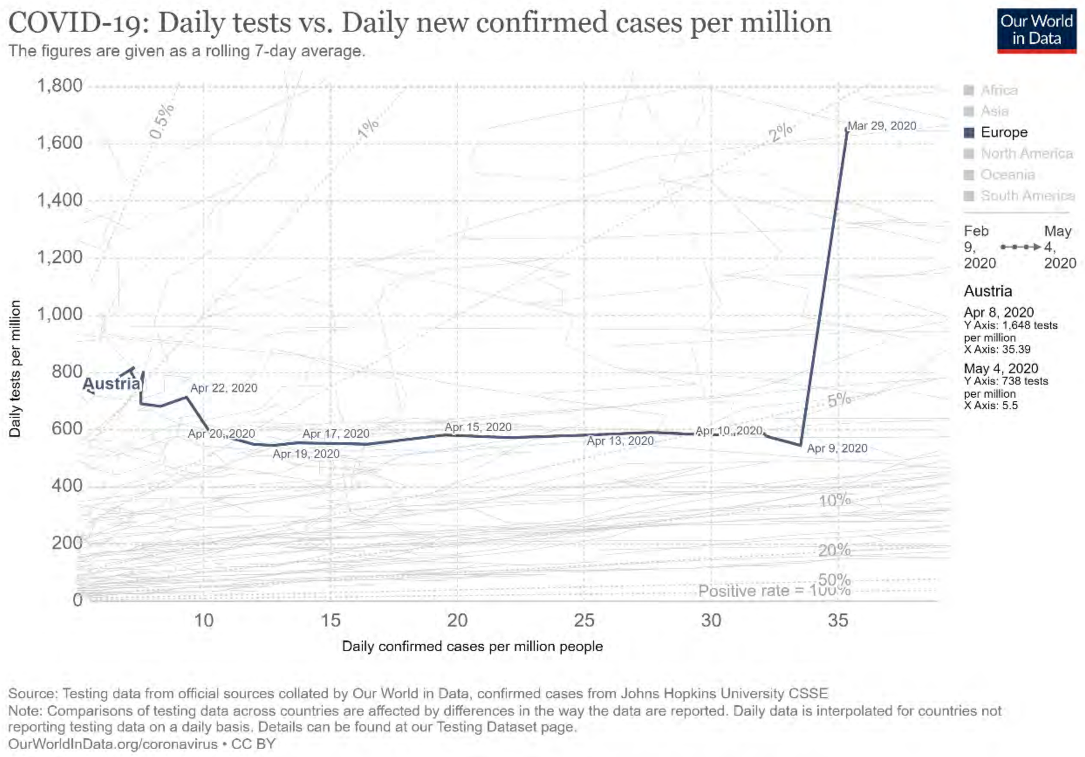
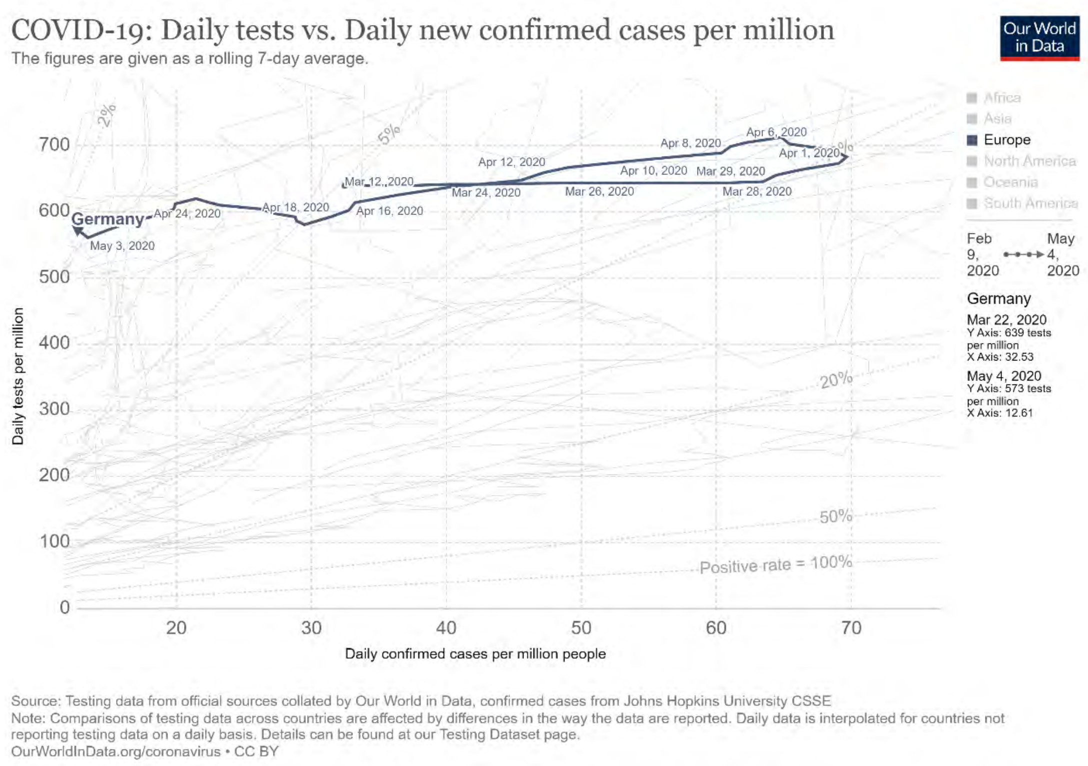
Appendix

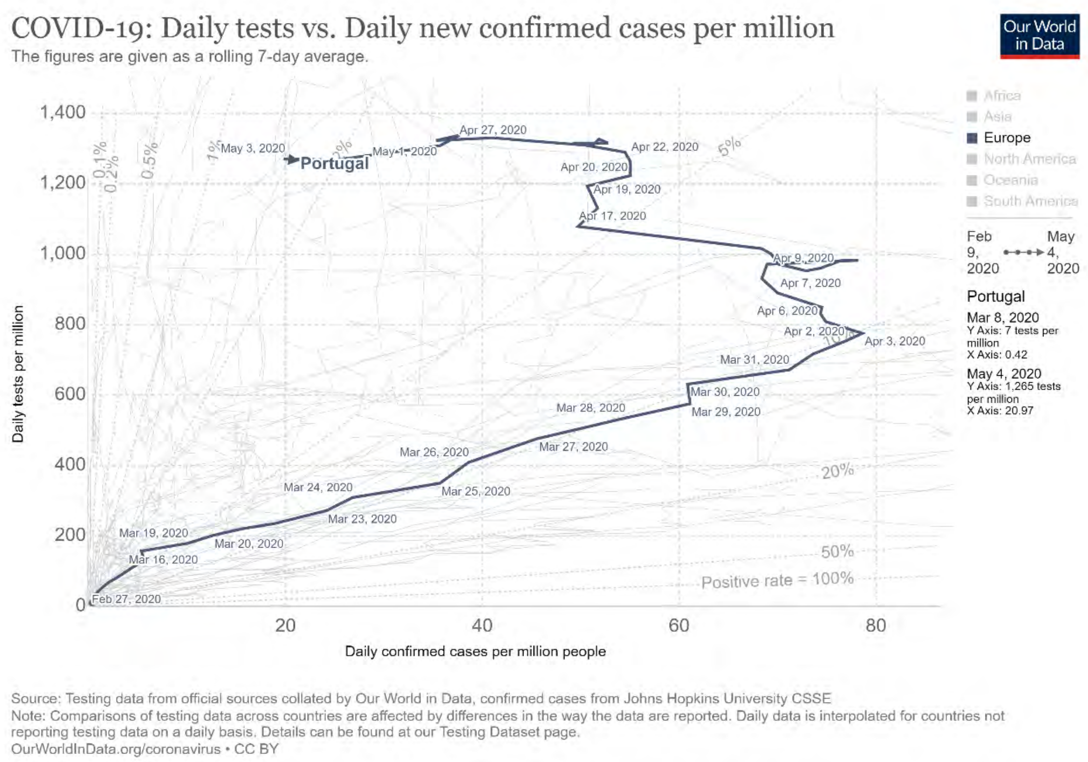
1. Charts of daily tests per million versus daily new confirmed cases per million for each country.

Source: our world in data [55] (https://ourworldindata.org/coronavirus-testing)



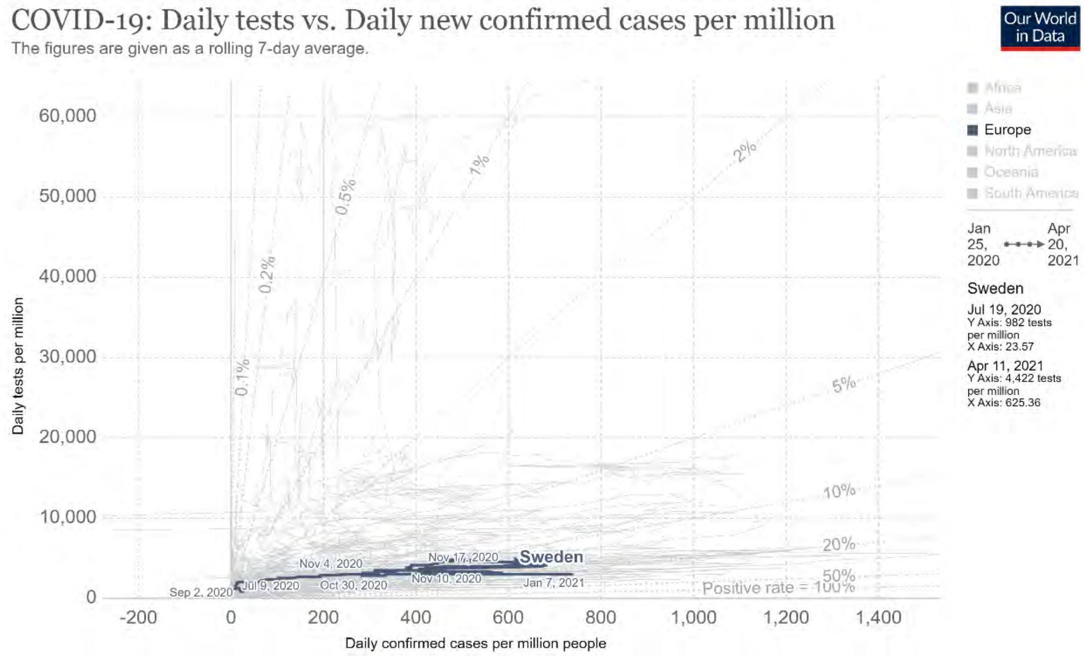



COVID-19: Daily tests vs. Daily new confirmed cases per million
The figures are given as a rolling 7-day average.
Our World in Data
Germany
Daily tests per million
Daily confirmed cases per million people
Positive rate = 100%
50%
20%
5%
2%
Africa
Asia
Europe
North America
Oceania
South America
Feb 9, 2020
May 4, 2020
Germany
Mar 22, 2020
Y Axis: 639 tests per million
X Axis: 32.53
May 4, 2020
Y Axis: 573 tests per million
X Axis: 12.61
Source: Testing data from official sources collated by Our World in Data, confirmed cases from Johns Hopkins University CSSE
Note: Comparisons of testing data across countries are affected by differences in the way the data are reported. Daily data is interpolated for countries not reporting testing data on a daily basis. Details can be found at our Testing Dataset page.
OurWorldInData.org/coronavirus • CC BY


COVID-19: Daily tests vs. Daily new confirmed cases per million
The figures are given as a rolling 7-day average.
Our World in Data
Portugal
Daily tests per million
Daily confirmed cases per million people
Positive rate = 100%
50%
20%
5%
1%
0.5%
0.2%
0.1%
Africa
Asia
Europe
North America
Oceania
South America
Feb 9, 2020
May 4, 2020
Portugal
Mar 8, 2020
Y Axis: 7 tests per million
X Axis: 0.42
May 4, 2020
Y Axis: 1,265 tests per million
X Axis: 20.97
Source: Testing data from official sources collated by Our World in Data, confirmed cases from Johns Hopkins University CSSE
Note: Comparisons of testing data across countries are affected by differences in the way the data are reported. Daily data is interpolated for countries not reporting testing data on a daily basis. Details can be found at our Testing Dataset page.
OurWorldInData.org/coronavirus • CC BY

COVID-19: Daily tests vs. Daily new confirmed cases per million

The figures are given as a rolling 7-day average.



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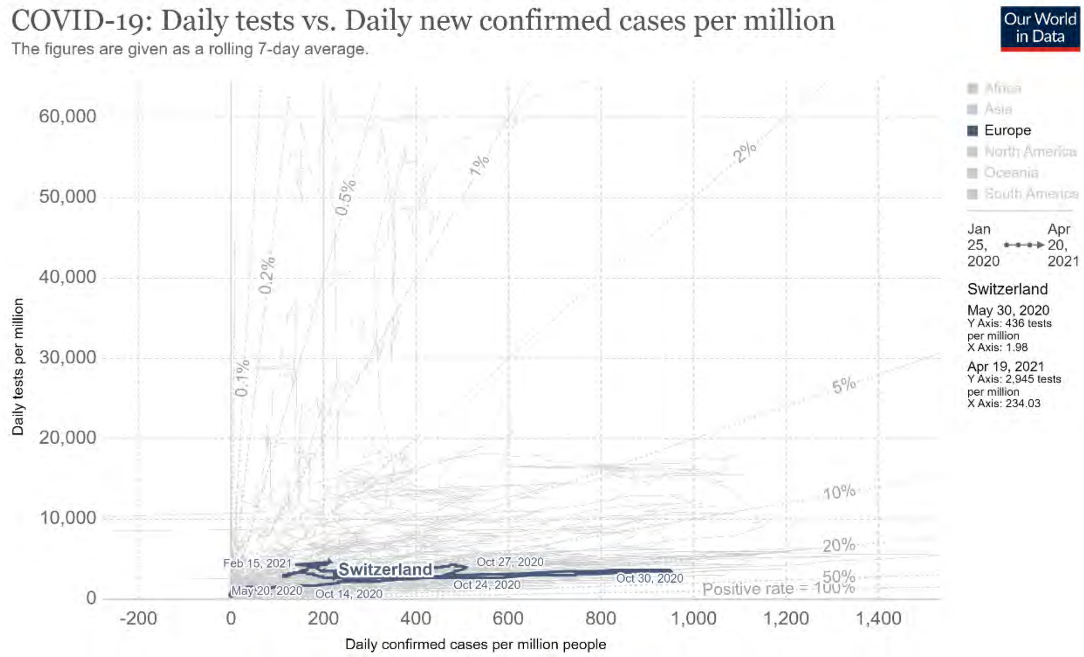

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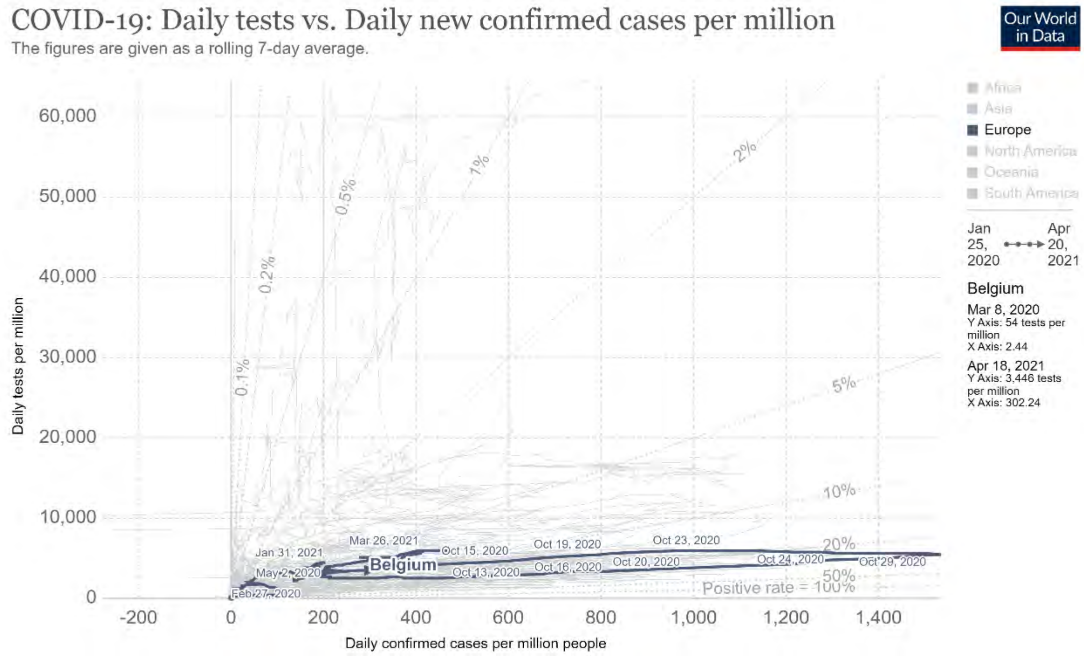

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COVID-19: Daily tests vs. Daily new confirmed cases per million

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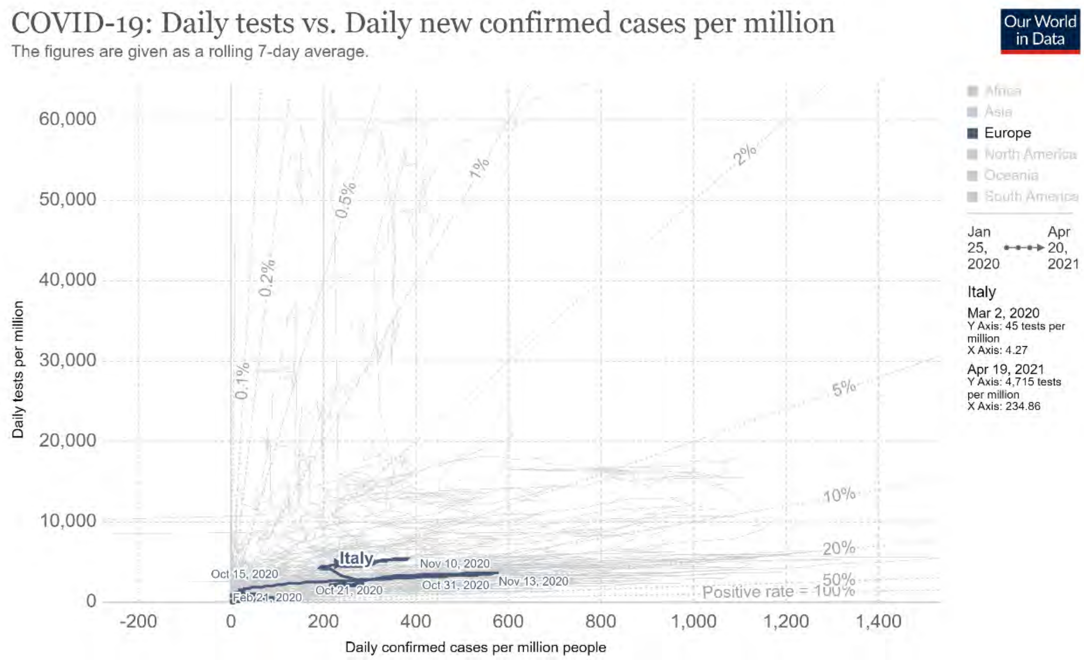

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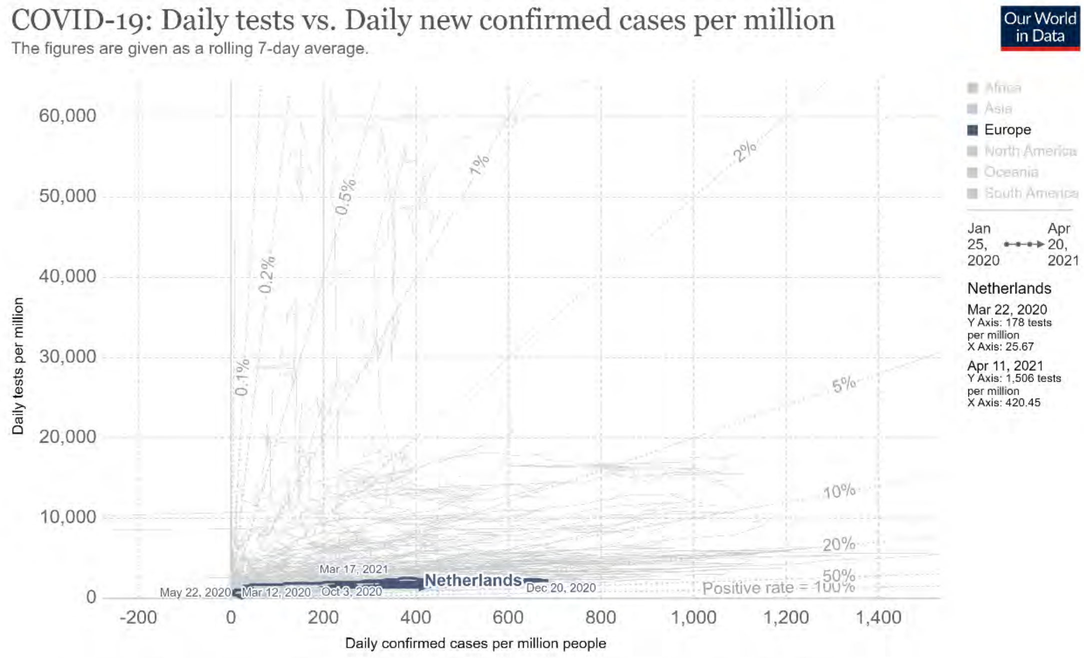
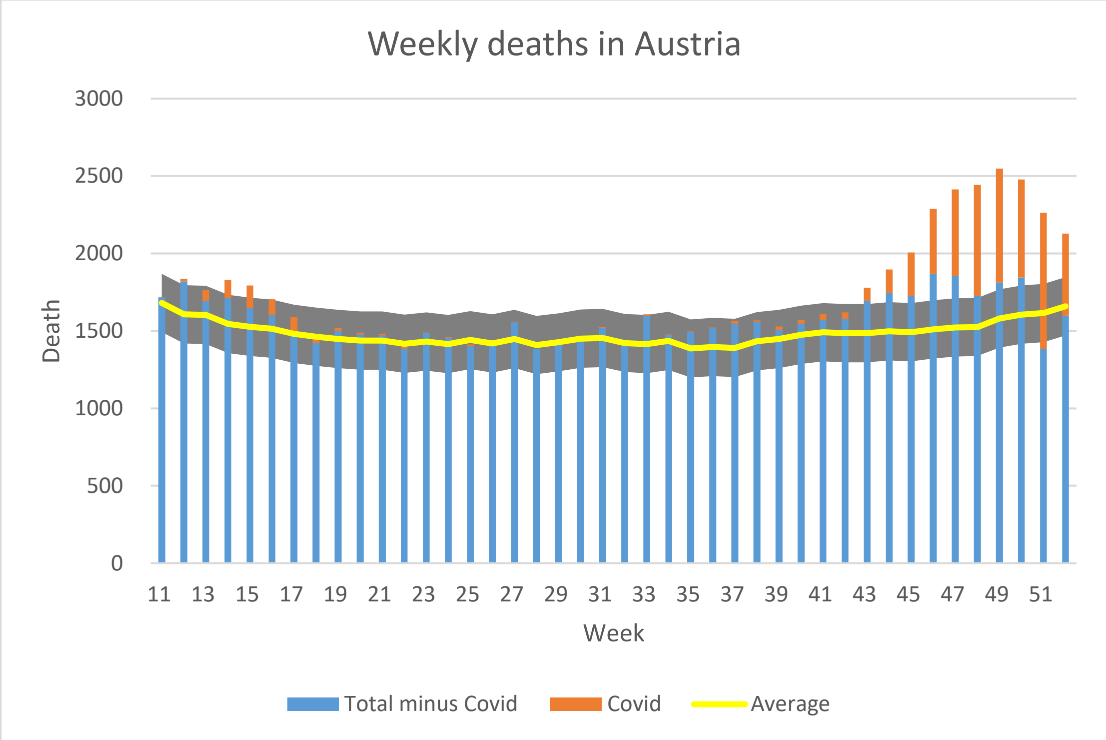
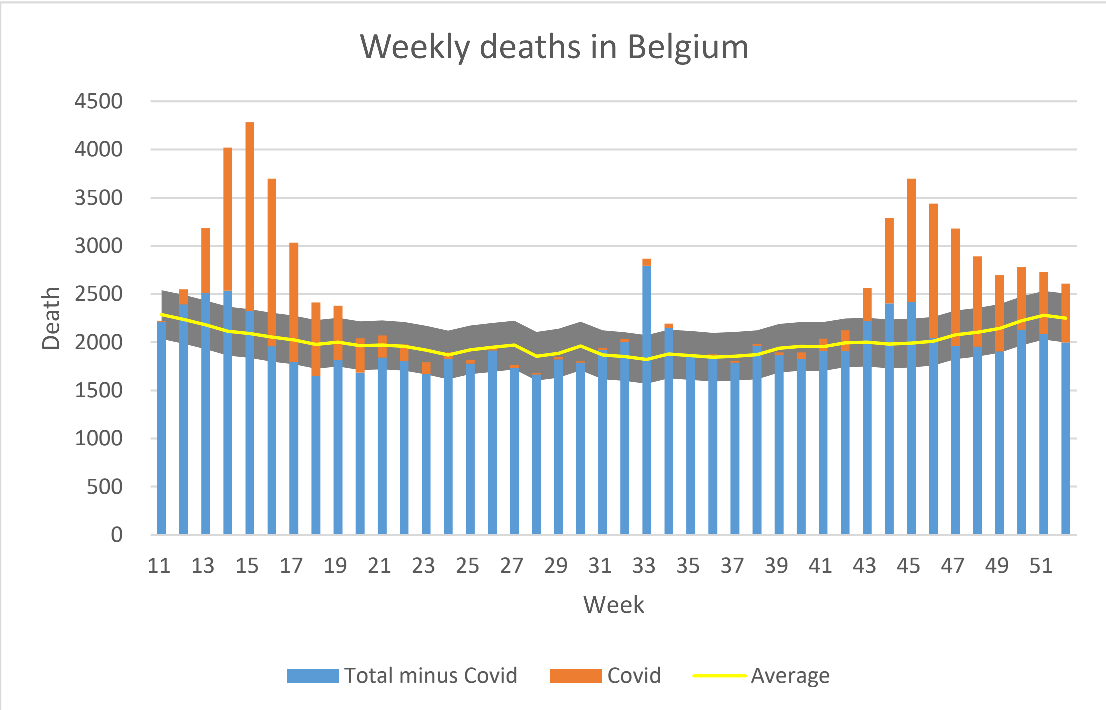
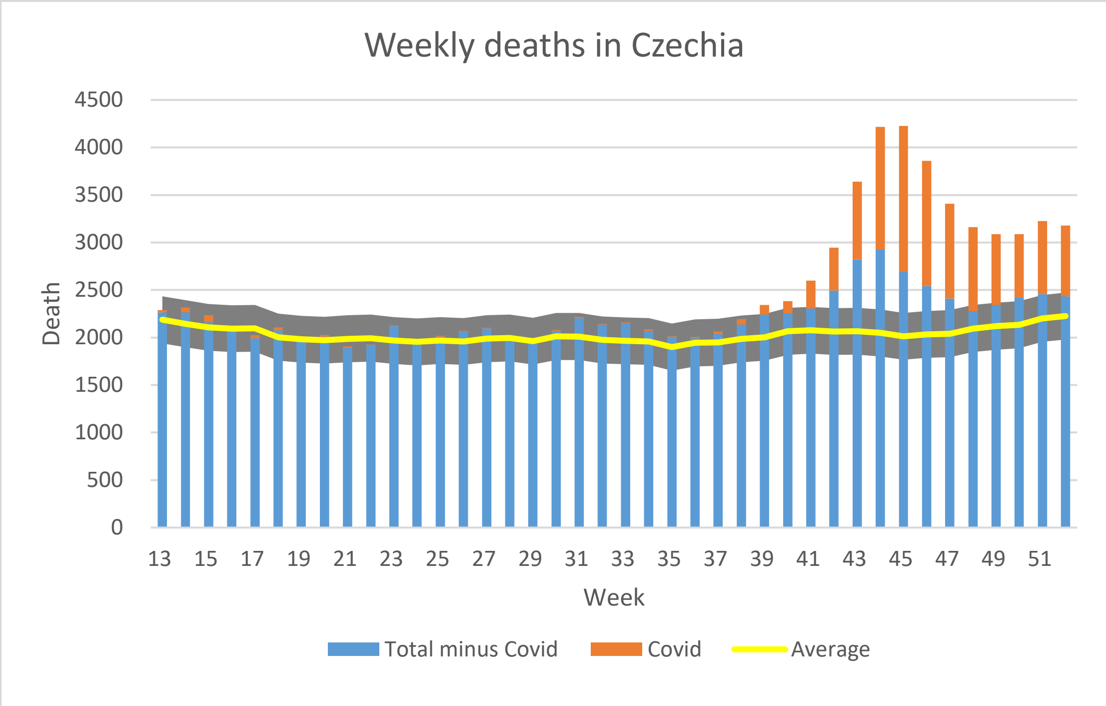


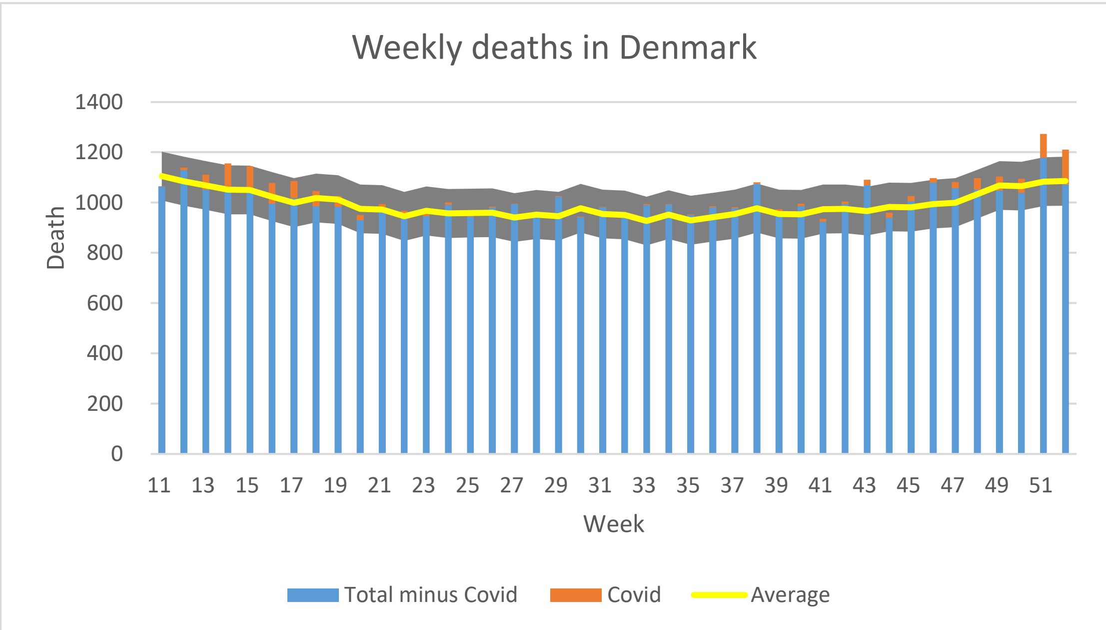
Source: Testing data from official sources collated by Our World in Data, confirmed cases from Johns Hopkins University CSSE
Note: Comparisons of testing data across countries are affected by differences in the way the data are reported. Daily data is interpolated for countries not reporting testing data on a daily basis. Details can be found at our Testing Dataset page.
OurWorldInData.org/coronavirus • CC BY

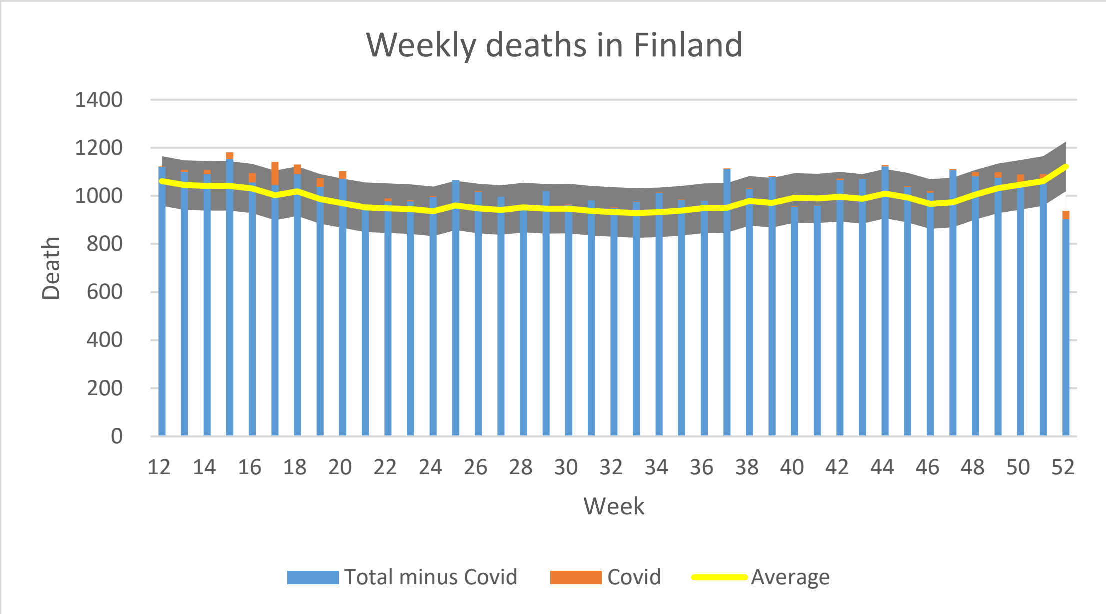
2. Weekly deaths graphs for other countries and regions. Data for Scotland is from NRS [47] and data for other countries is from Eurostat [1].

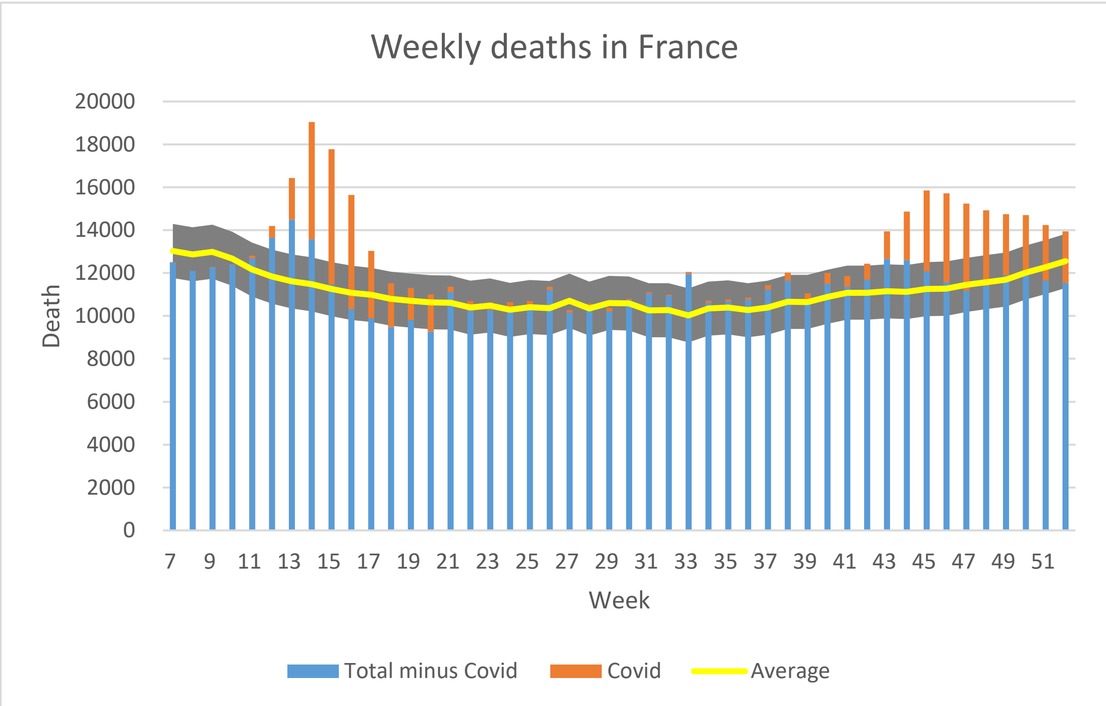


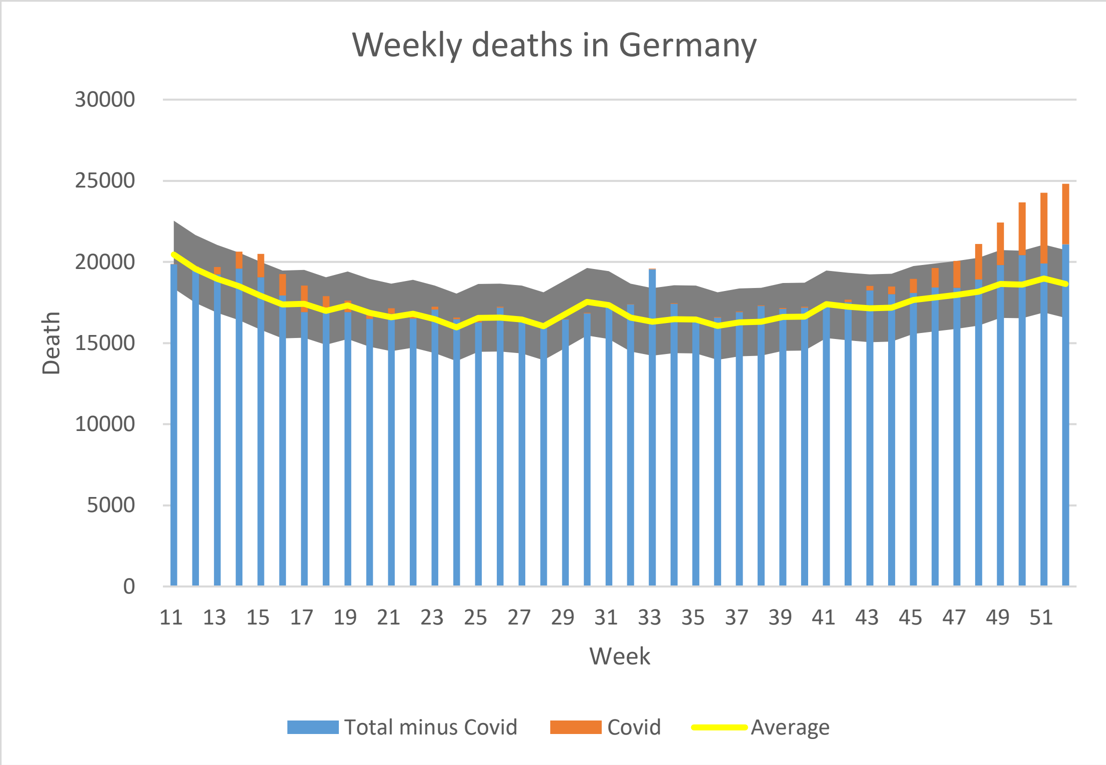


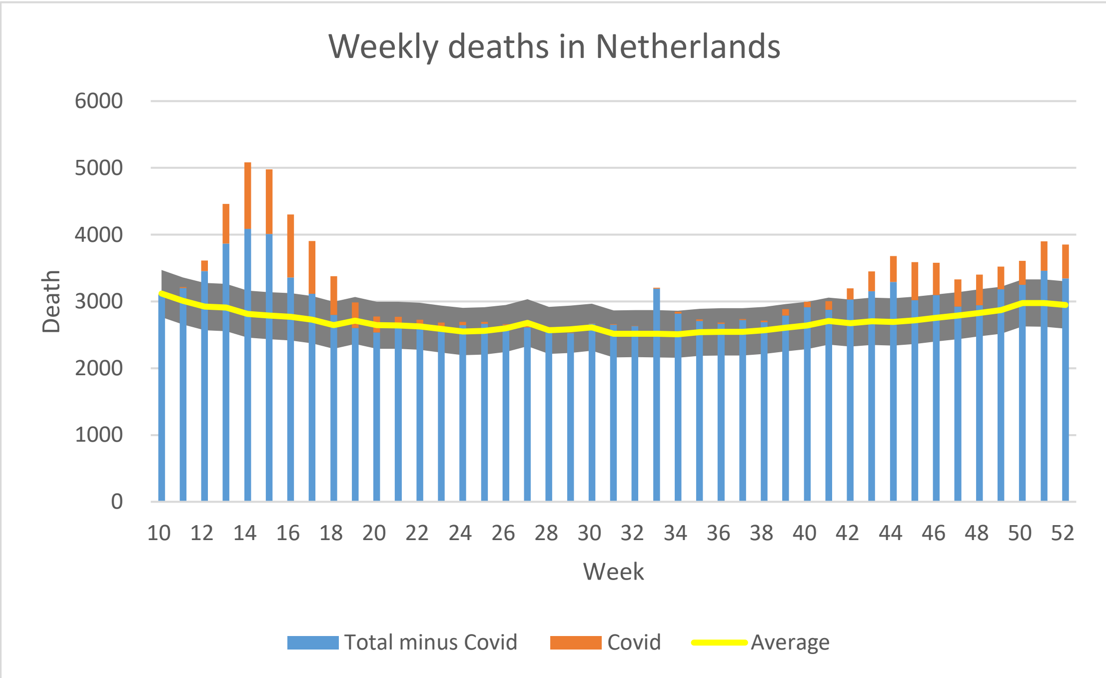

Weekly deaths in Czechia
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Death
13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51
Week
Total minus Covid
Covid
Average

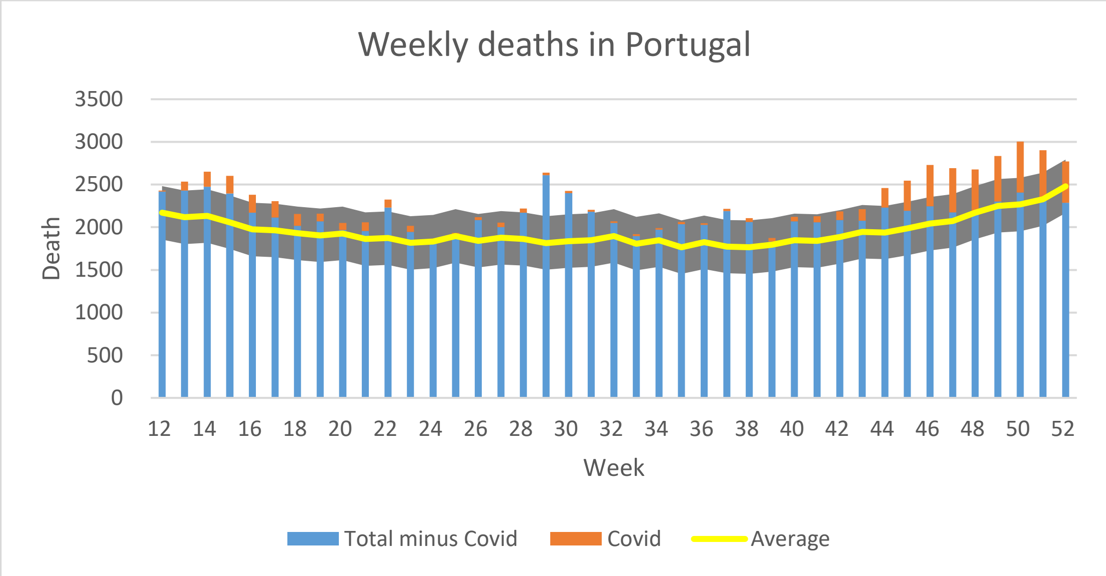

Weekly deaths in Denmark
1400
1200
1000
800
600
400
200
0
Death
11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51
Week
Total minus Covid
Covid
Average

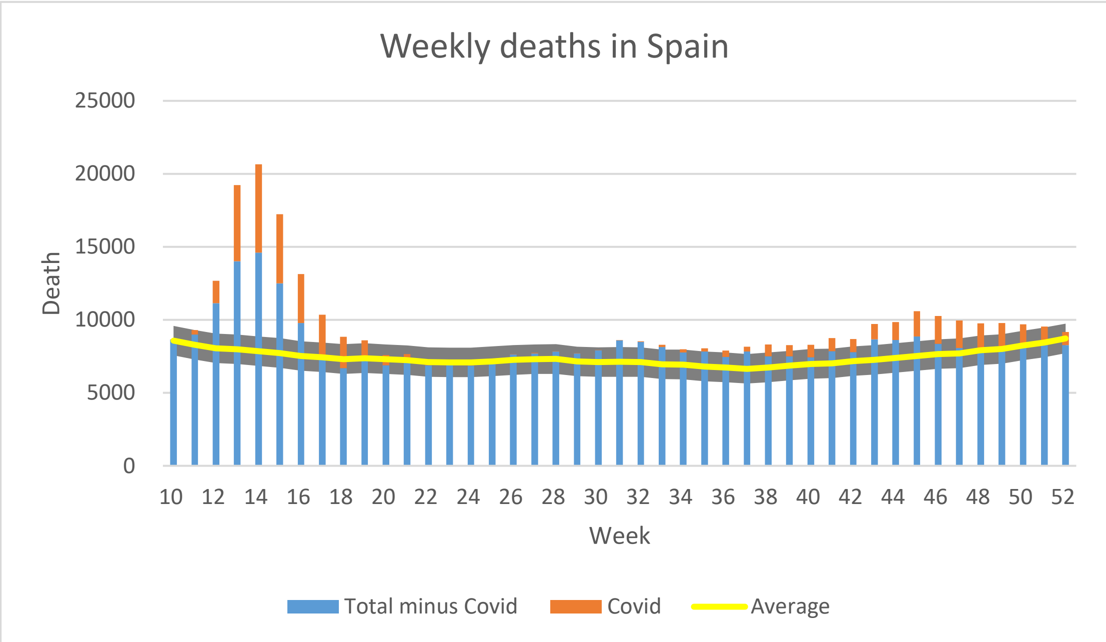

Weekly deaths in Finland
1400
1200
1000
800
600
400
200
0
Death
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Week
Total minus Covid
Covid
Average

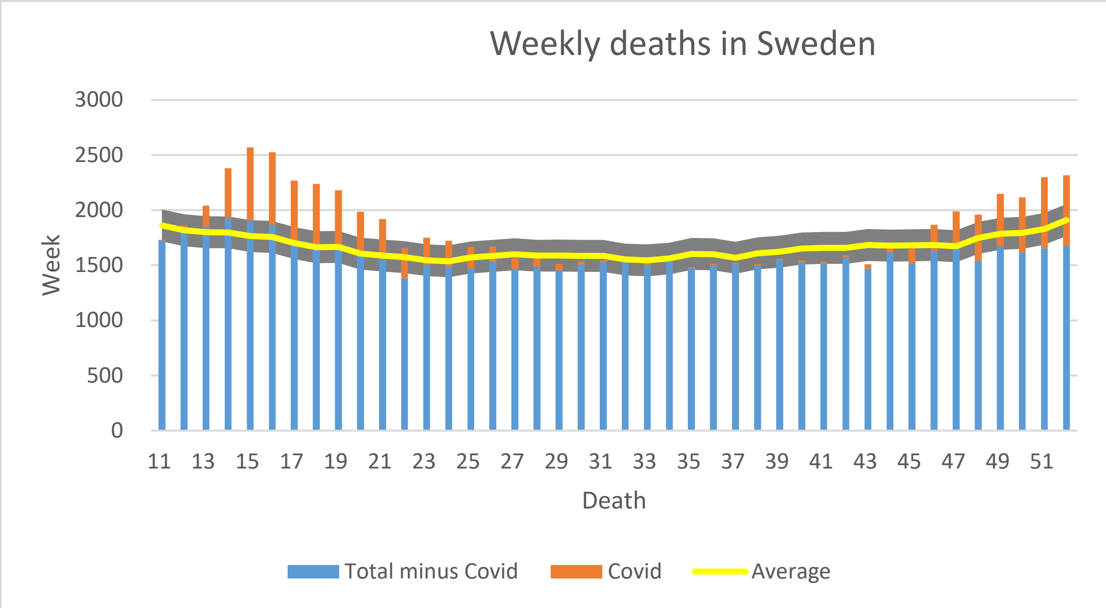

Weekly deaths in France
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Death
7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51
Week
Total minus Covid
Covid
Average

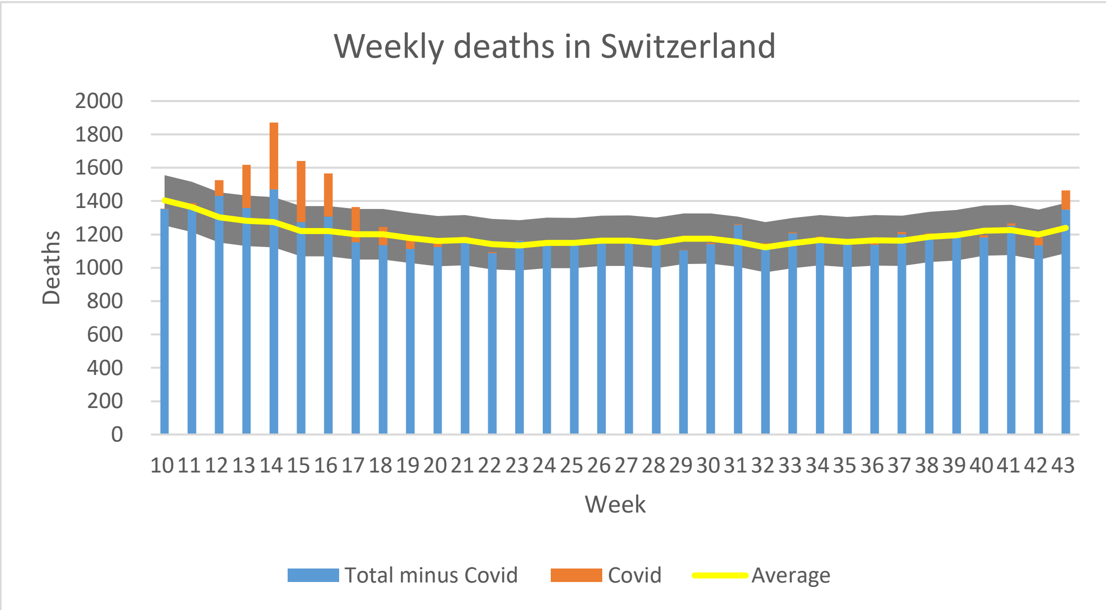

Weekly deaths in Germany
30000
25000
20000
15000
10000
5000
0
Death
11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51
Week
Total minus Covid
Covid
Average

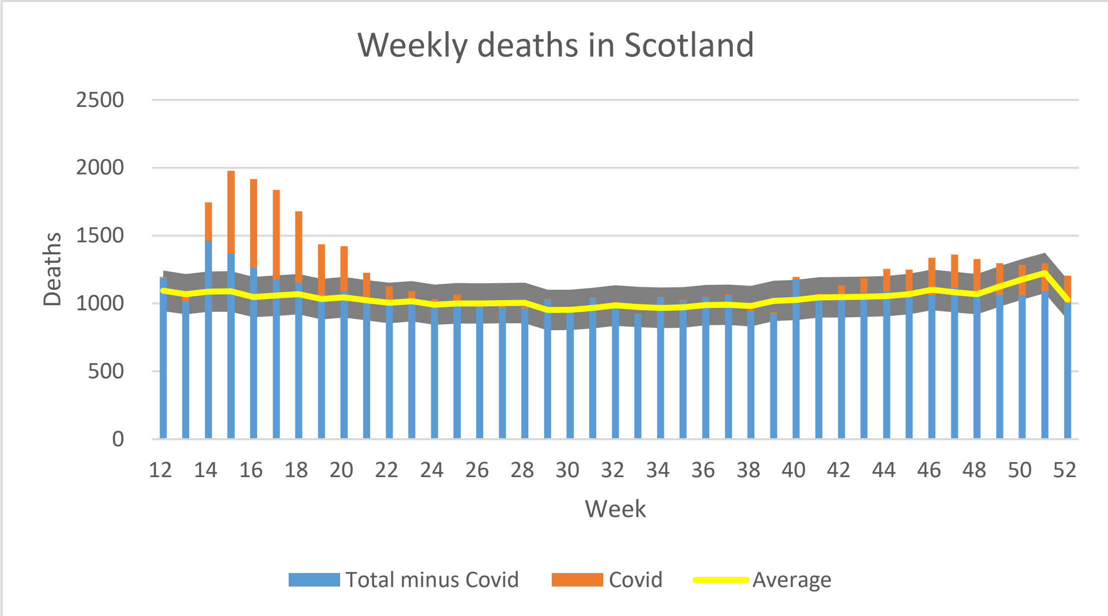

Weekly deaths in Netherlands
6000
5000
4000
3000
2000
1000
0
Death
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Week
Total minus Covid
Covid
Average


Weekly deaths in Portugal
3500
3000
2500
2000
1500
1000
500
0
Death
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Week
Total minus Covid
Covid
Average


Weekly deaths in Spain
25000
20000
15000
10000
5000
0
Death
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Week
Total minus Covid
Covid
Average


Weekly deaths in Sweden
3000
2500
2000
1500
1000
500
0
Week
11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51
Death
Total minus Covid
Covid
Average


Weekly deaths in Switzerland
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Deaths
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43
Week
Total minus Covid
Covid
Average


Weekly deaths in Scotland
2500
2000
1500
1000
500
0
Deaths
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Week
Total minus Covid
Covid
Average