MODELING AND FORECASTING THE IMPACT OF THE COVÏD-19 PANDEMIC ON SOCIO-ECONOMIC DEVELOPMENT

monograph

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2020

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UDC 353:330.4
Л-33

Recommended by the Scientific Council of Sumy State University.
Protocol № 6 from 24 December 2020.

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Л-33 Modeling and forecasting the impact of the COVID-19 pandemic on socio-economic development: monograph: Poland, 2020, 145 p.

ISBN 978-83-959336-3-9

The monograph deals with certain aspects of the problems in the world due to the spread of the COVID-19 virus. The governments' approaches in different states to curbing the spread of dangerous epidemics to stabilize and improve the socio-economic situation are analyzed. The authors investigate mathematical and economic models and scenarios for countries to emerge from the crisis caused by high rates of COVID-19 and quarantine measures. The monograph summarizes the features of models that allow predicting the further spread of the coronavirus and its impact and making significant managerial decisions to combat it. This research will help develop comprehensive economic and mathematical models for forecasting the effects of COVID-19 on the socio-economic development of countries and individual regions.

The monograph is for government officials, researchers, healthcare professionals, graduate students and students of Economics and some other specialties.

UDC 353:330.4

Bibliographic information of The National Library of Poland

The National Library of Poland / Biblioteka Narodowa lists this publication in the Polish national bibliography; detailed bibliographic data are on the internet available at <https://www.bn.org.pl>.

ISBN: 978-83-959336-3-9

DOI: 10.14254/ 978-83-959336-3-9/2020

First edition, 2020
Publishing House: Centre of Sociological Research http://www.csr-pub.eu
Szczecin, Poland

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Introduction

COVID-19 is a new dangerous virus that appeared in China in 2019 and spread rapidly. Panic has spread among all countries, and several divergent measures are being taken to prevent the spread of a dangerous infection, which causes mass morbidity cases among the population in terms of duration and complexity. Pandemics pose a threat to public health and negatively affect the economic situation in the countries. The COVID-19 pandemic has been a trigger that has unleashed the devastating large-scale imbalances that have accumulated in the global economy over the past two to three decades. In turn, methods of combating the spread of the pandemic in the form of widespread quarantine and forced isolation of large masses of the population, limiting its mobility and economic activity, have created an unprecedented socio-economic situation. Most developed and many developing countries have sacrificed their economies in favor of the imperative of preserving the population.

It is essential to consider the experience in dealing with the spread of such epidemics, which caused human disease in several countries or on different continents, to learn and understand how to overcome a new virus. Past epidemics remind the world community that such dangers occurred in the past, and COVID-19 is a confirmation that they exist and will occur in the future. The urgent task of society is if not to prevent such events but to be ready for a successful response to their possible negative consequences.

The authors set the goal to analyze the measures and tools used to support the world's economies in the outbreak of an epidemic, including swine flu H1N1, Ebola virus, and Zika virus. Most attention is paid to COVID-19 as a modern pandemic, which forces different countries and associations to overcome it. Mathematical modeling of epidemics of this type using various equations, systems, and software is essential to predict future developments and timely and skillful responses to new outbreaks. Many approaches to assessing the prevalence of viruses in the scientific community see the pandemic as a factor that causes crises in public life on a global scale. The task of the models for predicting the spread of infections is to develop appropriate measures to stop the spread of viruses based on the simulation results. Researchers aim to identify factors that contribute to the spread of morbidity by calculating the correlation between the hazard and the specific parameters considered in the equations and dependencies of such models. Prediction of COVID-19 today is complicated because only a small amount of information about the new pandemic is available. The infection and its features are still poorly understood. Due to the large number of asymptomatic patients who can convey the disease, it is challenging to model predictive scenarios.

The third significant task is to analyze the available examples of models that can demonstrate the impact of pandemic outbreaks on macroeconomic indices within countries and entire regions. An analysis of the short-term experience of coronavirus control already shows that large-scale lockdowns shock the countries' economies, but a return to everyday socio-economic life quickly will lead to new, often unexpected outbreaks of the virus.

Quarantine measures resulting from the COVID-19 pandemic show a very close relation between public and economic health. Forecasting, timely response and leveling based on the developed models of possible effects on the economy is a timely task. It confirms the feasibility and relevance of the author's study, which aggregates the set of existing models with their specifics.

The monograph was prepared as part of research work "Economic and mathematical modeling and forecasting of the COVID-19 influence on Ukraine development in national and regional contexts: public health factors and socio-economic and ecological determinants" (Application ID: 2020.01/0181).

Chapter 1. Preventive anti-epidemic measures and tools to support the economy during pandemia

The sudden epidemic of the Severe Acute Respiratory Syndrome-Coronavirus-2 (SARS-CoV-2), better known as COVID-19, has attracted worldwide attention. The first case of SARS-CoV-2 infection occurred in late December 2019 in Wuhan (China), but the disease spread to China and other countries in a few weeks. On January 30, 2020, the World Health Organization recognized a new danger to society globally (Durrheim, 2020). It was the sixth statement in the history of this organization (the previous ones are analyzed in Table 1). The Public Health Emergency of the International Concern (PHEIC) is a formal statement by the World Health Organization, defined as an emergency, a threat to public health for countries around the world due to the international spread of a disease that requires a coordinated global response (WHO, 2020).

During the first week of March 2020, the growing number of new cases of COVID-19 motivated the World Health Organization to consider COVID-19 outbreak a new pandemic. Experts estimate that COVID-19 could cost the world more than $ 10 trillion in losses. (Ahmed et al., 2020). However, not all infections of the past years are well-known. They were also dangerous, spread to some areas of the world, caused damage to the economies and led to irreversible consequences for the health of the population in certain countries.

Poliomyelitis mainly affects children under five years old. In one of 200 cases, irreversible paralysis develops. Since 1988 the number of cases of wild poliomyelitis has decreased by more than 99%. According to estimations, 33 of 350.000 cases were registered in 2018. The widespread immunization of the population facilitated it. Although there is at least one infected child globally, children from any country are at risk of infection. The impossibility to eradicate poliomyelitis outbreaks can cause up to 200.000 new infections worldwide each year in 10 years (WHO, 2019).

Table 1.1

Emergencies caused by international health hazards caused by viruses of various natures, proclaimed by the declarations of the International Health Organization, before COVID-19 (formed by the authors according to the data of Public Health Emergency, 2020)

Year	Title	Peculiarities
2009	Declaration on swine flu (A, H1N1)	It first appeared in the United States. On April 26, 2009, the declaration was announced. On the same day, almost 2 million unique users visited the WHO website for 3 hours. It showed the need to create a specialized site dedicated to the flu pandemic. By the time when H1N1 was declared PHEIC, it had already comprised three countries.
2014	Declaration on poliomyelitis	It was published in 2014 as a result of the poliomyelitis revival after its destruction. In October 2019, poliomyelitis cases continued to occur in Pakistan and Afghanistan and new cases in Africa and Asia. Therefore, PHEIC was continued on December 11, 2019.
2014	Declaration on Ebola	Cases of the deases were confirmed in Guinea and Liberia in March 2014, and in Sierra Leone until May 2014. Following the rapid spread of the virus in the United States and Europe, a decision was made to declare PHEIC.
2016	Declaration on Zika virus	It was announced on February 1, 2016 in response to the prevalence of microcephaly among newborns and Guillain-Barré syndrome (a condition in which the human immune system affects its own peripheral nerves) in the USA. This is the first declaration related to the mosquito disease. The declaration was revoked on November 18, 2016.
2018-2020	Declaration on Ebola Kivu epidemic	It was announced in July 2019. It was caused by the second Ebola outbreak in North Kivu province in August 2018. Besides, the active military conflict in that area complicated the outbreak.

The Ebola virus has infected West African countries. It began in Guinea and then spread to Nigeria, Senegal and Sierra Leone. In total, 26.593 people became ill with Ebola. 11.000 of them died. Guinea, Liberia and Sierra Leone have suffered the most from Ebola. The damage from Ebola for them amounted to 2.2 billion US dollars. Strict quarantine has been introduced to combat Ebola. If a flight from a dangerous or potentially dangerous area of Africa arrived at the airport of any country, all passengers were examined by medical staff. Travelers suspected of Ebola were isolated. In Sierra Leone, during the epidemic, all residents of the country were in quarantine. Six million people in the country were asked not to go outside to curb the spread of Ebola. Exceptions were only for doctors and police officers (Five epidemics, 2020). A set of measures is used To combat Ebola outbreaks. They include surveillance, monitoring contacts with patients, laboratory tests, special measures during the burial of infected dead, and social mobilization (Table 1.2). It is essential to involve local communities. An effective way to reduce human transmission is to raise awareness regarding risk factors for infection and their prevention, including vaccination.

Table 1.2

Ebola outbreaks worldwide since 2014* (WHO, 2020)

Year	Country	Number of cases, pcs.	Number of deaths, pcs.	Mortality rate, %
2018-2019	Democratic Republic of the Congo	continue		
2018	Democratic Republic of the Congo	54	33	61
2017	Democratic Republic of the Congo	8	4	50
2015	Italy	1	0	0
2014	Spain	1	0	0
2014	United Kingdom of Great Britain and Northern Ireland	1	0	0
2014	USA	4	1	25
2014	Senegal	1	0	0
2014	Mali	8	6	75
2014	Nigeria	20	8	40
2014-2016	Sierra Leone	14124	3956	28
2014-2016	Liberia	10675	4809	45
2014-2016	Guinea	3811	2543	67
2014	Democratic Republic of the Congo	66	49	74

Note: The Ebola virus has been known to the world since 1976, when its outbreak killed 88% of infected people in the Democratic Republic of Congo.

An outbreak of SARS (Severe Acute Respiratory Syndrome) in 2003 caused more than 8,000 illnesses and 800 deaths. The peculiarity of this virus is that it affects mostly young people. The epidemic has spread to 30 countries, especially Southeast Asia. Constant surveillance of patients, their isolation, strict isolation for those who have been in contact with patients, and the use of quarantine in some areas sustained the virus. The rupture of all possible connections between infected and healthy people helped to overcome the virus. Although scientists note that SARS and COVID-19 viruses are similar in some way, the differences between them radically change the approach to implementing the necessary measures to prevent the virus further. The SARS-CoV-2 virus, causing COVID-19, differs from SARS in terms of infection period, transmission, aspect of the disease, existing prevalence in the world. Fig. 1.1-1.2 demonstrates the disease coverage of the population in the world for both viruses. For the active COVID-19 pandemic, the real situation is observed in the world as of October 2020. The map was developed by Johns Hopkins University (Baltimore, USA).

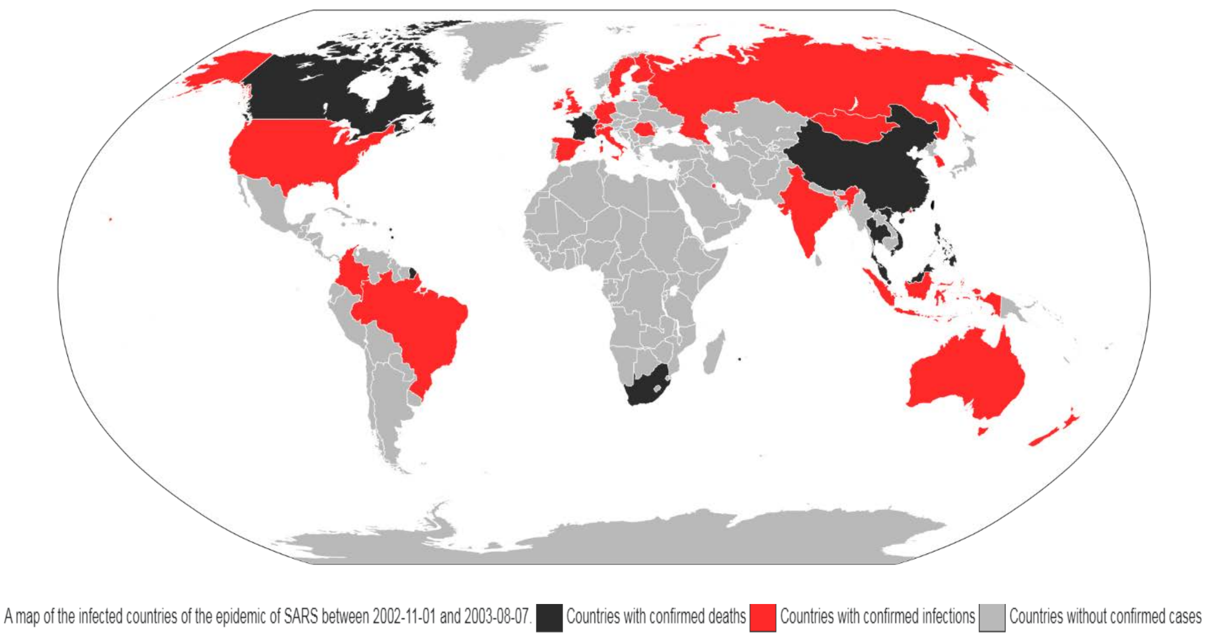

Figure 1.1 – Map of SARS prevalence in the world (WHO, 2003)

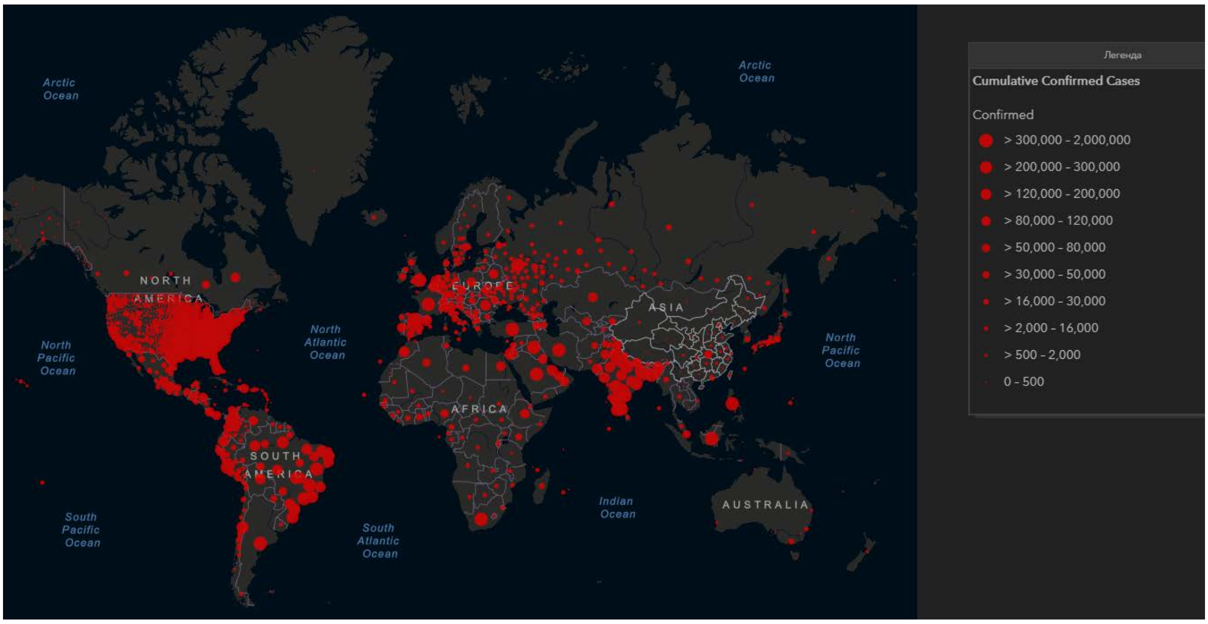

Figure 1.2 – Map of COVID-19 prevalence in the world as of October 7, 2020 (Johns Hopkins, 2020)

SARS has been liquidated through the introduction of pervasive stringent measures to stop its human-to-human transmission. In France, anyone who came in contact with the infected was required to be in quarantine for ten days. The measurements were useful and included actions to detect cases, isolate patients, track contacts and quarantine for all contact persons, social distance and general quarantine. The virus must be seen in the patient's body as early as possible to make the isolation measures effective. The number of infections was significantly reduced since the infected people were isolated for a maximum of four days after the onset of infection symptoms. Optimal isolation was introduced (for those who came into contact with patients and based on travel history) as a more effective action than the implementation of complete quarantine and universal isolation. People could be self-isolated at home or in special places, such as hotels. Both options were possible during the SARS epidemic in 2003. People in isolation had to measure their temperature daily and were called or visited by the public health team members. It is worth mentioning Toronto (Canada), where medical specialists investigated 2,132 potential SARS infection cases and identified

23,103 contacts who needed quarantine. In Hong Kong, police monitored the self-isolation during outings, and in Singapore, surveillance cameras were installed at each person's home in self-isolation to prevent leaving without permission (Goh et al., 2006; Tsang & Lam, 2003). During the SARS epidemic in 2003, China was an example of a country that introduced large-scale quarantine by declaring epidemic zones and effectively kept people in collective quarantine in cities, villages, or even some institutions. Besides, following the hygiene rules, namely frequent hand washing with soap, helped combat the epidemic.

In April, the country's authorities gained full control over all activities inside China to prevent the spread of the virus. Strict quarantine measures included the closure of schools, universities and public places, and the abolition of public holidays in May. China has shut down Beijing and more than 3,500 public places to contain the epidemic. The spread of the virus naturally stopped. Singapore has become a so-called "country of thermometers": The temperature monitoring has become mandatory in schools, and temperature screening has been applied at the entrance to all public buildings. Detection of cases has become even more effective when opening hundreds of specialized clinics and extensive media opportunities to inform the public. Concerned people agreed to follow the recommended restrictions on reducing virus transmission rather than getting sick. Public awareness of SARS was very high, and one could observe a very high level of motivation (about 90% of respondents in psycho-behavioral research in Singapore and Hong Kong) to resist a dangerous infection (Leung et al., 2004).

All countries affected by the virus were given strong political support. The governments of these countries were ready to implement the necessary measures to overcome the epidemic as soon as possible. One should notice that the level of awareness about COVID-19 in 2020 in the world is also relatively high. Findings of authors from different countries in studies from other fields (Bhagavathula, 2020; Rahmanov et al., 2020; Saqlain et al., 2020; Serwaa et al., 2020) proved that situation. Besides, most of the population believes that their government is taking adequate measures to prevent the spread of dangerous infections. Most people are well aware of the possible virus transmission. However, there are some gaps in the general public's awareness about the less common symptoms of COVID-19. Thus, many people want to get even more information about the 2020 pandemic, for example, through the media. According to this study (The study, 2020), more than half of the respondents believe that there is a low probability of SARS-CoV-2 transmission from person to person. Preventive measures within medical institutions included the placement of patients in special isolated rooms with barrier methods of patient care, strict adherence to personal protective equipment, restrictions on visitors, and staff movement. In Toronto, Canada, and Singapore, health care workers used gloves, gowns, eye protection, and N95 respirators to contact all patients, whether they had been diagnosed with the disease. Visits to patients with SARS were prohibited to prevent the spread of SARS outside the hospital. Medical workers or visitors to places where SARS occurred have been prohibited from traveling to non-infected areas. In Singapore, temperature control was performed twice a day for all workers. A hundred-seater hospital was quickly built in Beijing (within a week) to accommodate many patients (both confirmed and suspected). It provided an opportunity to take every seventh patient in the country with SARS (Wilder-Smith, 2020).

When talking about passengers' international transportation, almost all countries with imported infections have intended to prevent the spread of dangerous diseases. Exit temperature scans were used for all passengers arriving in countries with SARS infections. The psychological impact of the SARS virus on the population of many countries, together with travel bans announced by a large number of countries, resulted in significant economic losses for the aviation industry and the world economy in 2003, far beyond the central SARS regions. The financial loss from SARS was $ 59 billion. China and Hong Kong took the main brunt. However, unlike COVID-19 in 2020, SARS failed to stop the growth of the Chinese economy. Thus, in 2003, China's GDP grew by 10%, in 2004 - by

10.1%. It means that the SARS outbreak cost China's GDP only 1% (Five epidemics, 2020).

According to (Callaway, 2020), the spread of SARS-CoV-2 became inevitable. In the spring of 2020, according to several criteria, this virus was recognized as a pandemic. A coordinated response to such a global challenge is a prerequisite for the people’s survival and the economy. The health care system, indicating the most significant pressure in such phenomena as a pandemic, plays the most crucial role. The situation with this virus among many countries showed that regardless of age, most of the most severe patients had chronic diseases (diabetes, cardiovascular disease, or cancer) or previously had an unhealthy lifestyle (smoking).

SARS has affected the economies of 30 countries: the hotel business, tourism and air transport have been hit hardest by the epidemic. In the first half of 2003, a significant proportion of Chinese businesses were forced to close down. Air traffic in the country fell by 77%, and the average occupancy rate of hotels has tripled to 18%. The tourism population lost jobs, totalling more than three million people in China, Singapore and Vietnam. In China, losses in tourism amounted to $ 3.5 billion, and tourism flow decreased by 40%. Chinese retailers had to close their businesses for three months, employees had to take unpaid leave, and some, with the consent of employers, received a minimum wage of 300 yuan. Companies from Singapore, the United States and Canada were also forced to send their employees on unpaid leave. Some offices of the Australian bank The Macquarie Bank in Hong Kong allowed employees to stay at home at their discretion. Manufacturers of luxury items such as Burberry noted a decline in demand. Global clothing and electronics manufacturers have changed Chinese suppliers, and some companies (such as Sybase software manufacturers) have closed offices in China (Makarenko, 2009; Pelekh, 2013).

The epidemic has reduced the purchasing power of the population: the income of the average family in China has fallen by almost a quarter.

Unemployment has risen in the country: according to official figures, about 8 million people have lost their jobs. Journalists from the South China Morning Post wrote that unemployed migrants were not included in the statistics. In Canada, more than 28,000 jobs were cut, and in Singapore, the epidemic led to a 0.3% increase in unemployment, to 4.7%. In June-July 2003, the WHO lifted restrictions on China, Canada and Singapore and officially announced the end of the SARS epidemic.

As a result of the epidemic, Singapore's GDP lost $400 million, and Canada's fourth-largest SARS GDP loss was $5 billion in the first quarter of 2003. The World Bank has estimated losses for China's GDP at $14.8 billion and for the world at $33 billion.

The outbreak of the disease caused the active development of Internet services in China because it is through a quarantine that the population began to shop online actively. Online sales in China doubled in 2003 compared to last year to $ 471 million. The share of online sales is growing every year. It was then that the founder of the Chinese corporation Alibaba Jack Ma decided to shift the focus of the trading platform from selling for business to selling to private buyers. A week after the quarantine, he launched the Taobao online retail marketplace. Also, during quarantine, SMS became popular, which contributed to the growth of shares of cellular operators such as China Mobile.

First of all, China's economic sector has suffered the most from the pandemic. But at that time, China's contribution to the world economy was only 4%, as opposed to more than 16% today. As a result of the SARS epidemic, trade and economic ties were disrupted, and tourism and transportation services were affected. Stock and commodity markets were significantly damaged as demand for raw materials fell due to the economic slowdown. The Asian Development Bank has estimated the impact on the global economy of SARS at almost $60 billion.

In 2009, the world suffered from a new strain of the flu virus – "Mexican", or swine flu. In March, doctors recorded the first cases of infection in Mexico. Although the government considered the disease to be a typical seasonal flu, the virus quickly spread across the country and beyond. When the virus reached Europe, WHO declared pandemic status. Although the virus raged only 11 years ago, its scale remains controversial. The economic losses from the "Mexican" were significant. In particular, the world tourism industry lost $ 2.2 billion. Agriculture suffered losses.

Schools and universities in Mexico were quarantined on April 23, and mass events were cancelled. On April 25, the WHO was concerned about the rapid spread of the disease, the same day, Mexico declared a state of emergency in the country. On April 27, the WHO assigned the epidemic the fourth, and on April 29 – the fifth level of danger out of six possible. In May, nearly 5,500 people were infected in the United States, more than 3,500 in Mexico, and 496 in Canada. On June 29, the WHO declared the outbreak a pandemic. At that time, 30,000 people in 74 countries were infected. Since June, scientists have been actively working on a vaccine. Testing began in July. As a result, as early as November 2009, 78 million doses of the vaccine were available in 77 countries. On November 19, the WHO reported that 65 million people had been vaccinated. In August 2010, the WHO announced the end of the pandemic. As of July 2010, 18,449 people had died from swine flu, but there is no exact information on the number of infected people on the WHO website. According to the University of Minnesota, US scientists and the medical journal PLOS, in 2009-2010, about 10-20% of the world's population became ill with swine flu, and 200,000 people died.

Experts believe that the assessment of the effects of swine flu should be approached with caution, separating them from the effects of the global financial crisis of 2008-2009, which was reflected in the general slowdown in the world economy. One way or another, for the countries most affected by swine flu

(Mexico, the United States, Canada, Central and South America), scientists estimate the total loss from the pandemic at 0.5-1% of their annual GDP. For example, for Canada, total costs are estimated at at 2 billion Canadian dollars ($1.4 billion). These included the cost of treating patients, local school closures in cities, and the mass slaughter of pigs. The tourism industry also suffered losses. For example, the losses of airlines from the cancellation of flights are estimated at several hundred million dollars.

Employees of airports in the United States, China and other countries checked passengers for flu symptoms. In Mexico, all residents were required to wear masks, and the quarantine rules were monitored by the military. The United States, Australia, China, and other countries have quarantined and closed schools for two to four weeks. China, for example, has introduced a mandatory weekly quarantine for incoming travellers. 340 people, including 300 guests of the Metropak Hotel in Hong Kong, found themselves in quarantine in China due to one swine flu patient. However, not all of them were in contact with the patient. Australia has banned the disembarkation of 2,000 passengers on the cruise liner Pacific Dawn, which found three patients on board. The pandemic affected the airlines, tourism, food and entertainment industries the hardest. One of the few sectors that grew against the backdrop of the general economic crisis was pharmaceuticals. Officially, the WHO did not ban flights, and countries did not close the borders, but many refused to fly and returned tickets. The world tourism sector has lost about $ 2.2 billion amid a recovery from the 2008 crisis. Microsoft, General Electric, IBM transferred employees to the home office and limited the work of offices in Mexico. Cisco has temporarily closed offices in Mexico City. According to the NYT, about 40% of employees of private companies in the United States and Mexico were forced to go on unpaid leave on suspicion of illness. World GDP in 2009 was $ 60.3 trillion against $ 63.6 trillion in 2008. However, a decrease of 5% is due in part to the effect of the global economic crisis.

The previous epidemics mainly affected Eurasian countries, but Africa was affected by the Ebola virus pandemic. The virus was discovered in the 1970s, but mass infections began in 2013. The outbreak started in West Africa, or instead in Liberia and Guinea. Mortality from the Ebola virus is the highest per capita, as out of 27,000 infected, about 11,000 died and in some cells were fatal in 90% of cases.

The epidemic has caused irreparable damage to the already troubled economies of West Africa. In particular, researchers in 2016 reported that Guinea lost about $ 2 billion, or a third of its GDP, due to the virus. Many African countries affected by the epidemic have found themselves in isolation. Trade ties were broken. Importers refused goods, which caused even more significant damage not only to the economic sector but also to everyday life. In Liberia, due to the Ebola epidemic, the trade market lost 50-75% of turnover. Agriculture accounted for a quarter of Liberia's GDP in 2014. Quarantine and restrictions on the movement of labour affected the harvest and operation of farms, which led to food shortages and rising prices by 40%. In Sierra Leone, rice prices have increased by 30% due to the Ebola outbreak. The infection has led to a decline in the main exports of African countries affected by the virus, namely coconut and palm oil (Klein & Goldfarb, 2008).

However, the Ebola epidemic has affected the financial sector, not only in African countries. The risk of closing the borders of prizes to reduce travel between countries. Shares of American and British airlines fell. The losses were borne by hotel chains and businesses involved in Africa's logistics. Those who ran a mining business in areas where there were outbreaks of the Ebola virus became bankrupt. For example, the shares of the British mining company London Mining fell 100%, which led to its bankruptcy.

In general, according to experts from the Bank of England, the Ebola epidemic cost $ 53 billion. This amount included the cost of treatment, lost profits from the closure of enterprises, the cost of medical equipment, additional accommodation and doctors, financial assistance to affected citizens and businesses. On August 8, 2014, the WHO recognized the disease as a global problem and recommended that countries in the active stage of the disease introduce a state of emergency, and others to limit travel to countries with the disease and check the arrival of passengers.

In 2018-2019, the Democratic Republic of the Congo suffered from the epidemic. As of November 2019, 3,300 people became infected, and 2,199 died. According to statistics from the WHO and the US Centers for Disease Control and Prevention, more than 33,000 people became ill with the Ebola virus from 1975 to 2019, of which more than 15,000 died. Sierra Leone, Guinea and Liberia lacked physicians. Hospitals often lacked water, soap and protection. In 2014, more than 700 physicians from these countries were infected. Half of them died at the end of the year. In Liberia, 8% of medical staff have died, and more than 17,000 children have been orphaned (Leavitt, 2008).

In 2014-2016, the authorities of the affected countries imposed quarantine and restricted movement, including with the involvement of the military. Schools and grocery stores were closed. To allow doctors to detect new cases, Sierra Leone was banned from moving for three days. In Sierra Leone, more than 1.5 million people were quarantined. The country has closed its border with Georgia. Authorities blocked roads within the country and only allowed to travel within the regions along established routes from 9 a.m. to 5 p.m. Commercial banks have switched to a two-hour mode to reduce the risk of infection. Despite government bans, Africans continued to care for sick relatives on their own, arranging funeral rites that involved physical contact, which led to the further spread of the infection.

Africa’s agriculture has been hit hardest by the virus. The industry did not receive a third of the income. One-fifth of enterprises in the sector were forced to close due to bankruptcy. Due to the epidemic, the volume of air transportation and tourism, including neighbouring countries, has decreased. Tourism in West

Africa has halved during the illness. World Bank experts estimated the total impact of the epidemic on the economies of Guinea, Liberia and Sierra Leone at $2.8 billion. For Guinea, GDP growth fell from 4.5% to 3.5%. The World Bank has interpreted that in 2016, Sierra Leone's GDP will not recover. The country lost $800 million, or 20%. In Liberia, GDP losses amounted to $ 100 million. Almost every second person in Liberia lost their jobs. Unemployment has risen in other West African countries. The epidemic has reduced living standards in West African countries. According to a World Bank survey, more than 70% of respondents admitted that they did not have enough money for food.

In 2018, the Oxford Journal of Infectious Diseases estimated the economic and social losses of the disease in the world at $53 billion. In addition to the economic effect, the estimate included the cost of loss of life, treatment and control costs (Phelps, 2008).

Stock market declines during the SARS, H1N1 and Ebola pandemics were short-lived. And against the background of a significant increase in demand for medicines and masks, shares of pharmaceutical companies and manufacturers of medical masks have risen in price (Leonig, 2008). Data from Goldman Sachs in 2002-2003 show that trading in the market largely depended on the number of cases reported daily. The most substantial decline in the markets was recorded when the number of patients increased sharply. A factor that exacerbated the harmful effects of the epidemics and the crisis in 2008-2009 was the unfounded optimism of investors, which was based on expectations of further increases in commodity prices due to increased demand for limited supply. Based on speculative data on the spread of the swine flu epidemic, there has been speculative excitement over certain commodities. It primarily applies to oil, ferrous metals, wheat, coffee, soybean and sunflower oil. Table 1.3 shows the dynamics of world prices for these goods in 2007-2009.

Table 1.3

Dynamics of world prices for goods of special importance (formed according to (Leonig, 2008; Zaglynskyi, 2013)

Name	Measuring instrument	2007	2008	2009
Oil	dollar/barrel	74	133	64
Ferrous metals	USD/t	530	1000	600
Wheat	USD/t	238	328	225
Coffee	cents/pound	94	115	75
Sunflower oil	USD/t	673	337	1022

In 2008, compared to 2007, world prices increased from 123% to 337%. To neutralize the seasonal factor in the comparison, the data were taken for July each year. Without this factor, the growth of world prices was even more noticeable. In particular, the world price of wheat in 2008 reached $440 USD/t, for coffee – 1.22 dollars/pound, soybean oil – 1414 USD/t. In 2009, the price of oil dropped to $39 USD/barrel, for wheat – up to 191 USD/t, for soybean oil – up to 694 dollars USD/t. Such a sharp fluctuation in world prices for all these goods (except coffee) has not been observed for at least the last 30 years (Leonig, 2008; Shvaika, 2013; Zaglynskyi, 2013).

As the swine flu epidemic has significantly affected one of the most powerful sectors of the economy, agriculture, which is actively using credit programs, the response has been for central banks to lower the discount rate and reserve ratios for commercial banks. This path was chosen by the United States, the European Union and Japan, and since the beginning of 2008, the United States has reduced the discount rate seven times from 4.5 to 0-0.25%. The Bank of Japan lowered its key interest rate from 0.5% in early 2008 to 0.1% in late 2008. The Bank of England cut the rate five times during 2008 from 5.25 to 2%, and in March 2009 it was 0.5%. The European Central Bank's rate changed from 4% in early 2008 to 1.25% in April 2009. To this list should be added China, which moved from a tight monetary policy announced in 2003 to a softer one and began to gradually reduce interest rates and reserve ratios for commercial banks to stabilize lending to the economy (Shvaika, 2013; Zaglynskyi, 2013).

The main assistance from the states to overcome the global crisis and the consequences of the swine flu epidemic was directed to the financial sector. In all national anti-crisis programs of the countries, much attention was paid to the financial market. But on the other hand, the provision of assistance to banks is accompanied by the establishment of many mandatory requirements. In the UK, to obtain financial resources from the state, banks must enter into a so-called "lending agreement" with the government, which provides for specific amounts and types of mandatory lending to consumers and businesses. In France, a particular institution of “credit ombudsman” has been established, which monitors the use of state aid by banks and compliance with the transparency of procedures for business access to credit.

Today, China has higher medical standards, better medical services, and more experienced medical personnel than in 2003, when SARS spread. It is strange why the SARS-CoV-2 virus spread around the world so quickly. Since the end of January 2020, the coronavirus pandemic has affected more than 37.5 million people, with the number of fatalities of more than 1,070,000 people. The virus has spread from Wuhan in China to more than 180 countries and territories, affecting virtually every continent except Antarctica. Countries' efforts to combat the virus that caused severe pneumonia made many countries apply full entry-exit blockades, suspending international passenger traffic, mass layoffs, and financial crisis (Bloomberg, 2020). Fig. 1.3 demonstrates the dynamics of the epidemic prevalence in some countries since January 22, 2020, when in Mainland China, the number of confirmed cases of the new virus reached 500.

There are several explanations for the rapid spread of COVID-19. Today's situation differs slightly from the SARS pandemic. The city where SARS-CoV-2 was first diagnosed is the largest in central China. It is home to more than 11 million people. Wuhan is the central transportation hub, the industry and trade center, home to the largest railway station, the largest airport and port in central China. The urban population density is very high. The proximity of people to each other contributes to the spread of infection. During the outbreak, hospitals were overwhelmed with many patients. Therefore, most of them was not hospitalized, leading to the further spread of the virus in society. One should note that a new hospital was built in 10 days to accommodate more patients. It is also worth mentioning that a few days before Wuhan was quarantined, over five million people (most of them could already be infected) left their regions for other parts of China for the annual Spring Festival. Wuhan Airport's close links with other international airports have also contributed to the further spread of SARS-CoV-2 to cities and countries with significant air passenger traffic (Singapore, Japan, Thailand) (Bogoch et al., 2020).

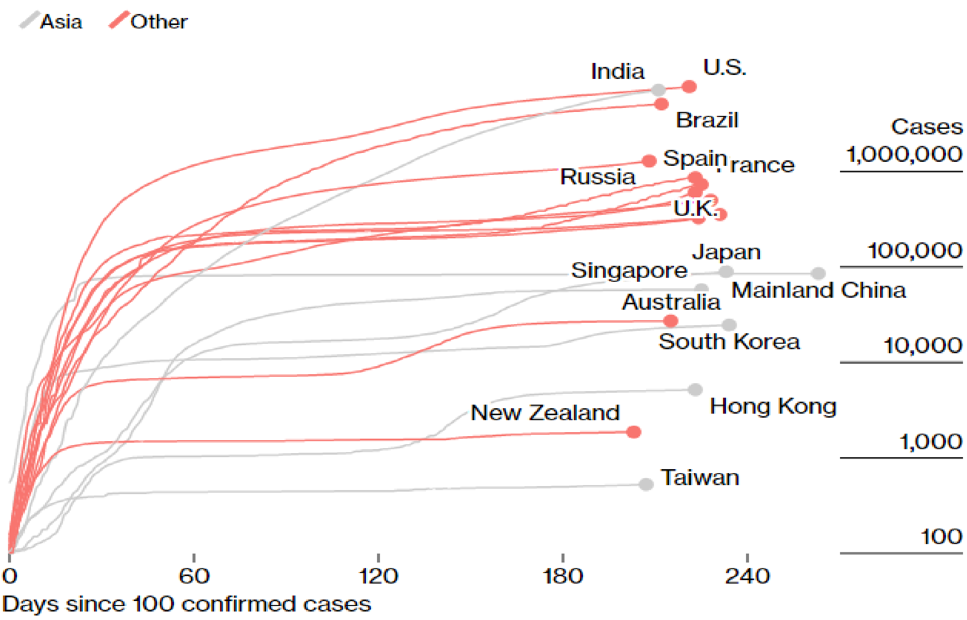

Figure 1.3 – Dynamics of confirmed cases of COVD-19 in the world (Bloomberg, 2020)

China took strong health measures: social distance, protective masks and a ban on public transport in Wuhan, including buses, trains, ferries and planes. In the course of the virus prevalence, by January 30, 2020, quarantine spread to more than 60 million people in more than 20 cities in China. It was the harshest quarantine in Chinese history. These efforts have negatively affected traveling and trade, the Chinese economy, and the mental health of millions of people in quarantine.

More than 140 countries have banned entry to their countries, any meetings and public events, and closed educational institutions. The easing of bans on restarting the world economy leads to a reactivation of the virus.

In March 2020, the Italian government took extraordinary measures to stop the spread of the virus, including a strict ban on movement to the Lombardy region, home to one-sixth of the country's population with the capital Milan, the largest city in northern Italy. The governor of Lombardy initiated the formation of quarantine zones (Coronavirus in Italy, 2020). However, the government did not implement that idea. Such measures to prohibit people's movement had to stop the virus prevalence due to the impossibility of contact between the infected and healthy population. The most crucial aspect for successful combat of the COVID-19 pandemic is strengthening the health care system, which must be ready for possible outbreaks in the number of infected people. Due to the high mortality rate of critically ill patients and the long recovery time (from one to two weeks), the number of infected people in Italy put a heavy burden on local hospitals. Some medical facilities did not have sufficient resources to cope with the new circumstances of the deadly pandemic. In the Lombardy region, restrictions on people's movement have not reduced the workload on hospitals. The medical staff has been working within 24 hours since February 20, 2020, and approximately 20% of them have been infected with SARS-CoV-2. Some of them died. Due to a lack of beds for patients in the Lombardy region, some of them were taken to the other areas.

Since the SARS viruses of 2003 and SARS-CoV-2 have significant differences, their spread dynamics and the effectiveness of preventive anti-epidemic measures depend on it. In particular, SARS-CoV-2 is more easily transmitted from person to person. It is also mild for many patients, which increases the probability that they will not be isolated in time and will be able to transmit the virus to other people. Fig. 1.3 demonstrates the dynamics of SARS-CoV-2 spread in the world. It is possible to argue that such a dynamic makes governments in many countries to move from a virus containment policy to a mitigation policy for the COVID-19 epidemic. Even those countries that have effectively combated the infection, for example, China and South Korea, are witnessing an intensification of its re-spread. A warm climate does not affect the virus and does not reduce its activity. In May 2020, the World Health Organization stressed the need to develop a plan that would include testing for the virus and antibodies to it, tracking people who contacted with the sick and their isolation, and educating the general public to prevent the spread of coronavirus infection (WHO, 2020). The world's best scientists and leading producers of medicine are continually working to develop effective treatments for COVID-19, as well as vaccines against this disease.

Full implementation of infection control, prevention and early response measures can significantly reduce the spread of SARS-CoV-2 worldwide. These measures enable the world to spend more time preparing for the possible intensification of COVID-19 in some countries, namely:

– improve the health care system for identification, proper isolation and medical care of patients with COVID-19;
– prepare health care facilities for the admission of patients with COVID-19 (ensuring the availability and constant supply of necessary medicines, consumables, disinfectants and personal protective equipment, the supply of medical equipment, etc.);
– develop and timely update appropriate standards for medical care.

On March 7, 2020, the World Health Organization recommended the countries to consider four scenarios for the transmission and spread of COVID-19:

scenario 1 – there are no registered cases of COVID-19 in the country;

scenario 2 – cases of COVID-19 among the population are sporadic; one or more imported cases of COVID-19 are registered, which relate to visits or stays in other countries;

scenario 3 – the first infection cases with COVID-19 were revealed within the country (local cases). They were localized in a specific administrative territory in the form of clusters (district, city, region) and for which there is an epidemiological link with a previously registered case of disease investigation;

scenario 4 - there is an intensive spread of COVID-19 in more than two regions or throughout the country (local and imported cases are registered).

Unfortunately, as of October 2020, Ukraine has the fourth scenario of COVID-19 spread.

In July 2020, the World Health Organization informed about another group of COVID-19 development scenarios worldwide, since several states that have fought the infection since the spring of 2020 had some investigations in this area. Undoubtedly, all countries are at risk of infecting, but the complexity of the situation with COVID-19 differs. The Head of the World Health Organization, Tedros Adhan Gebreyesus, states that the WHO sees four scenarios for the spread of SARS-CoV-2 in the world:

1) It is implemented in countries that have been warned of a possible COVID-19 outbreak (some countries in Southeast Asia, the Pacific, the Caribbean and Africa). They responded quickly and effectively to the first cases. As a result, they managed to avoid significant outbreaks.

2) Large-scale outbreaks of infection taken under control thanks to strong authorities and a population that is ready for radical action (many European countries).

3) Countries managed to overcome the first peak of the disease, but after easing the restrictions, the virus returned. The WHO did not name examples of such countries but only noted that most of them took a wrong path.

4) Intensive spread of infection (North and South America, South Asia and several African countries).

In general, Table. 1.4 shows the number of registered cases of COVID-19 and the number of deaths caused by it as of October 15, 2020.

Table 1.4

25 countries of the world where COVID-19 became the most widespread (as of October 15, 2020) (formed by the authors according to (Countries, 2020)

№	Country	Number of registered cases, pcs.	Number of deaths, pcs.	Region
1	USA	8,150,383	221,850	North America
2	India	7,309,164	111,337	Asia
3	Brazil	5,141,498	151,779	South America
4	Russia	1,354,163	23,491	Europe
5	Spain	937,311	33,413	Europe
6	Argentina	931,967	24,921	South America
7	Colombia	930,159	28,306	South America
8	Peru	856,951	33,512	South America
9	Mexico	829,396	84,898	North America
10	France	779,063	33,037	Europe
11	South Africa	696,414	18,151	Africa
12	United Kingdom	654,644	43,155	Europe
13	Iran	513,219	29,349	Asia
14	Chile	485,372	13,415	South America
15	Iraq	413,215	10,021	Asia
16	Bangladesh	384,559	5,608	Asia
17	Italy	372,799	36,289	Europe
18	Indonesia	349,160	12,268	Asia
19	Philippines	348,698	6,497	Asia
20	Germany	341,742	9,771	Europe
21	Saudi Arabia	340,590	5,108	Asia
22	Turkey	340,450	9,014	Asia
23	Pakistan	321,218	6,614	Asia
24	Israel	299,502	2,109	Asia
25	Ukraine	281,239	5,302	Europe

R. Baldwin, Professor of International Economics at the Geneva Institute of International Relations, stated for the American journal Foreign Policy (Johnson, 2020) that coronavirus is both medically and economically infectious. COVID-19 had a triple impact on the manufacturing sector of most leading economies in the world. Many factories have been closed, there are supply failures worldwide, and demand for goods is declining due to people's expectations. Governments are taking many steps to struggle with the economic impact of COVID-19 (Reuters, 2020). Different countries respond differently to the new threat, from closing public facilities to the emergency and restricting people's free movement. Many countries with a low level of the disease are still trying to prevent it from becoming the epicenter of the epidemic. Even the United Kingdom, where security measures were less stringent from the beginning than anywhere else in Europe, isolated the elderly, and the country's government insists on quarantine for anyone diagnosed with coronavirus (Savkova, 2020).

Impact of COVID-19 on the socio-economic situation of the world and actions aimed at its support and overcoming the crisis

The USA. This country was among the first where the first cases of COVID-19 were registered. On January 21, 2020, the government informed about the danger of a new infection. There were travel bans, and US citizens were expected to be evacuated from countries affected by the coronavirus.

COVID-19 affected US companies operated in the market in partnership with businesses from China and other countries affected by the infection. The pandemic has negatively affected the country's economic growth. Boeing's representative announced that the decline in demand for airline services would significantly affect the economic indices of such companies in all quarters of 2020. There is an impact on the US pharmaceutical and medical industry since the US depends on the EU and India companies. The coronavirus outbreak in China affects the supply of finished medicine and active pharmaceutical ingredients (APIs) in the United States. About 83% of Chinese imports from the United States included finished drugs, and only 7.5% were APIs. Blocking the plant in China and delays in logistics in ports lead to reduced production and delays in delivering necessary components to manufacturers in the United States. Imports of Indian-made APIs were very profitable for the United States in terms of cost savings. According to American sources, API imports from India saved 30 to 40% of pharmaceutical companies' costs in the United States and Europe. However, the coronavirus outbreak in many countries worldwide, including India, can complicate logistics and lead to delays in deliveries and price rising for products. It is clear that with the spread of the virus in the EU, US pharmaceutical companies have to deal with an increase in their costs. Pharmaceutical company AstraZeneca, for example, has already pointed to the negative impact on its revenues in 2020.

The medical device industry is another sector of the US economy temporarily affected by the COVID-19 pandemic. Since China is the leading exporter of US medical devices, it accounts for almost 40% of medical imports. Delivery delays mean loss of revenue for local market operators. For example, such producers, General Motors, started manufacturing medical equipment, namely ventilators, which are essential for the treatment of critically ill patients with COVID-19.

On the contrary, other economic sectors hope for positive market developments, particularly US pharmaceutical companies investigating vaccines and drugs. For example, Johnson & Johnson, Vir Biotechnology, Novavax and NanoViricides are working on coronavirus vaccines. In 2020, US biopharmaceutical companies Abbvie and Gilead are expected to benefit from increased sales of their Kaletra and Favilavir products, respectively.

A large number of companies in the United States purchase parts and components from China. Since only 30% of small businesses resumed production in China after the coronavirus outbreak, US producers try to buy details they previously imported from China to avoid production disruptions. Such companies as Apple, Caterpillar, Deere & Co, Komatsu and Morton Industries look for local component suppliers. Limited supply and significant demand have increased the cost of components, domestic prices of which are 30% higher than the Chinese ones.

According to predictions, the US tourism industry will lose about $ 10.3 billion, half of which will fall in 2020. The number of visitors from mainland China in 2020 will decrease by 1.6 million people. US foreign tourism is expected to suffer losses by 2024 since China is currently the largest export market for the United States in tourism (Vasanthi, 2020).

In the United States, emergency expenditures of $ 8.3 billion were given to fight the spread of the virus and develop vaccines. The United States sent millions of dollars to other countries to fight dangerous infections. In March 2020, the US Senate approved the allocation of 2.2 trillion dollars to help the national economy and to purchase the necessary medical equipment. US President D. Trump entrusted the Treasury Department to defer tax collection for specific individuals and businesses affected by the coronavirus. The government also provides low-interest loans for small businesses in the affected states (Savkova, 2020).

US President Trump has instructed the Treasury Department to defer tax collection for certain individuals and businesses affected by the coronavirus. The government also provides low-interest loans for small businesses in the affected states (Savkova, 2020).

The government banned public meetings of more than ten people in the country; public places (restaurants, bars, cafes) were closed. People were advised to avoid unnecessary travels. It is obligatory to screen the travelers' health at the airports. On January 31, 2020, the US President approved a ban on entry for all travelers from China or those who passed through China 14 days earlier. The ban did not cover permanent residents and visa holders. The government designated eleven airports for flights from China and those who have been to China. These airports are better equipped with special devices to prevent the spread of coronavirus. The US hotel industry is also expected to suffer losses since only according to the tourism experts' first estimates, the number of tourists from China to the US will decrease by 28%. The loss from hotel shortages will be up to $ 4.6 million for the hotel industry because more than 60% of Chinese visitors to the United States stay in hotels for an average of 15 nights. The states of California, New York, Utah and Oregon suffer the most since they are the biggest beneficiaries of foreign visitors.

India. In response to the spread of COVID-19, the Indian government has wholly closed the country since March 24, 2020. The decision was so unexpected that most stakeholders in the state did not have time to prepare for such actions. The Indian economy during the pandemic outbreak was not sufficiently ready for any external negative influences. In a concise period, the unemployment rate increased, small industrial enterprises closed, and supply chains collapsed. There was a further collapse in prices in the agricultural sector of India. The cost of input resources has increased within the country, and there were problems with their timely delivery. Consumption of the country's population decreased, and domestic debt increased. The unemployed workers in India became migrants, intensifying the movement of the population (reverse migration) in the country. Such a significant number of negative consequences can be offset only by government support (COVID-19, 2020). India is a developing country and one of the fastest-growing economies in the world. Therefore, COVID-19 affected India when there was a significant increase in GDP in the third quarter of 2019-2020. Many economic sectors are negatively affected by the pandemic, and their recovery is quite a challenge soon because these industries continue to decline steadily. Many companies took loans from commercial banks and other financial institutions. They have to pay interest on loans, despite their unsatisfactory financial condition. Various factors (blockage, low consumption, increased patient numbers, job losses, rising health care costs, reduced imports and exports, etc.) undoubtedly have a significant negative impact on the Indian economy.

The mobile application "Arogya Setu App" was launched in the country to track people's movement to prevent the spread of a dangerous virus among the population. The Government of India and the Reserve Bank of India have introduced various economic and fiscal incentives to combat the country's financial crisis caused by the new pandemic. The Indian Reserve Bank has taken specific measures to facilitate credit institutions' work in liquidity, regulation and supervision, financial markets, etc. The repo rate was reduced to 4% from 4.9%. The cash reserve ratio decreased from 1% to 3%. It is the first time for India in the last eight years that this index has changed. Indian Banks were allowed to establish a 90-day moratorium on term loans and working capital for payments from March 1, 2020, to May 31, 2020. In April 2020, the government established the institution to meet the short-term liquidity needs of the states COVID-19, 2020).

There is the following support programs in India: Mahatma Gandhi National Law on Guaranteeing Rural Employment (MGNREGA). It will increase the demand for their products for people working in other fields. The government allocated additional funds for this; The Reserve Bank of India implements long-term repo transactions; loans are given for businesses affected by the coronavirus outbreak.

China. Ophthalmologist Li Wenliang was the first to register COVID-19 infection. He informed about his discovery on the social network WeChat. The authorities did not trust him. When Li Wenliang contracted the coronavirus and then died, the Chinese Supreme Court formally criticized the Wuhan Police Department for concealing the doctor's discovery. At that time, the number of victims was rapidly approaching 30 thousand people. Authorities began active action against the new type of coronavirus in late January 2020. Ten cities were closed, businesses stopped their working, and public meetings, including marriages and funeral ceremonies were banned. Major international events were canceled: the World Athletics Championships in Nanjing (postponed to next year), the Formula 1 Grand Prix postponed indefinitely, the Asian Economic Forum, etc. A temporary Huoshenshan Hospital for Coronavirus Patients was built in Wuhan in ten days. In two weeks, scientists from Hong Kong created a portable device that enabled to diagnose a new type of coronavirus. The device can analyze liquid secretions samples from the body and gives the result in 40 minutes. In late January 2020, Hubei Provincial authorities told about criminal liability for those who evaded treatment, harmed medical personnel, or intentionally spread the virus. Patients cannot refuse inspection, treatment, quarantine since they are dangerous to others. China used the same disciplinary measures in the early 2000s during the HIV epidemic. Besides, for example, the authorities of Qianjiang, China's Hubei Province, promised to pay citizens $ 1,420 if they report symptoms of SARS-CoV-2 infection. Those people whose diagnosis is confirmed received the money. In other cases, citizens receive $ 285 (if they have similar symptoms).

The Chinese government supported creating a particular mobile application allowing users to check whether they have been in contact with coronavirus-infected people. After downloading and registering, users must enter the name and ID number to understand where they may have met infected people. The State Committee for Hygiene and Health, the Ministry of Transport of the People's Republic of China, the Chinese Railways and the Civil Aviation Administration of China provide their data to the developers to ensure the application work.

In the southern Chinese province Hainan, authorities pay up to $ 287,000 compensation to companies that resume their work. This amount will help cover commodity losses and losses from employees' quarantine. In total, the Chinese government allocated $ 15.9 billion to fight the epidemic. The Central Bank of China reduced several vital rates, including the lending rate, urging banks to provide cheap loans.

Latin American countries. Most Latin American countries have quarantined due to the COVID-19 pandemic. Many countries in the region have a similar problem that most local workers are employed informally, so they cannot count on government benefits due to quarantine. There is significant social inequality in Latin America. Many poor people suffer significantly from the economic events caused by the pandemic. For example, 38 million people work informally in Brazil (about 40% of the working population). In this country, governors and mayors independently decide on quarantine measures in their district or city. Therefore, restrictions vary by region. For example, San Luis, in the north of the country, enforced a strict quarantine. The citizens are only allowed to leave the house for food, medicine and necessities. And in Sao Paulo, where most people have died from the virus, less stringent quarantine measures have been introduced. Public facilities are closed, and mass gatherings are prohibited. People should wear protective masks in public places. In Brazil, there are many social media discussions, where some believe that it is necessary to open everything and return to everyday life, as suggested by President J. Bolsonaro, others - that it is required to stay at home (Dzheims et al., 2020).

Italy. On January 31, 2020, two tourists from China had the first coronavirus infection in this country. Authorities decided not to wait for the epidemic and immediately closed flights to China. Simultaneously, an emergency was imposed in the country for six months and five million Euro were allocated for disease prevention. In late February, the Italian Council of Ministers passed a decree allowing the relevant ministries to ban all activities. All sports events in Venice and Lombardy, including national championship matches, have been canceled. School trips abroad were restricted. Ten cities with a total population of 50 thousand people in the Lodi region enforced quarantine. Universities in Lombardy and neighboring Venice have been closed. Actors and world brands have joined the fight against the spread of the infection. Milan La Scala Theater has canceled all performances. The Italians also had to stop the last days of the Venice Festival. G. Armani held the show at Milan Fashion Week without spectators. Besides, the fashion house closed all its offices in the city and factories in the north for seven days. On February 25, the coronavirus adjusted the activities of the film industry. The shooting of the seventh film in the series "Mission Impossible" in Venice was stopped for actors and film crew safety. The country's ski resorts have been suspended ahead of schedule. And in March, the Italian Prime Minister closed 14 provinces with a population of 16 million. People were forbidden to leave the cities. Exceptions were made only for those who traveled on business because of family problems or deteriorating health. But even in such cases, people had to carry a supporting document.

According to experts' comments, Italy's reaction to the new virus was feeble and belated. For example, as of February 23, 2020, there were already 123 cases of coronavirus in the country, and 11 cities were quarantined. The government's policy was ambiguous: on the one hand, the government insisted on social distance, and on the other hand, it assured citizens that it was not necessary to change their living habits in the country. The Italian health care system was not ready to deal with such a global crisis. The country lacked protective masks and respirators. Italian hospitals were overcrowded with patients with uncritical symptoms that could be treated at home.

The government has passed a decree providing 25 billion Euros to cover losses from the coronavirus and special measures to save the economy. In mid-March 2020, the Italian government issued an emergency resolution, which indicated the allocation of almost $ 4 billion to finance the health care system, mainly to increase the number of intensive care units and the purchase of ventilators, protective equipment. Experts compare the northern region of Italy, Lombardia, which suffered the most, and the north-eastern part of Veneto, which suffered much less. The Veneto region succeeded since there was mass testing here, so it was possible to track people who could contact patients. Further, it enabled to isolate people who were at high risk of contracting the virus.

The government has allocated € 100 million to support the agricultural sector and fisheries to cover interest costs (up to 70%) on working capital loans and debt restructuring. Licensed airlines also received compensation. Air transport infrastructure support includes an increase of € 200 million in funding from the Solidarity Fund through existing mechanisms. The guarantee mechanisms support companies' liquidity affected by the pandemic through a guarantee fund set up by the Ministry of Economic and Finance, to which 500 million Euros have been allocated. Companies registered with the Wage Allowance Fund with more than five employees that have suspended or stopped working due to an emergency had the opportunity to obtain a loan for the period up to August 2020 for wage payments. The funding amounted to 80 million Euros. Companies whose employees were already on special leave or were fired applied similar measures without additional requirements for the number of employees or registration with the Fund. The funding amount is 332.3 million Euros. The financing of state guarantees on export credits amounted to 2.6 billion Euros. Companies that have overdue receivables for more than 90 days can receive a tax credit until December 31, 2020, for the overdue sum, but not more than 2 million Euros for each company. An accelerated procedure for certification of protective equipment (masks), producer's temporary self-certification, mainly imported goods. Mortgage payments were suspended and covered by state guarantees for banks. Italians who are unable to work due to quarantine obtain special payments. Working parents are offered a voucher for 600 Euros to compensate for the child nurse's services. It is available for families with children under 12. Parents working in the private sector have the opportunity to go on paid leave. Moreover, they can receive up to 50% of the allowance if they have a child under 12. All workers with a total income of at least 40,000 Euros per year, who continued to work in March 2020 during quarantine and emergency, could receive a bonus of up to 100 Euros. A total of 10 billion Euros is provided to support families and entrepreneurs.

Iran. The first cases of the new virus in Iran were recorded in mid-February 2020. Both infected were in the province of Qom. On February 25, the president announced that the coronavirus was less dangerous than the flu and urged citizens not to be afraid of infection. The heads of other countries did not support the optimistic mood of H. Rouhani. Turkey, Russia, and Kazakhstan blocked the transport connections with Iran. In late February, authorities still refused to accept the danger of the disease. Instead of quarantine, the government has announced restrictions on the movement of people with COVID-19. Special groups measured people's temperatures at the exits from the cities. If someone was suspected of having an infection, he or she was in a two-week quarantine. The Health Minister announced that visits to Shiite shrines would be restricted. They were opened for visits only at the end of May 2020 (with a visit in a protective mask, passing through a disinfection tunnel and checking the temperature) (Iran, 2020). Disinfection tunnels have been produced and installed in many countries (India, Malaysia, Albania, Argentina, China, Pakistan, France, Mexico, Sri Lanka, Azerbaijan, Kazakhstan, etc.) (Changoiwala, 2020).).

These are tunnels of different types (Fig. 1.4).

Figure 1.4 – Disinfecting tunnels installed in different countries

At the end of February, schools in 21 Iran provinces (most of the country's provinces) announced a vacation due to the spread of the coronavirus. The Ministry of Education and Development started preparing the conditions for distance learning. In early March, Iran's parliament temporarily stopped working. At the same time, checkpoints were set up to restrict travel between cities on the roads. The Head of the Ministry of Health advised Iranians to use paper money less often and not get out of cars at gas stations. Universities are also closed. About 70,000 prisoners were released to fight the spread of the coronavirus. Despite the spread of the infection, Iran's largest airline, Iran Air, has resumed flights to Europe since March 10. Before that, the company suspended work for two days due to restrictions imposed by Europe. However, most countries have imposed restrictions on flights to Iran due to the spread of the coronavirus.

Given Iran's economic embargoes, that country needs to maintain a domestic economy and consumption. Many businesses are experiencing crisis times since most consumers decided to stay at home; sales rates have declined. Unfavorable circumstances also affected large companies. In particular, the country's leading automaker Iran Khodro, has stopped production to combat coronavirus spread among employees. Iran's hotel industry also suffers from coronavirus. For example, the Halvacara recreation house in the center of Isfahan (known for its Persian architecture) stopped taking in guests after the coronavirus outbreak. Experts point that two million jobs will be lost in the country after the closure of hotels, restaurants, schools and other institutions. At the same time, Iran's poorest people are losing their jobs, and without income, they are losing access to the health care system, which increases the risks of dangerous virus spread. In general, Iran's domestic economy depends heavily on the service sector, particularly vulnerable to coronavirus exposure, creating about 12 million jobs, or almost half its employment.

Meanwhile, demand for Iranian oil is falling. China, the leading buyer of oil from Iran after the imposition of US sanctions, has reduced oil imports. The Iranian currency has lost 10% of its value since the virus was detected (Statistical Center of Iran, 2020). Non-productive exports also decreased with the closure of neighboring countries and the cessation of flights.

The government tried to encourage consumers to shop on New Year's Eve (in Iran, the Novruz New Year is celebrated on March 21 or 22) by involving more than 100 businesses in an online shopping promotion program to keep the country's economy. Terms of loan repayment and utilities have been extended, and loans have been offered to small businesses. However, such measures, in the long run, may increase inflation in countries (Rasmussen, 2020). There is a negative dynamics of Iran's national currency since the beginning of the coronavirus pandemic (Fig. 1.5).

Figure 1.5 – The exchange rate of the Iranian rial to the US dollar (Rasmussen, 2020)

Today, the exchange rate of the Iranian currency against the dollar is even lower and is 29,600 iranian rials for 1 US dollar.

South Korea. For a long time, South Korea was among the countries with the highest number of coronavirus cases. The first case of coronavirus in this country was discovered on January 20, 2020. People believed that the infection could not be transmitted from person to person, so the ban measures began to be introduced later. In early February, foreigners who had been in the Chinese province of Hubei for the past two weeks were banned from arriving in South Korea. Citizens of the country coming from this province were in a two-week quarantine. In mid-February, the mayor of Daegu, near Seoul, recommended that 2.5 thousand residents wear protective masks and stay indoors. The government declared Daegu and Cheondo areas of special interest. On February 24, for the first time in ten years, authorities announced a red alert due to coronavirus. School holidays continued. Army conscripts were banned from being outside their base when one of the Jeju Navy's officers visited Daegu and contracted the coronavirus. At the same time, South Korea and the United States postponed spring joint military exercises. It is the first time that exercises were postponed for similar reasons. In early March 2020, the number of people infected with COVID-19 almost reached 5,000. The President of South Korea announced the beginning of a "war" with the coronavirus. According to his report, the infection situation has become critical, so the government introduced a 24-hour emergency and emergency response regime for all state institutions in the country. The president also noted that the virus has strongly affected the national economy, so the government allocated $ 25 billion to combat the crisis.

South Korea has stopped spreading the coronavirus better than any of the developed countries in the world. According to experts' estimates, it was twice as effective as in the US and the UK. South Korea's economic indices are expected to fall by only 0.8% in 2020. One can argue that South Korea got success by a combination of technology and testing (including the use of unique plastic telephone booths, allowing people to be tested for the virus quickly and safely. Then it was possible to track the infected people, their contacts, centralized authority and well-established communications, citizens' understanding of danger (Martin et al., 2020). South Korea tested 15,000 people daily and became one of the world's leaders in this field, and gained experience in dealing with new dangerous viruses during an outbreak of respiratory syndrome MERS reorganizing its disease control system in 2015. The country has a high-quality health care system and a highly developed biotechnology industry that can quickly carry out many virus tests (How to deal, 2020).

Canada. The coronavirus appeared in this country in late January 2020. The readiness and well-functioning of the medical system, information policy transparency of governmental and non-governmental organizations, the citizens' responsibility are factors that enable Canada effectively to combat the spread of dangerous infections. The country's medical institutions work efficiently. They always have hand antiseptics and medical masks for colds and flu. Antiseptics are available in all public places. There is a useful government website in Canada where you can find relevant information about coronavirus infection. In February-March, all medical institutions sent patients e-mails with information on measures to prevent coronavirus infection. Patients were informed about the importance of refraining from traveling to countries with virus outbreaks. People received an algorithm of action in case of suspicion of COVID-19 disease. When the World Health Organization informed about a pandemic on March 11, 2020, similar letters began to arrive from work and study, from banks, insurance companies, and even movie theaters and restaurants. In Canada, all media are adequate and professional. Their publications state the facts, telling the population about the real situation and how to act in emergencies. An essential aspect of the effective fight against coronavirus is the Canadians' mentality. Here people obey the laws and rules. They use hand antiseptics, wash their hands for 20 seconds and do not touch their faces after visiting public places. Besides, a significant number of Canadians have a seasonal flu vaccination and are not used to treating a cold at home. They immediately go to the doctor and, if possible, do not go to work or visit educational institutions.

Despite the relatively slow spread of SARS-CoV-2, Canada still announced on March 12, 2020, the need for people's self-isolation. All sporting events, exhibitions and concerts were canceled. Schools, colleges, universities, some private companies started working remotely. Local cafes stopped selling reusable coffee cups, which are so prevalent in Canada. The country's post office changed the rules for delivering valuable parcels to restrict courier communication with recipients. Antiseptic wipes appeared at the entrances and exits of stores and pharmacies. All residents move their cars, use the drive-through service in fast-food restaurants, cafes and banks. Amazon orders, home food orders from restaurants and supermarkets became popular (Svezhentseva, 2020). The state allocated 83.5 billion Canadian dollars, which is 3.6% of the country's GDP, to overcome the coronavirus effects. Simultaneously, the government gives 1.125 billion to improve the health care system (intensified testing of the population, investigation of vaccines, purchase of medicines, smoothing of economic consequences and support of indigenous peoples). About 23.6 billion are given to the country's residents (payments to employees who do not receive sick leave, unemployment benefits, issues, increased tax benefits and childcare benefits). About 58.8 billion are spent on business support, including deferred tax payments and wage subsidies for downtime. The main monetary and macro-financial measures include:

- reduction of the interest rate on overnight deposits (for one business day) to 0.75%;
- expansion of the bond redemption program;
- expansion of conditions for urgent repo transactions, except for the portfolio of non-mortgage loans;
- support of the national mortgage bonds market through their purchase on the secondary market;
- raising the target for the current account of banks from 250 million to 1 billion Canadian dollars;
- The Bank of Canada together with the central banks of Japan, the Eurozone, the United Kingdom, and the United States expanded the liquidity of these countries’ currencies;

– The Bank of Canada has launched a permanent liquidity mechanism to lend to relevant financial institutions that need temporary liquidity support.

The Canadian financial sector took other measures: the banking regulator OSFI reduced the required size of the internal stability buffer for large banks from 2.25% to 1% of the risk-weighted assets; the government allocated $ 10 billion to lend to businesses affected by a coronavirus. Major agricultural lender Farm Credit Canada gave $ 5 billion to support lending to the manufacturing sector, agribusiness and food waste processors (Kozhemiakin, 2020).

Japan. The support of the Japanese travelers' return from abroad, strengthening immigration controls, and credit for small and medium-sized enterprises were key measures to respond to COVID-19 in Japan. In March, the Japanese government informed about the second set of steps to respond to the epidemic, namely, initiating an increase in hospital beds, additional support for corporate loans and measures to support employment. In April, the government announced the third package of support to stimulate the Japanese economy by $ 1.1 trillion, equivalent to 22% of GDP. About ¾ of this amount was used to support business, the rest - to finance the health care system, public investment, and public consumption campaigns. The country imposed a state of emergency, but it was lifted for 39 prefectures in Japan in May. By the end of May, it was abolished everywhere. At the end of May 2020, the Japanese government announced an additional set of economic support. It was $ 1.1 trillion.

The key list of measures within this package included benefits to support rents for small and medium enterprises, subordinated loans to large companies, tax policy measures (deferred payments, tax cuts, etc.), compensation in case of job loss, financing the study in case of retraining. The state supports employers whose businesses are in crisis, and they keep their employees, give them jobs and holiday pay, and allow employees to take part-time paid leave without dismissal. From April to December 2020, the state subsidizes up to 100% of leave allowances for small and medium enterprises and up to 80% of leave allowances for large enterprises. Large companies can obtain loans to respond to the crisis. These are low-interest loans provided by the Development Bank of Japan. According to the terms of the loan, there is no upper limit on the amount. Airlines and car producers mainly take such loans. The Ministry of Finance has introduced a secure loan (the limit is 720 million Japanese yen) and a loan to respond to the crisis (the limit is 300 million Japanese yen) to support small and medium-sized enterprises. Besides, the Ministry of Economy, Trade and Industry introduced lending: a guarantee program (guarantee limit – 280 million Japanese yen) and guarantees related to the crisis (guarantee limit – 280 million Japanese yen) to support small and medium enterprises (Japan, 2020).

As for other measures during the epidemic, Japan has rejected the World Health Organization call that it is necessary to test patients actively. Only a small part of the country's population has passed PCR tests. Although there was a state of emergency in the country, residents were not required to stay home. It was only recommended not to leave their own home without a particular need. Stores selling non-essential goods were advised to close, but there were no penalties for non-compliance. The Japanese effectively follow recommendations. Besides, this country's citizens are accustomed to staying away from each other; they hug and kiss less. People in Japan began wearing masks 100 years ago during the Spanish flu epidemic that started in 1919. Since then, masks have been worn if a person has a runny nose or cough to protect others. The contact tracking system in Japan was established in the 1950s when tuberculosis intensified in the country (Uingfield-Geis, 2020).

The United Kingdom of Great Britain. The first case of coronavirus infection was confirmed in Great Britain at the end of January 2020. The country's blockade was announced on March 23. People were asked not to leave their homes. Meetings of more than two people were prohibited; less important shops, gyms, libraries, playgrounds were closed. People (at least two persons) could visit physical exercise parks. The British airline company took preventive measures, canceling direct flights to China and back. The airline has canceled hundreds of flights to Europe and other regions. The private airline Virgin Atlantic announced similar measures with a full reimbursement of booking costs. The major UK airports introduced obligatory temperature screening. Schools were closed to hold the spread of the disease (Duddu, 2020).

The coronavirus outbreak is expected to negatively affect those British companies that export their products to China or carry out other commercial transactions with that country. In November 2019, China accounted for 9.4% of total imports of goods from the United Kingdom. China is also one of the five largest import markets from the United Kingdom. KPMG predicts a 2.6% decline in the UK economy in 2020, and economic recovery is projected for the second half of 2021 (KPMG, 2020). The business activity expectations index in May defined significant reductions in the UK, but in August 2020, the country's economy began to grow at this rate (Fig. 1.6). It provides optimistic predictions for the future with the stable easing of quarantine measures and stabilization with the number of infected people. The business activity index identifies the procurement managers' activity level in the country's services sector. An index above 50 shows an expansion of the industry, and below 50 indicates a reduction. Traders monitor this indicator since procurement managers typically have early access to their company's performance data. It can be a leading index to assess a country's economic performance. A higher-than-expected index should be considered positive/bullish for the country's GDP, while a lower-than-expected index should be negative/bearish for GDP.

The coronavirus outbreak directly or indirectly affected many British companies. The manufacturer Volex suffered from the prolonged closure of manufacturing suppliers of components in China. The British brand Burberry Group has expressed concern about declining sales of its products in China and Hong Kong. The company closed 24 of 64 stores in mainland China, while other stores operate with time constraints. The British Petroleum Company believes that world oil consumption may fall by 0.5% due to its lower demand. The company expects to reduce consumption to 500,000 barrels per day (Duddu, 2020).

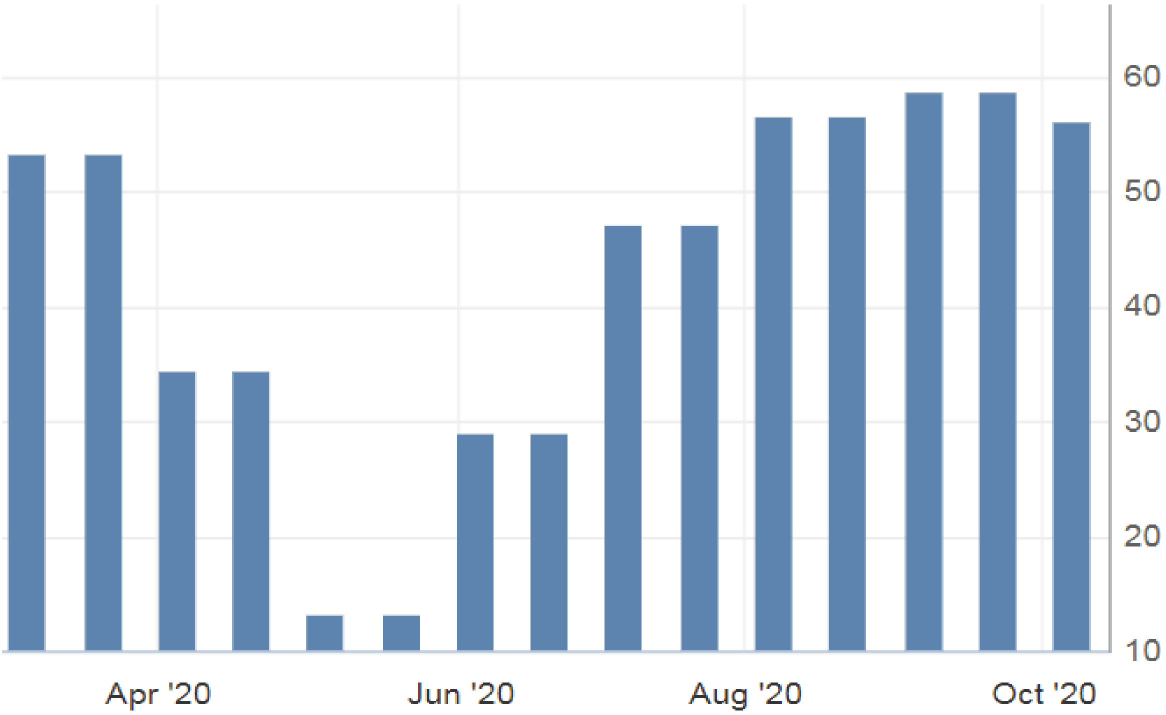

Figure 1.6 – Index of business expectations in the UK during the coronavirus pandemic (U.K. PMI, 2020)

The UK government sees the coronavirus as a factor affecting the country's economy in the short term. So, most measures are designed for the near future or until the 2020-2021 tax period. The government did not refuse the increase of expenditures to ensure economic growth in the medium term (investment in transport infrastructure, digital infrastructure, hospitals, schools, R&D expenses). The Financial Law, prepared in the fall of 2020, includes anti-crisis measures of the government.

The UK has developed a $ 39 billion economic stimulus plan. The Bank of countries lowered interest rates. The UK government informed about the payment of 80% of the salaries to 28 million private-sector workers to reduce unemployment in the country. Value-added tax companies were allowed not to pay VAT for three months (until the end of June 2020) with the right to receive a deferral of the tax debt that arose until mid-2021. Payments for personal income were postponed to January 31, 2021. The government provides a £ 10,000 grant to cover business costs. Since the end of March 2020, British Business Bank has opened access to overdrafts of up to £ 5 million per year for companies with an annual turnover of at least £ 45 million, under government guarantees of 80% on each loan. The guarantee is free of charge. All companies and self-employed persons who have financial difficulties and overdue tax liabilities through COVID-19 can receive individual advice and deferral in the tax authority through a particular service, "Time to pay" (Cherkashyn, 2020).

Sweden. This country has chosen a strategy to combat the coronavirus by ignoring it. The Swedish government does not impose strict quarantine and blockades. The country's authorities advised people to keep a safe social distance. There is a ban on meetings of more than 50 people. The authorities recommend that elderly people isolate themselves and avoid contact with other people as much as possible. Besides, citizens are advised to work, play sports, live as usual. The goal of this strategy is to protect the elderly and those most susceptible to SARS-CoV-2. Young people at low risk are allowed to spread the virus, become infected and produce antibodies necessary to fight such pathogens in the future. The Swedish approach contrasts sharply with the blockades in other countries. Blocks are costly, ineffective and have negative socio-economic consequences. One should note that the Swedish economy has suffered the least among others in Europe. It became the only major economy in the first quarter of 2020 that grew (Niman, 2020).

Saudi Arabia. The country, severely affected by the COVID-19 pandemic, reported the first case on March 3, 2020. Before this danger, MERS-CoV was the country's primary concern, but the Saudi government successfully controlled the infection. (Zaki et al., 2012). In response to the new threat, the government has taken unprecedented measures to inform the public and prevent the virus spread.

These measures included the closure of educational institutions, public transport and all public places, the isolation of the infected and suspected of infection (Arab News, 2020). On March 9, 2020, the government announced a blockade of the entire country and recommended that the population stay at home and adhere to social distance. For the first time in the country's history, prayers have been suspended in all mosques, including Mecca and Medina (Shrines, 2020).

Spain. The coronavirus situation is the most challenging circumstance that Spain has had to face since the Civil War of 1936-1939. In response to the epidemic, the country adopted more flexible mechanisms for temporary employment adjustment, particularly retail, hotel, and restaurant sectors. The priority task for the government is to minimize the fall in GDP in the country. It means that all companies must work remotely if it is possible. Spain introduced quarantine restrictions rather slowly. Since the state of emergency declaration in mid-March 2020, the government has closed all museums, archives, libraries, memorials, public shows, and other leisure and entertainment places. The reception of citizens in institutions and authorities is minimized. For this purpose, for example, passports, driver's licenses and licenses are automatically extended. During the emergency, the state decided to suspend all administrative and procedural terms. Only the Constitutional Court and specialized courts for violence against women did not stop their usual routine. Citizens cannot leave the house if there is no urgent need (receiving medical care, purchasing food, receiving money at an ATM). When leaving home, citizens need to plan the necessary time and distance.

People heard about the story of a fined citizen who walked a dog 800 meters from his house. Jogging or playing sports is not considered a good reason to leave home. The regularity of all public and suburban transport is preserved. Moreover, some long-distance routes of medium distances were preserved. Most hotel-type facilities redesigned to increase the number of sanitary beds were closed in the country. For the same purposes, the Spanish Ministry of Health controlled private clinics and large "field" hospitals. From March 30 to April 9, all spheres were blocked, except for the most necessary for the country's (Yakubuv, 2020).

The government allocated about 17 billion Euros from the budget. The state also expects that the private sector will undertake additional funding (about 100 billion Euros). The total amount of state guarantees should amount to 100 billion Euros. Thus, the total amount of support for the economy is approximately 217 billion Euros.

France. The first case of coronavirus in France occurred in late January 2020. The Louvre was closed immediately, the Third Canneseries Festival in Cannes and the International Television Market MIPTV 2020 were postponed, the French Championship matches were without spectators. On March 8, 2020, the authorities banned any events planned to be attended by more than 1,000 people. The government canceled the scheduled local elections and postponed the pension reform. Besides, there was the country's transport blockade. "Useful for the nation" events, which included rallies and competitions, made the exception. Taxis and hotels were mobilized to transport and accommodate medical workers. There are field hospitals in some regions, such as Alsace. The work of transport within the country was significantly reduced (We are at war, 2020).

However, the French gave in to panic. Thus, in early March, pasta sales in the country increased by 60%, flour - by 25%, rice - by 25%. Sales of other essential goods also increased since the French people worried about a possible shortage of food due to the coronavirus. According to predictions, due to the pandemic, the French economy in 2020 will fall by 1% (Ventura, 2020). The French government allocated 345 billion Euros to support the country's economy. 300 billion of them was directed to the state guarantee of enterprises' loans, mostly small and medium-sized businesses, another 45 billion - for direct assistance to enterprises. 2 billion Euros has been allocated to support microbusiness (France, 2020).

Germany. This country differs in quarantine measures by region due to the federal system of this state. In particular, one can buy ice cream in street cafes anywhere except for four lands (Hesse, Saxony-Anhalt, Rhineland-Palatinate, Baden-Württemberg). Small picnics in the company of people living in the same apartment are allowed in Berlin, Bremen and five other federal states but were banned during the quarantine at six. You could sunbathe everywhere except Berlin, Brandenburg and Saxony. There were special "Corona taxis" in Heidelberg, a university campus in southwestern Germany. Physicians with personal safety equipment examined the in-home quarantine patients on the fifth or sixth day of illness. Germany responded rapidly to the pandemic. All schools, kindergartens, playgrounds, universities, theaters, cinemas, museums, libraries, and other public institutions were closed. Supermarkets and grocery stores, hardware and cosmetics stores, bakeries, pharmacies, post offices and bookstores remained open. Flower shops were closed for a short time, but they quickly returned to work. Restaurants and cafes sold food with them or via home delivery. People could walk in parks, forests, play sports on the street to prevent mental disorders and prevent domestic violence. Some workers in the country started remote work. Some took leave, including at own expense. Some schools and kindergartens continued to work: there were children of workers of those professions that are necessary for the functioning of society (doctors, police, public transport drivers, salespeople). Three main ways ensured compliance with quarantine rules: constant government communication with the public, mutual assistance, fines and penalties. For example, in Berlin, each violator must pay a fine of 25 to 500 Euros for violating a social distance of 1.5 m and staying in someone else's apartment - from 10 to 100 Euros. Entrepreneurs have higher fines: from 500 to 10,000 Euros for violating the first time and 25,000 Euros for repeated violations of quarantine rules. Failure to self-isolation could result in imprisonment for up to two years or a fine of up to 2,500 Euros. Germany conducts more than 350,000 coronavirus tests per week to ensure patients' timely isolation and reduce the death rate.

According to experts' estimates, Germany's GDP in 2020 will decline by 5.4%. The relatively mild recession in Germany is due to the relatively low number of coronavirus infections. Besides, this country is less dependent on the tourism industry, unlike France, Italy, or Spain (OECD, 2020).

The website of the Federal Government of Germany (Official site Germany, 2020) contains information on state aid to cultural figures, private entrepreneurs and startups. The German government considers preserving the cultural sphere to be one of the top priorities, so 50 billion Euros was allocated in the short term to help cultural figures and private entrepreneurs. Applications for assistance were submitted online and processed within 24 hours. One-time aid of 9-15 thousand Euros, depending on the number of employees, is paid for three months. Besides, the German state development bank KfW provides fast loans to medium-sized enterprises (more than ten employees), including workers in the cultural and creative industries. The quick loan's peculiarity is 100% protection by the federal guarantee and the lack of risk assessment by the domestic bank. The loan amount was up to three monthly sales in 2019, and depending on the number of employees, it can reach up to 500-800 thousand Euros. The government also canceled bureaucratic barriers to various forms of social assistance and unemployment benefits and banned the termination of leases in the case of non-payment by a tenant due to a pandemic (Rits-Rakul, 2020). The value-added tax rate was reduced from 19% to 16% for six months (preferential rate - from 7% to 5%). Each child living in the country received a one-time payment of 300 Euros. 25 billion Euros is provided to help the industries most affected by the pandemic (such as tourism and restaurants). The total amount of Germany's anti-crisis program for 2020-2021, agreed in early summer 2020, is 130 billion Euros. Its goal is quickly to get the country's economy out of the crisis and direct its development in the right way (German government, 2020).

Australia. The central government budget provides A$ 213.6 billion for a support program (direct budget expenditures of 11% of GDP), and total regional budget expenditures amount to A$ 12.8 billion (0.7% of GDP). The state guarantees amounting to A$ 320 billion are provided (16.4% of GDP) (How is budget, 2020).

The Czech Republic. This country has one of the most detailed programs to help the economy from the harmful effects of the COVID-19 pandemic. At the state expense, the country covers 80% of workers' salaries from shops, restaurants, and other enterprises, forced to stop working due to quarantine. Companies must pay the remaining 20%. The Czech government also covers half the salaries of the supply business employees, namely companies with limited access to the materials required to function correctly through quarantine measures and companies that faced declining demand for their products. Another action plan is provided for the self-employed. They may suspend social security payments, and those who are significantly affected get support. The state pays care allowance to all employees with children under the age of 13. The benefits will be 424 kroner per day or about 14,000 kroner per month (about 500 Euros). The entire package of the Ministry of Labor is designed for six months, and its cost is about 630 million Euros.

The State Czech-Moravian Bank for Guarantees and Development investigated an interest-free “COVID Loan” to pay salaries when the business does not operate. The loans of 1.5 to 15 million kroner (5.5-55 million Euros) with a payback period of up to two years are announced. The Czech Ministry of Finance has also granted a three-month deferral of income tax and personal income tax returns (To survive the crisis, 2020).

The European Union. In March 2020, the European Union Council agreed to allocate 37 billion Euros to protect the bloc economies from the coronavirus effects. Eight billion Euros of this sum is distributed between the businesses and companies, suffered the most from the pandemic. The Governing Council of the

European Central Bank decided to launch a securities repurchase program for 750 billion Euros to maintain financial stability in terms of the coronavirus. The EU's Economic and Financial Affairs Council approved a proposal by the European Commission to suspend the Stability and Growth Pact to support the economy in response to the pandemic for the first time in its history. This decision abolishes the budget deficit limit (not more than 3% of GDP) for the Commonwealth, provides governments with unlimited loans to support business (What measures, 2020).

In general, the authors of studies on consumer preferences in countries before and after the pandemic conclude significant changes in the market. In particular, the authors of the work (COVID-19, 2020) studied changes in purchasing behavior in many countries affected by COVID-19 (Nigeria, Turkey, USA, European countries). They analyzed people with different income levels and different genders. Besides, the labor market was assessed according to the respondents' answers. According to the survey results, initially, 8.5% of respondents belong to the category of "Housewives," the rests are employees or business owners. Among that 91.5%, more than 9% lost their jobs due to the COVID-19 pandemic, 6.3% expected to lose their jobs, and 24% understood that they could lose their jobs if the pandemic continued. According to (Ryder, 2020), the number of people who lost their jobs due to the coronavirus pandemic reached 200 million people worldwide, 30 million of which was in the United States. The survey's generalized results regarding the growth and reduction of their expenses on various needs are presented in Fig. 1.7. 44.6% of respondents reported a decrease in income in their family. Moreover, for 17.4% of families, incomes decreased to 25%, for 16.4% to 25-50% and for 9.8%, such a decrease was much higher. Only 12% of respondents reported that their income increased during the coronavirus pandemic. We can confirm D.M. Keynes's theory regarding the reduction in market demand and the investment amount in the case of a decline in household income. And in the case of the market situation during the COVID-

19 pandemic, there is a downward trend in demand for various products in the markets of different countries (Arestis et al., 2018). In the survey, respondents noted that their expenditures increased during the pandemic (59.6% of respondents). Only 20.3% informed that their expenses, on the contrary, decreased. However, for 20.1% of families, the costs remained at the same level during the epidemic. There is an increase in the expenses for purchasing beverages and food for 68.5% of families. Moreover, for 23.7% of families, the costs increased within 25%, for 28.7% – within 25-50%, for the rest, this growth was higher than 50%. Given the SARS-CoV-2 virus specifics, one should look at changes in household expenditures on cleaning and hygiene. Here 75% of respondents confidently pointed to an increase in such costs. For 27.5% of families, there was an increase of up to 25%, for 27.7% – within 25-50%, for the rest – more than 50%.

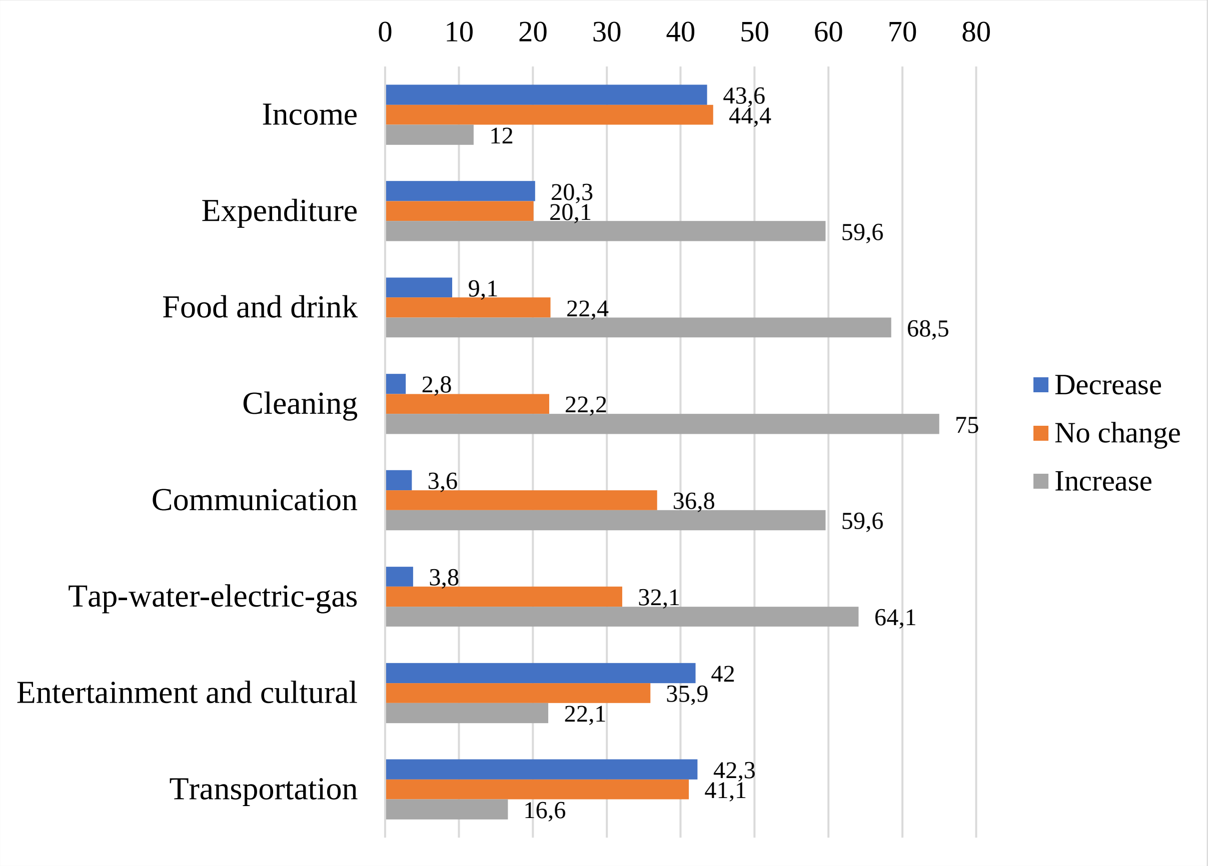

Figure 1.7 – Changes in income and expenditure of the world's population during the coronavirus pandemic in 2020, as a percentage (COVID, 2020)

Expenditures on communications in households increased (59.6% of respondents). However, the costs remain the same for 36.8% of them during the pandemic. The utility costs for families in the world increased during the coronavirus pandemic noted by most respondents (64.1%). Only a small part of the respondents indicated that their utility expenses decreased (3.8%) during the pandemic. One-third of respondents say that these expenses remain the same. The social distance and closing of many public places reduced household expenses on entertainment for most respondents (42%). Some respondents are optimistic about the growth of their entertainment and cultural enrichment costs, mostly within their country. People's expenses on transport and car service were significantly reduced. More than 40% of respondents reported a decrease in their costs, and only 16.6% said their transport costs increased. About 41.1% of respondents said that their transportation costs remained the same. According to the weighted average calculations, households' expenditures on transport, car service, and related services decreased by 14.9%.

In general, if we talk about the socio-economic impact of COVID-19 in the world, people in most countries began better maintain hygiene and cleanliness in private and public places during the pandemic outbreak. The virus harms the mental health of the population, a large number of negative social consequences. Thus, the COVID-19 pandemic has prioritized several forms of racism, religious hatred, and caste discrimination in China and India. During the long blockade in many countries, people must live only in their own homes with social distance from others. As a result, some social groups of the population suffer from prolonged depression. Persons who had to isolate or be in quarantine complain about negative thoughts, including suicidal ideation. One can note a misunderstanding and hostile actions of people towards each other. Kishore & Jha (2020) state that a pandemic impact varies depending on the economic sector, region, social groups, etc. If this negative impact does not significantly affect agriculture, other sectors will be much more negatively affected. The economic sectors with many people employed will be substantially affected. It was much more difficult for the building sector to reach a pre-crisis state than the financial sector. Stock markets, banks, non-bank financial institutions feel the economic consequences of the pandemic. People spend money only on the most necessary items. They save funds in case of emergencies. Since the lack of income caused delays in loan repayments, most credit institutions found themselves in an unstable environment.

COVID-19 is compared to the emergence of the "black swan" effect (Taleb, 2019). Its outbreak in the world was challenging to predict. Therefore, the economies of many countries, including the United States, are in a global shock. The market situation has changed both in terms of supply and demand. The dependence on China's goods leads to supply disruptions in such developed economies as the United States. As a result of the blockade and quarantine measures in China, electronics, garment, technological and other industries faced severe production disruptions, leading to declining inventories and a natural decline in sales soon (Halliburton, 2020). People are actively stocking up on hand sanitizers and face masks. In the market, it caused a shortage of supply for these products since manufacturers do not have time to meet the demand for them (Roy, 2020).

In general, the coronavirus pandemic has caused large-scale shocks in all economies of the world (Baker et al., 2020). Today, it is difficult to predict how long the pandemic will last and its effect. The time required for countries to return to the COVID-19 stage can be calculated based only on some factors, namely the industry's blockade duration most affected by the epidemic. Although some countries have made progress in preventing and treating coronavirus disease, it is difficult to determine whether they will have new outbreaks.

Let us observe the impact of the coronavirus pandemic on the world's most vulnerable economic sectors.

Air transportation industry. The COVID-19 pandemic significantly affected global airlines due to travel restrictions and flight canceling to reduce the virus's harmful effects. The aviation industry has lost its revenue. In the second quarter of 2020, there was a drop of about 2 billion passengers. The decline in airport revenues amounted to $ 39.2 billion in the second quarter of 2020. According to the forecasts, it is about $ 97 billion for the whole of 2020 (Gittens, 2020). Airlines have taken various measures to reduce financial losses: reducing passenger capacity, abandoning old aircraft, reducing compensation to managers, voluntary leave for employees, reducing the hiring of new employees, minimizing insignificant costs (for example, travel, marketing), restrictions on food distribution and beverages onboard, sale of shares, sale or lease of aircraft, engines and other assets and termination of share repurchases and dividend payments. Fig. 1.8 indicate the unemployment rate in air transport in different regions of the world due to the coronavirus pandemic.

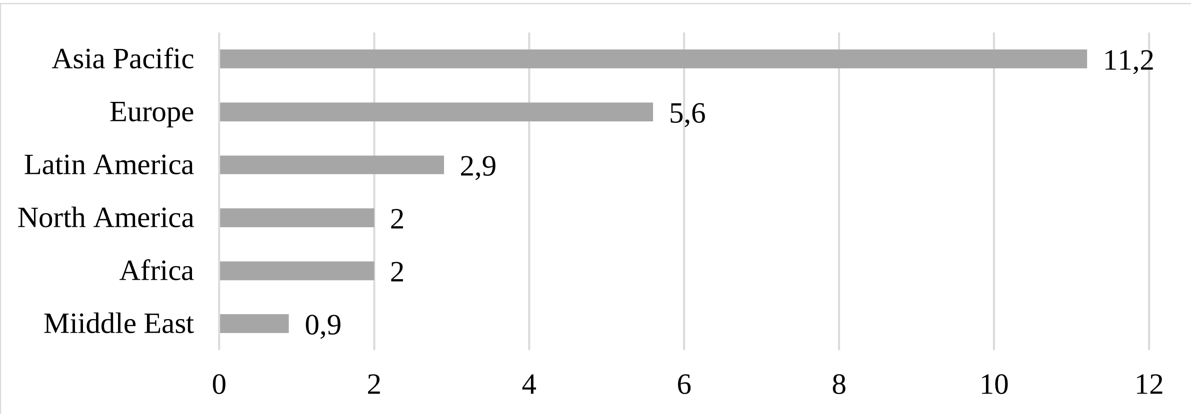

Figure 1.8 – The number of unemployed people in the air transportation field bt region in 2020, due to the pandemic COVID-19, million people. (Statista, 2020)

Fig. 1.8 shows that in the Middle East, there are about 0.9 million aviation workers who became unemployed as a result of the COVID-19 pandemic. For example, in the Asia-Pacific region, the number of unemployed is much higher – 11.2 million people. In the European area, there were 5.6 million unemployed people. According to the International Air Transport Association, about 25 million people employed in the aviation industry may lose their jobs due to reduced demand for flights during a pandemic. According to statistics (25 Million Jobs, 2020), 65.5 million people worldwide depend on the air transport industry, including people working in the tourism industry. Pilots, flight attendants, baggage handlers and other aviation workers are not sure in the future because they may lose their jobs in the short or medium-term if the pandemic prolongs. Naturally, if there is an excessive unemployment level in the aviation industry and insufficient unemployment insurance, such unemployment can lead to income loss in cities and metropolitans. The total global losses of the air transport industry due to the pandemic are $ 314 billion. Fig. 1.9 shows the loss of the air transport industry income in different regions due to the coronavirus pandemic in a percentage ratio to the total losses.

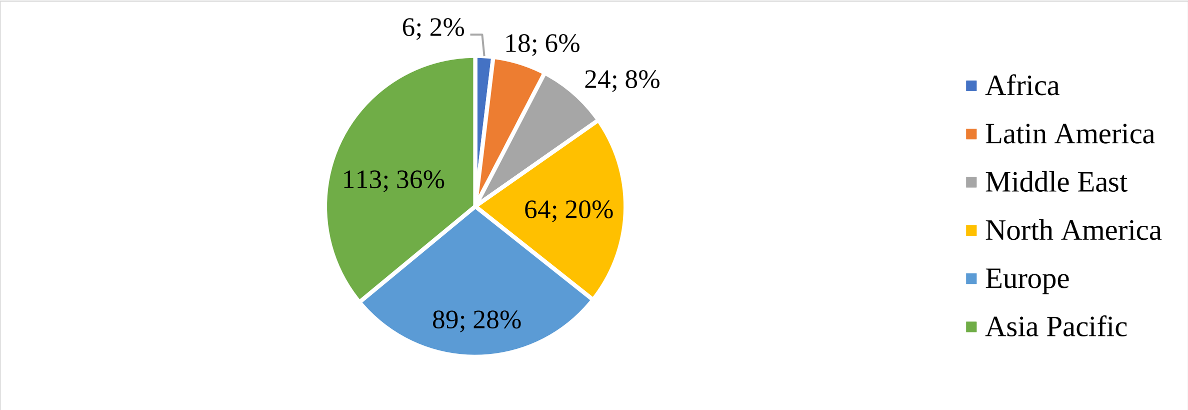

Figure 1.9 – Loss of airline revenues by region, billion dollars USA (Statista, 2020)

The maximum losses of $ 113 billion are observed in the Asia-Pacific region. The smallest income loss in Africa – 6 billion dollars. The expected decline in revenues from passenger transportation in the aviation industry is $ 252 billion (-44%) in 2020. In contrast to 2019, in 2020, the air transport industry suffered the most significant negative impact in the second quarter. Since the demand in this sector fell by about 70%, the aviation industry depleted about $ 61 billion in cash.

Tourism industry. The experts suppose that the coronavirus pandemic will have a long-term impact on world tourism. It is not yet known whether the tourist destinations in Europe, North America and other regions will have enough tourists to support the local industry. Even if most countries open their borders, traveling will involve a high social distance between tourists. The summer season is the main tourist period for such countries as Spain and Italy. Even before the pandemic became widespread, these countries had already faced economic slowdown due to large amounts of debt and high unemployment. Thus, the initial factors influenced the fact that these economies were more vulnerable to economic recession due to the pandemic. Data from the World Tourism Organization (UNWTO, 2020) show that the travel and tourism contribution to Spain and Italy's GDP was 14.3% and 13%, respectively, in 2019. It includes income from hotels, travel agencies, airlines, restaurants, and other economic spheres that get revenue from tourists' visiting the country.

If we analyze history, we can see that pandemics and macroeconomic shocks have always affected the tourism sector. Suffice it to mention the pandemics of the Spanish flu (1918-1920), swine flu H1N1 (2009-2010), Ebola virus (2014-2016). The Spanish flu imposed travel restrictions for four months and killed 21 million people. The H1N1 flu has caused a significant economic downturn in Mexico's tourism industry and killed millions of international tourists in five months. In general, the tourism industry lost about 2.8 billion dollars. The coronavirus pandemic distracts people from popular tourist destinations because they are afraid of contracting a new dangerous disease. Besides, news in the media affects people who cancel trips and bookings and do not participate in tourist activities. As one of the countries significantly affected by the COVID-19 pandemic, Italy suffered from a considerable decrease in tourists' number. The occupancy rate of such attractive tourist destinations as

Rome, Milan, Venice decreased by 6%. The World Tourism Organization estimates that about 50 million people employed in the tourism industry may face unemployment (Mensah, 2020).

Global measures to curb the new virus can reduce the tourism sector ranging from 45% to 70%. There are many micro and small enterprises in the hotel and restaurant business, especially in developing countries. Such companies do not have access to credit opportunities and have limited assets. So, the losses from the closure or limitation of customer service are critical for them.

One should note that tourism is one of the primary sources of income for some of the least developed countries. The population of the 47 least developed countries in the world is about 900 million people. A significant level of socio-economic instability characterizes them. For such countries as Bangladesh, Gambia, Kiribati, Lesotho, Malawi, Mozambique, Rwanda, Sierra Leone, Solomon Islands, Tanzania, Tuvalu, Uganda, Vanuatu, Zambia, the tourism industry is a significant resource for economic growth and employment. For example, for such countries as Cape Verde, the Maldives or Samoa, tourism has become the main reason they have grown above the economies' status with the lowest development. In these countries, pandemic events in tourism can significantly halt economic progress. The United Nations has estimated that tourism accounts for more than a million people in Nigeria, Ethiopia, South Africa, Kenya, and Tanzania. They also estimated that tourism accounts for more than 20% of employment in Seychelles, Cape Verde, Sao Tome, and Principe and Mauritius. The COVID-19 pandemic has created an unfavorable situation in these and other low-income African countries.

According to estimations, the Asia region will have the most massive fall in travel and tourism revenues in 2020. China will bear the largest share of expenses. In Europe, about 13 million people work in the tourism industry. Approximately 1 billion Euros will be a loss in tourism for the European region. The Spanish tourism industry will suffer losses of about 55 billion Euros in 2020.

Catalonia will suffer the most since revenue reduction, there is estimated at 11 billion Euros.

From sustainable development, let us consider the situation, aiming to promote constant, inclusive, and stable economic growth. There is an urgent need to find and implement new forms and means of tourism development, especially for economies where this industry is a crucial sector (Rahmanov et al., 2020).

COVID-19 in Ukraine.

A specific algorithm for introducing anti-epidemic measures is established for each scenario of the COVID-19 spread in Ukraine.

Scenario 1 – there are no cases of COVID-19 registration in the country. Objective is to prevent the spread (Algorithm for introducing, 2020):

– central and local executive bodies and local self-government bodies organize object, regional and intersectoral training simulation exercises to test algorithms for detection, transportation, hospitalization and isolation of a patient with suspected COVID-19 and, if necessary, adjust or clarify regional plans;

– there are measures to promote vaccination against influenza and other vaccine-controlled infections to prevent the simultaneous disease of the population during the epidemic with other pathogens;

– preparatory works are carried out and plans for long-term involvement of commercial institutions, volunteer and international organizations, non-governmental sector and employers in the development of future scenarios are formed;

– there is an explanatory work among the population on the means and methods of individual protection against infection, general measures for the prevention of COVID-19 and other acute respiratory viral infections, etc.;

– health care institutions become ready to develop future scenarios;

– there are seminars, conferences, meetings and training on the epidemic situation, prevention, clinical manifestations and treatment of COVID-19, regular training sessions of medical and laboratory staff, which will be urgently involved in case of the epidemic situation aggravation with COVID-19;

– ensuring the possibility of COVID-19 testing through existing systems of epidemiological surveillance in laboratories that have the appropriate conditions for diagnosis and biosafety;

Scenario 2 –cases of COVID-19 among the population of Ukraine are sporadic, one or more imported cases of COVID-19 from other countries are registered. Objective is to stop the transmission and prevent the spread:

– the measures provided for Scenario 1 continue to be implemented;

– work with the media and educational activity among the population on the status and prognosis of COVID-19, the risk of infection and the negative consequences of the epidemic is intensified to prevent panic and disrupt the established operation modes of enterprises, institutions and organizations;

– medical care (treatment) is provided to patients with COVID-19;

– the plans to convert beds and increase the number of medical staff and resources in case of mass admission of patients with COVID-19 are reviewed and optimized;

– support is provided to public health institutions in the active detection of infections, etc.

Scenario 3 identified the first cases of human infection with COVID-19 within the country (local matters) in a particular administrative area in the form of clusters (district, city, region) and for which an epidemiological link with a previously registered situation of epidemiological investigation is established:

– ban on holding mass events (concerts, fairs, conferences, sports competitions, etc.) and meetings in a certain area;

– suspension or transfer to a remote format of educational and upbringing processes;

– suspension of trade and entertainment establishments work (except for establishments providing the population with basic necessities, including food, hygiene, medicines, etc.);

– scheduled medical interventions are canceled;

– criteria for hospitalization are established. They consider that only severe and moderate patients are given preference to hospitalization, introduce opportunities for home care with volunteers, non-governmental sector, i.e. form a network of care for patients under medical supervision not in health care facilities (patients with mild course of the disease, suspicious patients waiting for medical care, etc.);

– additional human, material and financial resources are attracted to assist if there is a mass admission of patients.

Scenario 4 identifies the intensive spread of COVID-19 in more than two districts or in Ukraine's whole territory (the imported and local cases are registered). The objective is to slow down the transmission, reduce the number of instances and stop outbreaks:

- only certain checkpoints across the state border of Ukraine start operating. All others temporarily suspend their work;

- additional resources, including labor, are involved in providing home care, social and psychological support together with health workers;

- informing the population about the epidemic course, trends in its development, the effectiveness of anti-epidemic measures to increase people's awareness of the situation. Besides, the explanatory work on problematic issues related to the epidemic is carried out among citizens;

- self-isolation is recommended for people with mild symptoms and their treatment at home.

In August 2020, Ukraine was divided into quarantine zones according to the prevalence of COVID-19 within the national borders. There are "green", "yellow", "orange" and "red" zones in Ukraine. Quarantine measures are being strengthened or weakened in some areas or even cities. If the indices indicating the spread of the virus deteriorate in the region for five days, it is divided into districts and cities of regional significance and determine each district and city's impact on the spread of SARS-CoV-2. Depending on the extent to which each district or city affects the region's situation, they are assigned separately to a particular area.

There are necessary restrictions in the regions of the "green" zone: wearing protective masks in public places, organizing mass events with no more than one person per 5 m^2, half-full cinemas, transportation of only sitting passengers by public transport.

A region is considered to be one in which the virus rapidly spreads if at least one of the following indices characterize it: (Lutsenko, 2020):

– occupancy of hospitals by patients with COVID-19 is more than 50%

– the average number of tests using the method of polymerase chain reaction and enzyme-linked immunosorbent assay is less than 24 tests per 100 thousand people during the last seven days;

– SARS-CoV-2 infection detection rate is more than 11%;

– growth rate of SARS-CoV-2 infection is more than 10%.

– The State Emergency Commission reviews these criteria weekly and updates Ukraine's zoning. Besides, previously Ukraine compared the number of active patients with COVID-19 in other countries. If the country had more than 55 cases per 100 thousand population, it was a region with a significant prevalence of COVID-19. According to the approved decision, the country gets into the "red" zone if it meets at least one of the following criteria:

– the number of new cases of COVID-19 per 100 thousand population over the last 14 days exceeds the number of such cases in Ukraine;

– the increase in new cases of COVID-19 in the country over the last 14 days compared to the previous 14 days is more than 30%.

When a person arrives from the “red” zone countries, self-isolation is required using the application "Act at home" or passing a PCR test with a negative result. The Ministry of Health reviewed the list of countries every week. As of October 9, the countries of the "red" zone for Ukraine, for example, included Israel, Montenegro, the Czech Republic, Spain, the Netherlands, the Republic of Moldova, France, Belgium, etc., as well as Rwanda, Turkmenistan, the United Republic of Tanzania, Marshall Islands and other countries from which the Ministry of Health of Ukraine has not received data on the prevalence of COVID-19 (The Ministry of Health, 2020).

Ukraine introduced legal acts, which provided an exemption from several penalties in the taxation and collection of UST during quarantine caused by COVID-19. There is a moratorium on documentary inspections of enterprises, exemption from payment of land fees and real estate tax, exemption of sole proprietors from the obligation to pay UST, the introduction of VAT benefits and duties on medicines, medical devices and equipment necessary for the implementation of measures aimed at preventing the occurrence and spread, localization and elimination of outbreaks, epidemics and pandemics of coronavirus disease. The government introduced several amendments to labor legislation regarding flexible working hours, remote working, unemployment benefits due to disability, and employers' ability to place workers on unpaid leave (On business support, 2020). Small business credit support programs have been expanded, including "Available Loans 5-7-9" (Official page 5-7-9, 2020).

As of October 2020, due to the politicization of preventive measures, the governments of several countries set thresholds to introduce quarantine measures through transparent, objective criteria. For example, in terms of a new second wave in the EU and growing resistance to population restraints, European leaders try to depoliticize unpopular measures. Increasingly, specific triggers are set for further activities on a regional basis.

Thus, in France, the number of COVID-19 cases is growing. The country has introduced a new alert system that ensures that regions where the incidence rises above the thresholds automatically, have rights for certain preventive restrictions. In Germany, the government tries not to close educational and institutions. The Netherlands has introduced new quarantine measures to stop the coronavirus spread, namely a curfew for restaurants and bars. In the UK, in the regions most at risk for the virus, citizens are not allowed to meet with other households. Lockdowns affected Spain, where more than one million people in Madrid are restricted in their movements and are only allowed to go to work or study. Parks are closed; there are restrictions for hospitality (Hamann, 2020).

Chapter 2. Prediction models of COVID-19 waves

Modeling and simulation are sufficiently effective decision-making tools that can be useful to control disease among people. However, since each disease has its biological characteristics, it is necessary to adapt the models to each specific case so that their results are real and consistent with the actual state of affairs. COVID-19 is a new virus and has its peculiarities and patterns of distribution and flow among the world's population. The COVID-19 pandemic has killed thousands of people, destroying the whole world's health care system and economy. Most models predict that without intervention, most of the world's population will be infected with tens of millions will die as a result of the pandemic, and 10 million people will die as a result. Partially negative effects of the virus are caused by insufficient information about the space-time framework for the COVID-19 spread. Events that required important and timely decisions based on forecasts did not always have the appropriate response from governments. These circumstances demonstrate the importance of making reliable predictions, tools to model coronavirus spread, and other dangerous infections.

Mathematical models predicting the course of a pandemic are an essential tool to understand the quantitative parameters of the virus spread and make effective decisions to prevent the spread and negative consequences of epidemics. Many works of scientists who propose their investigations for predicting the spread of COVID-19 in some regions and the world are analyzed (Zhou et al., 2020; Chen et al., 2020; Verma et al., 2020). Today, there are over 1,000 articles on COVID-19 on the resource (MedRXiv, 2020). Most of them are devoted to modeling the spread of the disease. Some models offer specific indicators that consider the citizens' political reactions in the various measures taken to combat the spread of the virus. Combined compartmental and empirical approaches are mostly implemented (Ferguson et al., 2020; Gatto et al., 2020; Giordano et al., 2020). Zhang et al. (2020) used a statistical approach to the analysis regarding the space-time dynamics of COVID-19.

Raji & Lakshmi (2020) performed a regression analysis (linear and polynomial) to analyze the distribution of COVID-19 and its prediction. The models were formed using such data as the number of confirmed cases, the number of deaths, and the number of people who recovered. Such models help predict the number of infections and possible deaths shortly in days. A regression model is a statistical set of processes that make it possible to estimate and forecast a target or dependent variable based on the analysis of other variables. The regression model has many variants: linear, spinal regression, stepwise regression, polynomial regression, etc. Linear and polynomial regression are used to predict the spread of COVID-19. Linear regression is a simple model used to find the relationship between a dependent and an independent variable. The linear regression equation is as follows:

$$Y=\beta_0+\beta_1 x+\epsilon, \qquad (2.1)$$

where β_0, β_1 – independent variables, ϵ – error coefficient.

Polynomial regression is a particular type of regression that describes the curvilinear relationships between dependent and independent variables. The following equation describes polynomial regression:

$$Y=\Theta_0+\Theta_1 x+ \Theta_2 x^2+ \Theta_3 x^3 \ + \Theta_n x^n, \qquad (2.2)$$

where x – independent value, Ө0 – bias, Ө2, Ө3 …., Өn – partial coefficients, the forecasting objective, n – degree of polynomial regression.

Polynomial regression involves the transformation of data into polynomials. Polynomial regression with a degree equal to one is a linear regression. It is a responsible task to choose the value of the degree. If the polynomial degree is chosen incorrectly, it will not correspond to the model, and the model will not provide correct predictions (Gupta et al., 2020).

A mathematical SEIR model is used to analyze the spread of infections among humans geographically. An essential component in this model is the indicator R0, which indicates a particular virus infection level. This parameter determines the number of people affected by one infected person over some time. If R0<1, the virus will stop spreading soon, if R0 = 1, the spreading remains stable and, if R0> 1, the spread of the virus increases in the absence of intervention. Graphically, different variants of the R0 value are shown in Fig. 2.1.

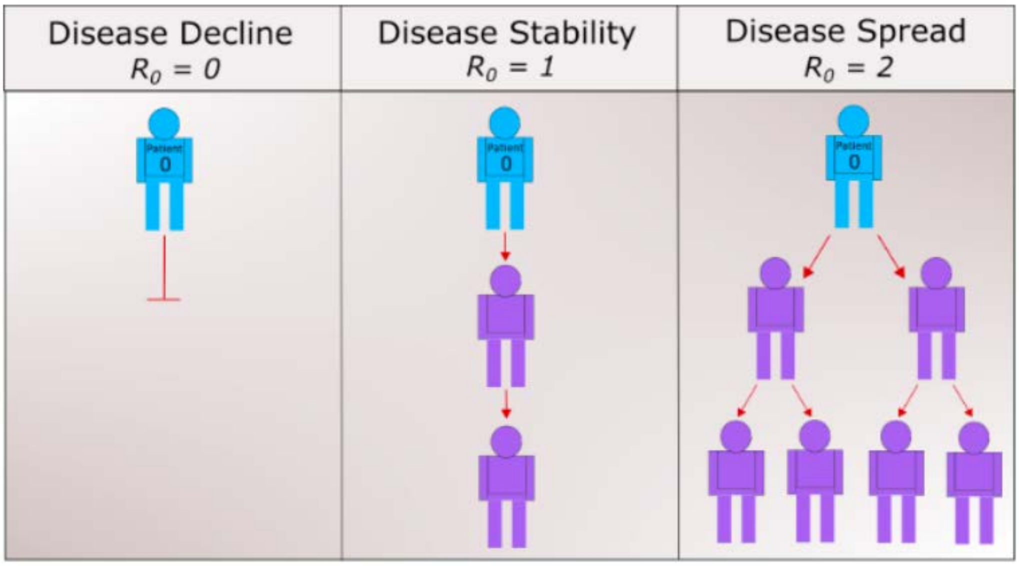

Figure 2.1 – Scheme of infectious disease spread considering the index R0 (Gupta et al., 2020)

The SEIR model generally has four components: Susceptible (S), Exposed (E), Infected (I) and Recovered (R), demonstrated in Fig. 2.2. S is the share of susceptible individuals, i.e., those who are able to be infected with the virus, E is the share of affected individuals, infected but not yet a carrier, I is the share of infected individuals, i.e., those who are already infected, R is the share of individuals recovered.

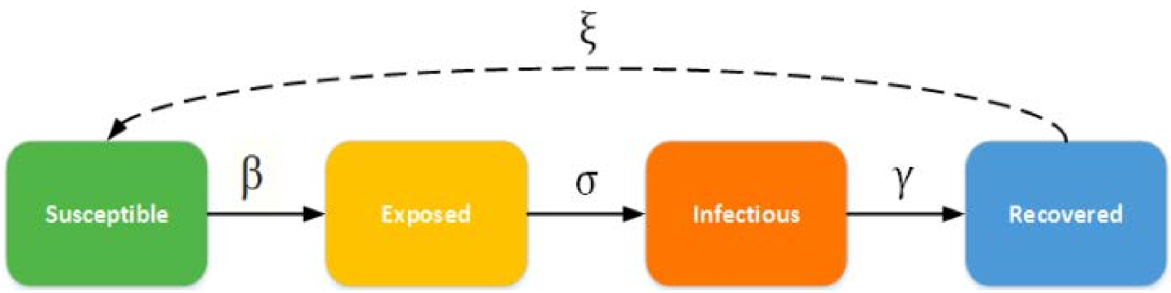

Figure 2.2 – Relationship between SEIR model components
(Gupta et al., 2020)

In fig. 2.2, the variable β is an indicator of the infection level, which describes the probability of infection transmission to a person susceptible to it from an infected person. The model also describes the duration of the incubation period. The variable γ represents the recovery rate, which is defined as $\frac{1}{D}$ (where D is the infection duration). The measure ξ indicates the rate at which recovered people become susceptible to a particular infection again due to low immunity or other health problems. The system of differential equations below describes all components of the SEIR model:

$$\frac{dS}{dt} = -\frac{\beta SI}{N} + \xi R,$$
$$\frac{dE}{dt} = -\frac{\beta SI}{N} - \sigma E,$$
$$\frac{dI}{dt} = \sigma E - \gamma I, \qquad (2.3)$$
$$\frac{dR}{dt} = \gamma I - \xi R.$$

In this system of equations N = S + E + I + R - the total population. The following formula is used to calculate index R0:

$$R_0 = \frac{\beta_0 \alpha}{(\mu+\alpha)(\mu+\gamma)}. \qquad (2.4)$$

The indices from this formula are calculated according to standard differential equations from four components of the SEIR model.

Since the availability of complete data is limited, there are several assumptions to predict the spread of COVID-19 using the SEIR model:

1. The number of births and deaths remains unchanged

2. 1 / α is the latent period of the disease, and 1 / γ is the infectious period.

3. During the calculation period, a person who has recovered was not ill again.

In the article (Viguerie et al., 2021), the authors propose a SEIRD mathematical model for determining COVID spread volumes based on partial differential equations in combination with a heterogeneous diffusion model. This model describes the space and temporal framework for the coronavirus pandemic spread. It considers such parameters as human habits and geographical features. Data from the Italian Lombardy region, which was severely affected by the virus in February-April 2020, were used to test the model. Testing the author's hypothesis showed a close relationship between the constructed space and temporal model and the real epidemiological data collected at the municipal level. The authors confirmed that their proposed model enables informing the health care system in time to develop effective anti-epidemic measures and predict the effective geographical distribution of critical medical resources. The authors note that their approach to modeling the spread of coronavirus is more appropriate for the disease dynamics in such regions as Italy. They studied different recovery scenarios after the epidemic in the country, obtaining contrasting results.

Fig. 2.3 shows the evolutionary spatial picture of the COVID-19 outbreak in Lombardy. The authors note in the study that although Lodi and Cremona were the hardest-hit areas at the beginning of the epidemic, they were rapidly rehabilitated and avoided significant patient growth, as it was in Milan, Bergamo and Brescia. The determination coefficient, which indicates the extent to which the observations confirm the model, is 0.997, 0.977, 0.976 and 0.998 for

Lombardy, Bergamo, Brescia, and Milan. The authors note that the blockade effectively stopped the spread of the virus in Bergamo and Brescia. Besides, the restrictions significantly reduced the spread of coronavirus in Milan, limiting the virus to a linear growth model, but could not completely stop it.

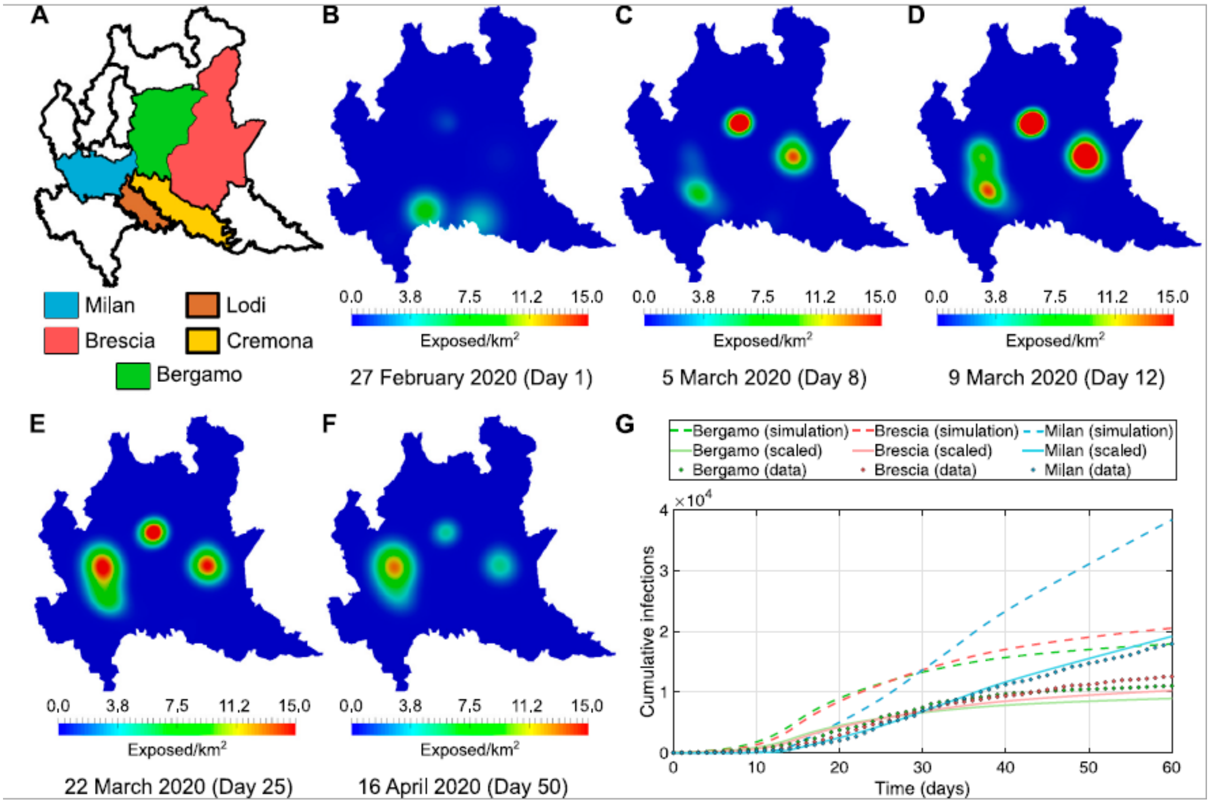

Figure 2.3 – Model for predicting the spread of COVID-19 in Lombardy (Italy) (Viguerie et al., 2021)

(A) Major areas affected by the pandemic in Lombardy. (B) Initially, the main affected areas are Lodi and Cremona, and to a lesser extent Bergamo and Brescia. (C-E) The author's model provides an increase in exposure in Bergamo and Brescia. Soon the outbreak in Lodz spread north to the Milan area, spreading further, despite restrictions on the blockade. (F) The model also assumes that government restrictions ultimately reduce the risk of disease, which occurs faster in Brescia and Bergamo than in Milan. (G) Cumulative infection curves according to reported data (dots) and simulations (dashed lines) for the three main areas of infection: Bergamo, Brescia and Milan.

The authors propose four scenarios for the country's recovery. Their modeling suggests that easing restrictions on blockages across the region can lead to a significant and rapid increase in cases in Milan. However, in large urban areas far from Milan (such as Brescia and Bergamo), there was only a slight increase in the number of cases, as evidenced by a favorable trend over time. On the contrary, while maintaining the blockade in Milan and easing it in other cities, the outbreak will reveal more favorable dynamics, similar to those in Brescia and Bergamo. The authors conclude that blocking measures support in high-density and densely populated areas, such as Milan, may take longer to stop the infection spread.

Evans et al. (2020) note that although COVID-19 caused havoc around the world, it is of particular concern in sub-Saharan Africa, where various models suggest that most of the population is at risk of infection due to environmental factors, socio-economic conditions, lack of water and sanitation, weak national health care systems. The authors use a spatial-age model to correctly interpret the analysis of COVID-19 cases in the island nation of Madagascar. The introduction of infection from other countries, the early introduction of non-pharmaceutical interventions and the low detection rate of infections indicate the number of cases in Madagascar as of July 2020. The authors then revised these findings in the context of the spread of coronavirus in August 2020. The analysis shows that Madagascar, along with other countries in sub-Saharan Africa, is at risk of spreading coronavirus. In fig. 2.4, component (A) shows that the trends fixed in Madagascar can be explained by the early stage of the epidemic, the low level of detection and lower transmission. The authors investigated different combinations of detection rates and efficacy of non-pharmaceutical interventions, along with predictions of epidemic morbidity and severity of cases. If the low level of detection causes a small number of the fixed cases, the level of detection in the future may exceed 13 million people (components (C), (D) Fig. 2.4). On the other hand, if a decrease in social contacts causes a small number of cases, the model assumes lower morbidity values – 8 million people. (components (C), (D) Fig. 2.4). If non-pharmaceutical interventions greatly impact, lifting of restrictions will lead to an uncontrolled epidemic outbreak. In fig. 2.2 the dark dotted line shows the median of predicted cases number from 25 simulations of daily fixed cases (average for seven days) on June 22, 2020 (71.71 cases). The shaded diamonds correspond to the specific scenarios in panel D. It demonstrates the detected infections dynamics, all infections, and the total mortality for the first year of the epidemic.

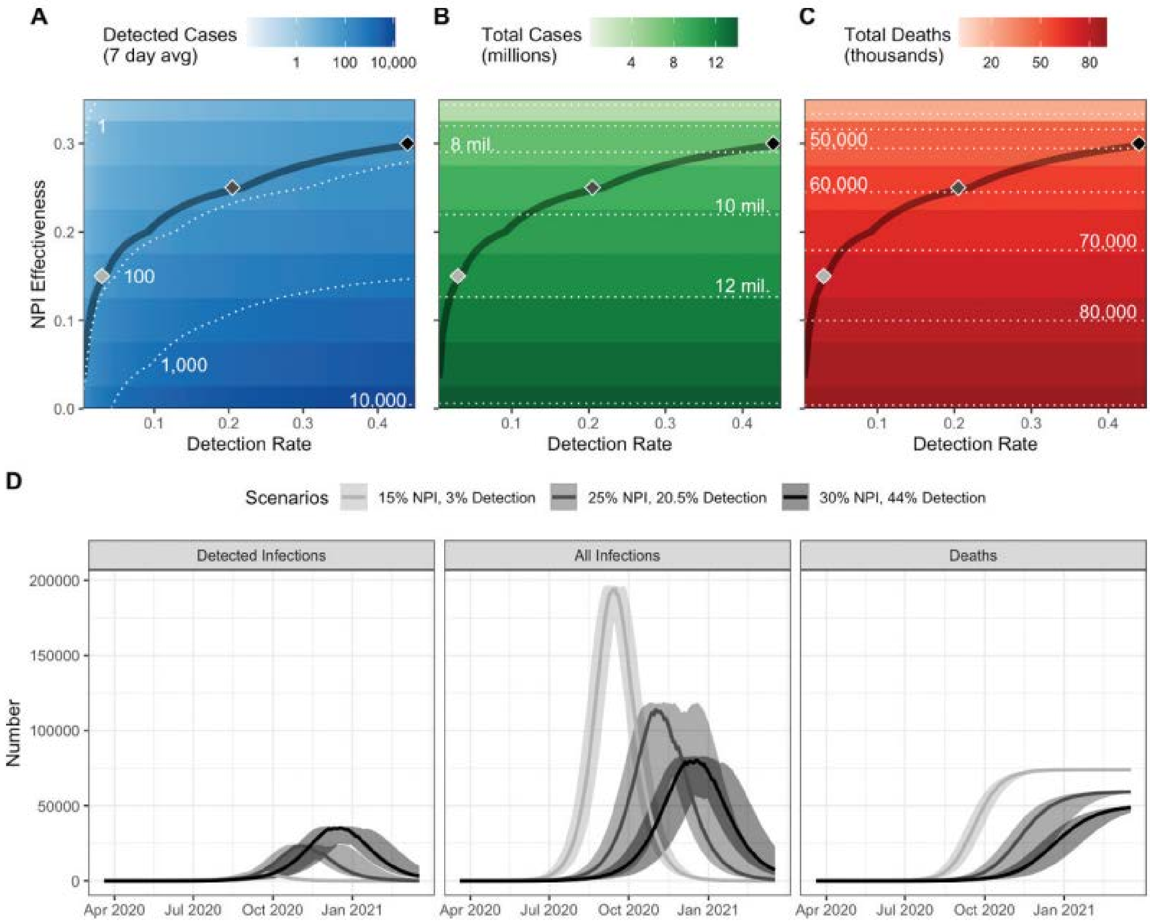

Figure 2.4 – A model of the revealed cases of COVID-19 in sub-Saharan Africa and scenarios (Evans et al., 2020)

Although the global epidemic began in early 2020, current disease patterns spread for Madagascar and sub-Saharan Africa still rely on limited initial data due to which forecasts differ in different works. Thus, Pearson et al. (2020) predicted a similar size of the epidemic in Madagascar as the authors of the previous work did, but during the undiminished scenario in which 75% of the population will fall ill and there will be almost 100,000 deaths. At the same time, for example, Cabore et al. (2020) predicted only a third of cases from the previous figure and a significantly lower share of deaths from coronavirus (1,500 cases). This study predicts that the countries' regional features will reduce the morbidity transmission and mortality since it has a specific climate, transport network, and contact matrix.

The simplest models for predicting epidemics, such as the SIR model, suggest that all people have the same chance to catch the virus. Besides, according to this model, infected people transmit the virus to the same extent throughout the disease period. A SIR model (susceptible – infected – removed) with the distinguishing of infected people with symptoms was proposed in (Gaeta, 2020). This model generalizes the previously developed models and proposes a scheme for adapting the model parameters to real data using time series with a calculation only for fatalities. The simulation was carried out on the examples of Lombardy's regions in Italy and the state of Sao Paulo in Brazil, which show different dynamics and features of the disease among the population. In both cases, the researcher concludes that compliance with social distancing measures helps slow down the growth of the deaths compared to the baseline, with violation of such measures. According to this model, the difficulty of determining the number of infected people complicates predictions by this model since there are asymptomatic cases of infection. The Kermack-McKendrick model (Kermack & McKendrick, 1932) is one SIR model defined by such a system of

$$\frac{dS}{dt} = -\frac{\beta IS}{N}, \quad \frac{dI}{dt} = \frac{\beta IS}{N} - \gamma I, \quad \frac{dR}{dt} = \gamma I \tag{2.5}$$

ordinary differential equations, where β and γ are the levels of infection and recovery, respectively. The model consists of three components: S - by the number of susceptible to infection, I - by the number of infected, and R - by the number of recovered or dead people. Besides, N denotes the stability of the population, calculated by:

$$N=S(t)+I(t)+R(t). \quad (2.6)$$

Moreover, the infectious class dynamics depends on the main reproduction number, defined as

$$R_0=\frac{\beta}{\gamma}. \quad (2.7)$$

If the reproduction number is high, the probability of pandemic is also high. This number also estimates the immune threshold of the population (HIT). If the number of spread multiplied by the percentage of susceptible individuals is 1, it indicates an equilibrium state and, therefore, the number of infected people is constant. The recovery period is determined by the formula

$$t_1=\frac{1}{\gamma} \quad (2.8)$$

and describes an average number of days for recovery. The transmission period through the average days is defined:

$$t_2=\frac{1}{\beta}. \quad (2.9)$$

The logistics model analyzed in (Taghizadeg et al., 2020) is a nonlinear ordinary differential equation commonly used to model population growth. The logistic growth model is as follows:

$$y'(t)=\alpha y(t)(1-\frac{y(t)}{\beta}),\ y(0)=y_0, \tag{2.10}$$

where $y_0 \neq 0$ is the initial size of the population (initial number of confirmed cases), the index y indicates the population size (the number of accumulated confirmed cases), the indicator t is the time. Besides, α and β are indices of growth rate (infection rate) and capabilities (maximum number of confirmed cases), which are positive constants.

The solution for logistics model equation is

$$y(t)=\frac{\beta y_0}{y_{0+(\beta-y}{}_{0)e^{-\alpha t}}}, \tag{2.11}$$

that can be written as follows:

$$y(t)=\frac{\beta}{1+Ae^{-\alpha t}}, \tag{2.12}$$

where

$$A=\frac{\beta-y_0}{y_0}. \tag{2.13}$$

The inflection point represents the time when there is maximum growth rate of confirmed cases. The inflection point of the logistics function is calculated as

$$I=\frac{\ln(A)}{\alpha}, \tag{2.14}$$

where the estimated number of infected people is calculated β/2.

Roosa et al. (2020) use phenomenological models implemented during previous outbreaks (SARS, Ebola, pandemic influenza, dengue fever) to form short-term disease rate predictions. They assessed the example of Hubei Province in China, the epicenter of the epidemic in February 2020, and the whole country. The authors collected data on daily cumulative confirmed cases of COVID-19 for each Chinese province from the China National Health Commission. Forecasts were made for 5, 10 and 15 days based on a generalized model of logistical growth, Richards' growth model and a subepidemic wave model. The authors form such short-term forecasts in real-time. In this case, the general model of logistics growth (GLM) extends a simple model, including an additional parameter. This parameter at different values shows the scale of growth in the number of infected people (if the rate is equal to one, it indicates early growth; if it is zero, it indicates constant growth; if it is from 0 to 1, it means early subexponential or polynomial growth) (Viboud et al., 2016). The following differential equation determines the GLM model:

$$C'(t) = rC(t)^p(1 - \frac{C(t)}{K}), \qquad (2.15)$$

where C'(t) – the total number of cases at time t; r - growth rate; p - the growth scaling parameter; K - the total number of infected people due to the spread of the epidemic.

Richards' model also considers the scaling parameter and deviation from the symmetric logistic curve. This model is a three-parameter extension of a simple logistics growth model that includes a scaling parameter (Wang et al., 2012). The model is described by a differential equation:

$$C'^{(t)} = rC(t)\left(1 - \left(\frac{C(t)}{K}\right)^a\right), \qquad (2.16)$$

where C' (t) is the total number of cases at time t; r – growth rate; K – the total number of infected people due to the spread of the epidemic; a - an index that measures the deviation from the symmetric s-shaped dynamics of a simple logistics curve.

K – the final size of the epidemic, index a measures the deviation from the symmetrical s-shaped dynamics of a simple logistics curve.

Besides, the authors used a subepidemic wave model that describes complex epidemic trajectories, including peaks. It was developed by scientists in the study (Chowell et al., 2019) to predict SARS spread in Singapore. This model is the most flexible extension. It helps build a consolidated aggregate curve formed by many major subepidemics. In this approach, each subepidemic is modeled using GLM, in which the growth rate r and the growth scaling parameter r are the same. An epidemic wave consisting of n overlapping epidemics is simulated:

$$C_i'(t) = rA_{i-1}(t)C_i(t)^p\left(1 - \frac{C_i(t)}{K_i}\right), \quad (2.17)$$

where Ci' (t) – total number of infections for subepidemic i; K_i – size of the i-subepidemic (i = 1, ..., n).

When n = 1, the model returns to a single GLM equation, as shown above. The researcher can simulate/model the initial time of each subsequent wave with a stable structure that (i + 1) -subepidemic begins when Ci(t) exceeds the C_{thr} threshold, and the (i + 1) -subepidemic begins before the end of the i-subepidemic. Then, the size of successive subepidemics (K_i) is modeled in such a way that the size decreases exponentially:

$$K_i = K_0 e^{-q(i-1)}, \quad (2.18)$$

where K_0 – the size of the first subepidemic (K1 = K0); q – the rate of successive subepidemic decline, where q = 0 indicates no decrease. Then, the total final size of the epidemic is as follows:

$$K_{tot} = \sum_{i=1}^{n_{tot}} K_0 e^{-q(i-1)} = \frac{K_0(1-e^{-qn_{tot}})}{1-e^{-q}}, \qquad (2.19)$$

where n_{tot} – final number of the overlapping subepidemics. This parameter is calculated as follows

$$n_{tot} = \left\lfloor -\frac{1}{q}\ln\left(\frac{C_{thr}}{K_0}\right) + 1 \right\rfloor. \qquad (2.20)$$

Kucharski A. et al. (2020) combined a stochastic model of virus transmission with data regarding the internal cases of coronavirus disease in Wuhan and imported cases in Wuhan to assess how the infection transmission changed during January-February 2020. The authors calculated the probability of new outbreaks in other parts of the country based on these estimates. They used such parameters as the daily number of new imported cases (or their absence); the daily number of new cases in Wuhan without market influence; the daily number of new cases in China; the share of infected passengers on evacuation flights. An additional two datasets were used to compare the results: the daily number of new exported cases from Wuhan (or none) in countries with a high level of relationship with Wuhan (20 countries most at risk), and data on new confirmed cases fixed in Wuhan during the analyzed period. The authors found that the establishment of travel restrictions reduced the average daily number of infections. Calculations have shown that SARS-CoV-2 transmission is likely to have declined in Wuhan, coinciding with the introduction of travel control measures, and the authors conclude that these measures are critical to prevent the spread of infection.

Ivorra et al. (2020) point out that COVID-19 is a disease caused by a new virus requiring a unique model that considers its already known specific features. They argue that the ideal model should take into account the impact of undetected but infected people with the ability to show the dependence of COVID-19 exposure on the detected cases percentage in the total number of infected people; the impact made by different sanitary and infectious conditions of hospitalized people dividing them into those who have mild and severe conditions; assessment of hospital bed needs. The authors propose a mathematical model adapted for COVID-19. The θ-SEIHRD model lets estimate different scenarios for the spread of coronavirus infection, namely the number of cases, the number of deaths and the need for beds in areas where coronavirus will become a severe threat to the public health. The model is quite complicated since it covers the most important consequences of a dangerous disease. Simultaneously, it is simple enough to identify its parameters using data on the pandemic reported by public authorities. The authors investigate the specifics of the coronavirus spread within countries with an appropriate number of people infected with SARS-CoV-2, for areas where local transmission is the leading cause of the disease. Researchers point out that they use a fundamentally new approach that links the mortality rate with the percentage of the revealed cases to the total real number of infected people. The model is tested on the example of China. Different disease spread scenarios have been studied to show how different values of the percentage of the detected cases change the impact of COVID-19 on society in China, which may interest politicians. The model can also measure the spread of human diseases in certain areas over a fixed period. The model also considers the effect of virus control measures. The authors' approach indicates the share of revealed cases to the real total number of deases cases. It enables us to study the importance of this relationship on the impact of COVID-19.

One should note that this model is based on the previously developed Be-CoDiS model (Ivorra, 2015) set to predict the spread of hazards to human health worldwide. Initially, this model was used to study the spread of the Ebola virus epidemic in 2014-2016. It was further used in 2018-2020 during the Ebola outbreak in the Republic of Congo. Both cases had quite realistic forecasts for this model.

Another model, SEIAMPR (Susceptible Exposed Infected Asymptomatic Mild Positive Recovered), is a simulation model. There are three categories of infected persons: asymptomatic, unknown cases, and officially confirmed cases. The three above categories of persons define the recovered. The "Exposed" category includes people who have been exposed to the virus after a certain incubation period. Fig. 2.5 presents the logical scheme of the simulated epidemic outbreak. In the diagram, solid arrows indicate the flow of official data, dotted - the flow of simulated data. The intuitive approach in this model is simple: about 80% of those infected with COVID-19 carry the disease asymptomatically or with mild clinical signs. Many cases remain unknown to national statistics because people do not pass the test.

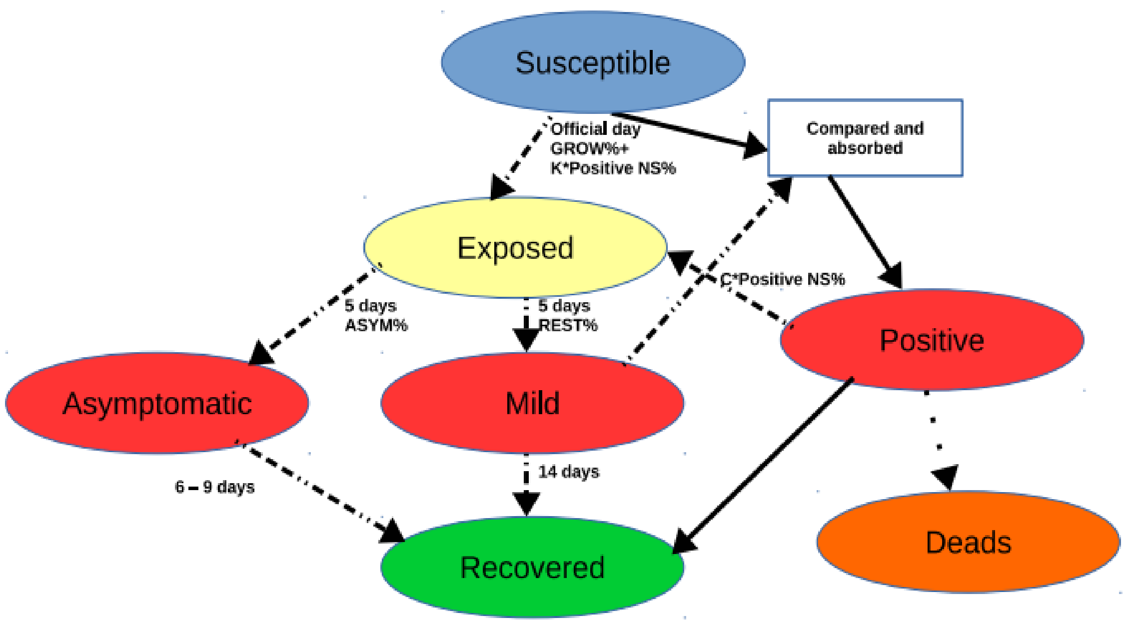

Figure 2.5 – Model SEIAMPR to forecast COVID-19 outbreaks (Gaspari, 2020)

The recursive mathematical model of COVID-19 distribution makes it possible to evaluate the effectiveness of quarantine measures. The model considers the infectivity of already infected people during the incubation period and the conditional non-infectious nature of sick people if they are self-isolated. This model was used to analyze the epidemic situation in eight countries (China, Italy, Spain, USA, UK, Japan, France, Germany) affected by the pandemic. It gave a brief forecast of the coronavirus spread.

The recursive mathematical model (Ilyin, 2020) is based on a set of unique parameters to each country due to differences in population density and people's behavior, the date the virus entered the country, and government action. The model includes the following parameters:

d_0 – the starting date of the epidemic as the date when the first undetected infected or detected person appeared, but too late;

d_1, d_2, d_3 – dates of changes in the citizens' behavior, for example, through awareness of the real situation, the introduction of quarantine and its strengthening;

t_D – the average time from infection to isolation of an infected person. It is equal to the incubation period, which to the authors' mind is six days. Theoretically, this parameter can be changed by testing the whole population, but this is only possible for small communities;

R_0, R_1, R_2, R_3 – viral transmissions that are equal to the average number of people infected by one person before his or her isolation and depends on the population's behavior at different stages of the epidemic. When R is less than 1.0, the epidemic subsides and vice versa.

r_0, r_1, r_2, r_3 – reduced transmission rates, which are equal to the average number of people who will be infected by one person per day: $r = R / t_D$. The r must be less than 0.167 to stop the spread of COVID-19.

Estimation of the virus spread is based on the calculation of N_D (d_i), namely the number of detected infected people for the d_i date, which is equal to the total number of infected persons six days earlier:

$$N_D(d_i)=N_T(d_i-t_D), \tag{2.21}$$

where N_T (d_i) is the total number of infected persons for the date d_i, which is the sum of the total number of infected persons the day before and the number of newly infected, which is equal to the product of reduced transmission and the number of actively infected people on the day before (because those who have previously been infected, cannot be re-infected):

$$N_T(d_i)=N_T(d_i-1)+r_0\cdot N_A(d_i-1)\cdot(1-N_T(d_i-1)/N_{P,} \tag{2.22}$$

where N_p – total population; N_A - the total number of active (undetected) infected persons for date d_i, which is equal to the difference between the total number of infected and the number of detected persons on the same day:

$$N_A(d_i)=N_T(d_i)-N_D(d_i). \tag{2.23}$$

When the epidemic began, the values (d_o date), NA (d_o) = 1, N_T (d_0) = 1 and N_D (d_0) = 0. It is necessary to know the values of only two parameters - d_0 and r_0 to calculate the virus spread dynamics. If the citizens' behavior is changed from date d_1, the parameter r_0 changes its value and becomes r_1. If the behavior changes again, the pair d_2 and r_2 is activated.

It is more difficult to model human losses. It is necessary to introduce another two parameters into the model: L – the apparent mortality rate, which is equal to the ratio of the number of the deaths to the sum of those who died and recovered; t_L – the average time from infection to death. These two parameters depend on the treatment effectiveness and may differ depending on the doctors' experience and hospital occupancy degree. The number of deaths on date d_i is equal to the total number of people infected with on t_L days earlier, multiplied by the mortality rate:

$$N_L(d_i)=N_T(d_i-t_L)\cdot L. \quad (2.24)$$

Two parameters tL and L in equation (2.24) have the same effect on the resulting value. The accuracy of estimating these parameters is low. It is clear that if more asymptomatic and mild cases of COVID-19 are detected, the mortality rate cannot be high. The authors set the average time from infection to death - 8 days. They use this duration for calculations on examples of countries.

It is difficult to predict the number of recovered since it requires a more significant number of independent parameters in the model:

$$N_R(d_i)=N_T(d_i-t_M)\cdot k_M+N_T(d_i-t_S)\cdot k_S, \quad (2.25)$$

where k_M, kS, t_M i t_S – patients with mild and severe disease, and the time from their infection to recovery, respectively; $k_M + k_S + L = 1$.

The equations of the model are presented in the discrete form (instead of differential). This model is easy to reproduce in any spreadsheet editor for calculations. The model does not consider the asymptomatic carriers of the infection. It is so because the share of asymptomatic carriers in the population does not change over time. Their presence is taken into account implicitly in the value of the transmission. This model can be abbreviated SILRD as one that considers the parameters Susceptible, Infected, isoLated, Recovered, and Dead persons.

Chakraborty et al. (2020), in their work, propose a hybrid model to predict the spread of COVID-19 based on the combination of Theta and ARNN models.

The authors carry out modeling on the example of eight countries most affected by the SAV-CoV-2 outbreak. First, we analyze two models that form a hybrid model. The Theta model is a time series prediction tool that proved itself well in practice (Assimakopoulos et al., 2000). The method divides the original data into two or more series, called theta series, and extrapolates them using prediction models. Predictions are combined to obtain final forecasts. Theta series can be estimated by modifying the curvature of the original time series. This change is obtained from a coefficient, called the θ coefficient, applied to the second differences in the time series:

$$Y''_{new}(\theta)= \theta Y''_{data}, \qquad (2.26)$$

where $Y''_{data} = Y_t - 2Y_{t-1} + Y_{t-2}$ at a time t for t = 3, 4, …, n i $\{Y_1, Y_2, \dots, Y_n\}$ indicate one-dimensional time series under observation. In practice, the coefficient θ can be considered a transformation parameter, creating a number of the same mean values and slopes from the original data but with different variances. The following equation, which depicts the differences in the population, has the form (Hyndman & Billah, 2003):

$$Y_{new}(\theta)=a_\theta +b_\theta(t-1)+ \theta Yt, \qquad (2.27)$$

where a_θ and b_θ – constants; t = 1, 2, … , n. Thus, $Y_{new}(\theta)$ is equivalent to a-linear function Y_t with added linear trend. a_θ and b_θ are calculated by minimizing the sum of square differences:

$$\sum_{i=1}^{t}[Y_t - Y_{new}(\theta)]^2=\sum_{i=1}^{t}[(1-\theta)Y_t - a_\theta - b_\theta(t-1)]^2. \qquad (2.28)$$

Predictions from the Theta model are obtained by the weighted average Y_{new} (θ) prediction for different θ values. A generalized version of the Theta method is suitable for automatic prediction of time series (Spiliotis et al., 2020).

Prediction methods based on an artificial neural network became popular in the late 1990s. The scientific sources represent various neural networks used for controlled classification, prediction, and nonlinear time series prediction. The architecture of a simple neural network of direct transmission can be described as a network of neurons located in the input, hidden and output layers in the prescribed manner. Each layer transmits information to the next layer, using the obtained scales with a training algorithm. The ARNN model is a modification of a simple ANN model specifically investigated for predicting time series data set. The ARNN model uses a predetermined number of lagged time series values as input. The number of hidden neurons in its architecture is also fixed. The ARNN model (p, k) considers the p lag inputs of the time series data in one hidden layered neural direct redirection of the network with k hidden units in the hidden layer. Let x denote the p-lag inputs and f – the neural network of the following architecture:

$$f(x)=c_0+\sum_{j=1}^{k} w_j\, \varphi(a_j + b'_j x), \qquad (2.29)$$

where c_0, a_j, w_j – weight; b_j – p-measurable weight vector; φ – limited nonlinear sigmoid function (e.g, logistic squash function or tangent hyperbolic activation function). The standard ANN faces the problem to choose the number of hidden neurons in the hidden layer. The optimal choice is unknown. We accept the formula k = [(p + 1) / 2] for non-seasonal time series data for the ARNN model, where p is the number of lag inputs in the autoregressive model.

The TARNN model is formed by the combination of Theta and ARNN models. This model is based on the error remodeling approach. In the additive error model, the predictor considers the expert's estimate as a variable $\hat{Y}_t$ and considers it as the sum of two parameters.

$$\hat{Y}_t = Y_t + e_t, \quad (2.30)$$

where Y_t is the real value, a e_t - the additive value of the error.

In the multiplicative model of errors, the predictor considers the expert's estimate $\hat{Y}_t$ as the product of two parameters:

$$\hat{Y}_t = Y_t \cdot e_t, \quad (2.31)$$

where Y_t is a real value, a e_t – values of the multiplicative error.

Thus, without losing the positive perception of the model, we can conclude that errors (additive) of the forecasting models are rather random shocks not occurring often. However, if the time series data have complex correlation structures and there is less information about the data generation process, the model may have prediction errors. An illustrative example is the number of daily confirmed cases of COVID-19 for different countries, where not much is known about the structural properties of the current pandemic. Therefore, forecasting reliability requires a two-step approach to modeling to solve the problem of time series. The proposed TARNN model is a hybrid model based on additive re-simulation of errors. The TARNN hybrid approach consists of the following main steps:

1) the Theta model is applied for time series to model the linear components of given information.

2) the Theta model helps form predictions in the sample and errors are calculated.

3) Residues (additive errors) generated by the Theta method can be modeled using the nonlinear ARNN model.

4) Both predictions derived from Theta and ARNN models are combined together to obtain the final prediction result for the original time series.

The mathematical formulation of the proposed hybrid model TARNN (Zt) is as follows:

$$Z_t = L_t + N_t, \quad (2.32)$$

where L_t – linear part; N_t – nonlinear part of the hybrid model. It is possible to assess these indices using the data of the time series.

Let $\hat{L}_t$ is a forecast of the model Theta in time t. Index ϵ_t demonstrates residues of errors at time t, that we obtain from the Theta model. Then, we use the equation:

$$\epsilon_t = Z_t - \hat{L}_t. \quad (2.33)$$

These residues are modeled further according to the ARNN model and are demonstrated as follows:

$$\epsilon_t = f(\epsilon_{t-1}, \epsilon_{t-2}, \dots, \epsilon_{t-p}) + \xi_t, \quad (2.34)$$

where f – nonlinear function. The simulation is performed using the ARNN model. Index ξt demonstrates random shocks.

The combined forecast can be obtained as follows:

$$\hat{Z}_t = \hat{L}_t + \hat{N}_t, \quad (2.35)$$

where $\hat{N}_t$ – the predicted value of the ARNN model.

Fig. 2.6 demonstrates the general diagram of the TARNN model. In the proposed TARNN model, the ARNN approach is used to remodel residual autocorrelations in residues which Theta model cannot model alone. Thus, the TARNN model is seen as an approach to re-modeling errors. It is important to consider errors because due to incorrect model specification and disruption of the epidemic spread rate, the Theta linear model may not accurately describe the forecast.

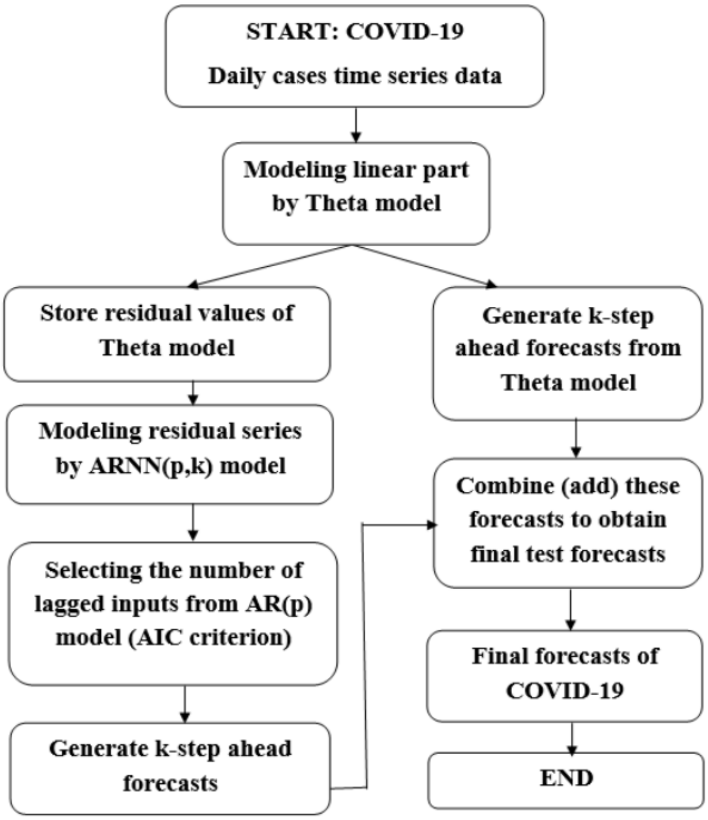

Figure 2.6 – Flow-diagram of the proposed TARNN model (Chakraborty et al., 2020)

The idea of additive error modeling is a useful tool for modeling a set of time series for which it is difficult to predict random shocks based on individual models. The TARNN approach is investigated to consider already confirmed cases of COVID-19, for which data generation is only in progress and the various peculiarities of the epidemic are still unknown.

Bukin et al. (2020A) proposed a universal model of the SRID epidemic process. It allows using the bootstrap analysis to assess the confidence intervals for the most important epidemic process parameters, considering errors and initial statistics. The authors suggest forming stable immunity in people with COVID-19. It is assumed that the spreading of the infection occurs in a population of people with a total of N persons. S is the number of people in the population who have not yet been in contact with the pathogen; R is the number of people who became ill and recovered, they came into contact with the pathogen and received a stable immunity; I is the number of patients or carriers; D is the number of deaths; K is the total number of infected and recovered (K = I + R + D, K = NS); Z is the number of newly infected people per day (growth rate of the number of infected, the growth rate of K). Variables in the model must meet the conditions N = S + I + R + D, N = S + K. The time t = 1 is when the first patient (zero patient) appears among the population.

The system of equation of this model is as follows:

$$
\begin{gathered}
S(t)=S(t-1)-\frac{\alpha}{N}S(t-1)I(t-1), \\
I(t)=I(t-1)+\frac{\alpha}{N}S(t-1)I(t-1)-\beta I(t-1)-\gamma I(t-1), \\
(t)=(t-1)+\beta I(t-1), \\
D(t)=D(t-1)+\gamma I(t-1), \\
Z(t)=\frac{\alpha}{N}S(t-1)I((t-1), \\
K(t)=N-S(t).
\end{gathered}
\qquad (2.36)
$$

There are three free parameters in this system of equations: α - the rate of infection per unit time (the number of people infected by the ill person per day); β - recovery rate per unit time; γ - the rate of death per unit time. The parameter α is determined by the infectivity of the virus (biological properties of the pathogen, which identify the probability of infection by direct contact of an ill and healthy person, the resistance of the pathogen in the environment, etc.) and the number of contacts with other people (degree of human interaction). Parameters β and γ are determined by the biological properties of the pathogen and the effectiveness of therapy in the event of the disease. The initial conditions for the model at the start from time t = 1 are as follows: S (1) = N-1, I (1) = 1, R (1) = 0, D (1) = 0, Z (1) = α / N and K (1) = 1. At the start from other points of time, the initial values of the variables corresponding to this time interval are taken. If we observe the initial stage of the epidemic in a population of N people, there is a set of data describing the variables S, R, K, D and I for a certain number of days. Let td be the moment until which there are no real data on the epidemic process development. The time t will vary from 1 to td (t = 1, 2, 3,…. Td). Real data on the epidemic process during td are S', R', I' and D'. Based on the above data on the change of real variables at each time step and equation (2.36), it is possible to calculate samples of values for parameters αt, βt and γt by the following formulas:

$$\alpha_t = -\frac{N(S'(t)-S'(t-1))}{S'(t-1)I'(t-1)} \quad \overline{\alpha} = \frac{1}{td-1}\sum_{t=2}^{td}\alpha_t,$$
$$\beta_t = \frac{R(S'(t)-R'(t-1))}{I'(t-1)} \quad \overline{\beta} = \frac{1}{td-1}\sum_{t=2}^{td}\beta_t, \qquad (2.37)$$
$$\gamma_t = \frac{D'(t)-D'(t-1)}{I'(t-1)} \quad \overline{\gamma} = \frac{1}{td-1}\sum_{t=2}^{td}\gamma_t.$$

In these equations, $\overline{\alpha}, \overline{\beta}, \overline{\gamma}$ are the average values of the parameters that can be used as assessed values of the parameters α, β and γ for the epidemic forecast. When calculating according to the above formulas, samples of values of αt, βt and γt containing td-1 elements are obtained. These samples calculate the confidence intervals of the estimated parameters α, β and γ.

The bootstrap method in this implementation enables estimating the confidence interval for the peak date and the total number of deaths after the epidemic. The peak incidence of infection is identified by t when the curve I(t) will have a maximum value. When calculating with the parameters $\overline{\alpha}, \overline{\beta}, \overline{\gamma}$ from bootstrap replicas, we will have a series of curves I(t) with maximum values at different time t. Thus, the researcher obtains a sample of bootstrap values of the time t for the peak incidence. From this sample, it is possible to find the confidence interval of the peak incidence date. At the final point in time, when the number of patients I(t) will be equal to 0 or close to 0, we will have a bootstrap replica regarding the values of the variable D(t), which can estimate the confidence interval for the proposed number of deaths..

More complex models divide people into small groups according to specific features (age, gender, health status, number of contacts, etc.). Using detailed information on population density, the share of the elderly, transport links, the size of social groups, the health care system state and other factors, scientists build virtual copies of cities, regions, or even countries using differentiated equations that reflect the interaction of different groups of population in space and time. Then, they add the SAR-CoV-2 virus to this virtual world and monitor the events. Based on such equations, mathematical models can be very complicated since the entire population can be divided into small groups to reflect the real picture better. There are alternative approaches to modeling the spread of the virus, which allow demonstrating the entire course of the disease spreading in a particular region in more detail. It does not use equations as a complex component of the model. Alternative approaches are based on creating and using special tools - "agents" that operate according to specific rules of individuals' conduct. Although this tool is less complicated, it requires a large amount of input at the level of individual households: who and how one gets to work, where and with whom they spend time, where they buy basic consumer goods, etc. (Koidan, 2020). A combination of artificial intelligence methods for design and statistical analysis methods to form the sampled data parameters is useful to build an adequate model that can effectively solve complex socio-economic problems in times of pandemics. It is worth noting that only after some time (several months, possibly years) it will be possible to assess how accurate mathematical models are that currently try to predict the spread of coronavirus and, accordingly, underlie critical decisions made by governments around the world. Ready-made forecasts are analyzed, refined and adjusted ex post facto.

Chapter 3. Forecasting models of the epidemics impact on the countries' macroeconomic indices

The global COVID-19 pandemic and the blockades it caused in various countries worldwide have demonstrated the close link between public health and the economic situation (Rahmanov et al., 2020). Many scientific works deal with the economic impact of the coronavirus pandemic on the world's financial sphere in 2020. Ivanov (2020) points out that the epidemic is a kind of risk factor for the world's supply chain, causing long-term supply disruptions, and has a so-called ripple effect and high uncertainty degree. Zhanga et al. (2020) present to the scientific community a statistical analysis of the coronavirus pandemic impact on the global stock market. The results of the calculations showed that the risks in the global financial market had increased significantly. Individual reactions in the stock market are strictly related to the difficult pandemic situation in each country. Uncertainty about further pandemic forecasts and related economic downturns have made markets volatile and unpredictable. Ali et al. (2020) examine the reaction of financial markets in terms of volatility in shifting the pandemic epicenter from China to Europe and the United States. Kraus et al. (2020) describe a new type of company and approach to their management during a coronavirus pandemic. Such models can adapt to different pandemic development scenarios successfully. The authors consider the situation in terms of a short-term and long-term exit strategy. The authors' research has shown that almost all companies in all industries and different sizes in selected European countries adapt their business models to changing environmental conditions throughout the whole pandemic. Donthu et al. (2020) analyze many scientists' works covering research in various economic fields (tourism, retail, large and medium enterprises, etc.). They focus on changing consumer behavior and approaches to doing business, ethical issues and various aspects of employment and personnel management. Many works deal with exclusively certain economic areas of activity. For example, Pantano et al. (2020) analyze the impact of the pandemic on the management decisions and marketing of retailers.

When analyzing the various options for further developments in the pandemic COVID-19, experts pay attention to the chain of risks. The unpredictable nature of the spread of the virus contributes to the expansion of the list of risks that threaten the local and global economy.

The first group is the risk of continuing the epidemic. It is that states are not able to control the situation after the weakening of quarantine measures fully. In this case, the scale of losses to countries and the global economy will have a significant long-term impact.

The second group is the risks of social instability. It applies to social unrest associated with rising unemployment, declining social standards and too harsh anti-epidemic actions by the central government. It is evident that under such conditions in the world, it will be challenging to ensure the effective implementation of quarantine measures, the need for which is emphasized by the World Health Organization.

The group of risks of aggravation of trade relations between the countries should be singled out. It is that, due to domestic economic difficulties, some countries will not be able to expand imports of goods, which in turn will lead to higher import tariffs. This risk is characterized by several features that have developed both during the pandemic and before. In particular, the transition from free foreign trade and globalization to protectionism, which began in 2001 after China acceded to the World Trade Organization, will accelerate. Declining production activity and job losses in the West, as a result of globalization and the vulnerability of global supply chains, will contribute to the independence and self-sufficiency of countries, but also associated inefficiencies.

Termination of the business and educational process due to quarantine will reduce the frequency of business trips and study time. The practice of face-to-face meetings will lose its relevance, and a significant proportion of business meetings will be held online. The public will be able to appreciate the benefits of remote communication fully. In turn, this will harm airlines and the hotel industry. Also, the home office will be more comfortable for employees of some sectors. Consumer prudence will last much longer than after the 2008 financial crisis. The attitude of the population to the purchase or use of certain goods and services as such, without which it is possible to do without, may prevail for years. It will affect consumer spending and, consequently, retail sales. Except for total protectionism, supply will continue to exceed demand. As a result, excess savings will lead to lower inflation and interest rates. Low inflation and possibly even deflation will weaken the population's propensity to spend, further holding back any economic recovery. Falling crude oil prices may push oil-producing countries to seek new partners, which could provoke new oil wars (Smith, 2020; Yap, 2020).

Lending standards will be tightened in the world, as in the case of mortgage loans after the failure of subprime lending. Treasury bonds, which are the ultimate asset-shelters, will continue to be attractive even with unchanged or possibly negative real returns in a deflationary climate. The changes will also affect pension funds, due to the transition to riskier investments in search of higher returns. Businesses in various industries face challenges since logistics suffer almost everywhere (Teletov et al., 2020). The coronavirus phenomenon is difficult to predict. In March 2020, Esin (2020) described three scenarios for the development of the world economy:

1) Fast recovery. In this scenario, although consumer demand will fall, the nature of this fall will be localized by duration.

2) Global delay. The author predicts a recovery in China's economy, and the spread of the virus is projected to decline due to seasonality. The economy will recover at the end of the second quarter, but world GDP growth will decline.

3) The global epidemic. In this scenario, the world economy is exposed to a serious shock lasting a year. There is a global economic downturn.

Depending on whether the economy can avoid a recession, the path to growth under COVID-19 depends on some factors. Scenarios V-U-L are offered. The V-shaped scenario describes the classic shock of the real economy, the shift in production, but growth eventually resumes. In this scenario, the annual growth rate may completely absorb the shock. The U-shaped scenario appears when the shock persists, and although the primary growth path is restored, there is some permanent loss of production. The L-shaped is the worst among these three scenarios. For this scenario, a coronavirus pandemic must cause significant structural damage, i.e., disrupt labor market areas, capital accumulation, or productivity function.

The four main scenarios for overcoming the crisis of the world economy caused by the COVID-19 pandemic are listed in table. 3.1.

Opinions of experts and rating companies agree that changes in various spheres of life will not be profound and irreversible. The speed of recovery may be affected by the fact that different industries will recover unevenly. A possible development scenario is demonstrated by China, which has already survived the first wave of the epidemic. Tourism, air travel, export-oriented industries, international manufacturing, and traditional services and entertainment, where close people-to-people contacts and mass gatherings were practised before the epidemic, will take much longer to recover. Most likely, the recovery schedule in the world and different countries will be V-shaped (sharp decline and equally sharp recovery) or U-shaped (the rise will be delayed because many companies will have to restore production chains and re-hire employees). If the situation cannot be brought under control, then scenario L is possible, and governments will not be able to help businesses and banks. Many of them will go bankrupt or lose their competitiveness, causing a debt crisis and a lack of liquidity. The collapse of banks and companies will threaten the entire world financial system and production, and the problem will drag on for months.

Table 3.1

Forecast scenarios for exit from the crisis after the coronavirus pandemic (built using (How is COVID-19, 2020; Economics in time, 2020; COVID-19 outbreak)

Scenario name	Main characteristics of the scenario
V: rapid decline and growth	Proponents of this scenario suggest that after a sharp decline, there will be an equally rapid growth almost to pre-crisis levels. According to some economists, after a large-scale decline in world GDP this summer, already in the fall, stimulus measures by governments around the world could lead to a rapid economic recovery. Starting a business and resuming business activity can lead to tangible results in the 3-4th quarter of 2020.
U-graph: decline, stagnation, and active growth	In this scenario, recovery will take more than a few quarters. In this case, the crisis will be more like the situation in 2008-2009. This theory is followed by many surveyed economic experts. Exit from quarantine will be smooth, which will affect the speed of restarting the economy. At the same time, many industries will recover more slowly - these include, for example, tourism.
W: recovery and the second wave of the crisis	This is the so-called “double-fall scenario”: easing lockdown measures will bring recovery to the economy, but the crisis will remain. During the quarantine, many businesses and businesses will go bankrupt, unemployment will rise. There is also a possibility of a second wave of the epidemic closer to autumn – it may be provoked by the abolition of quarantine measures.
L: protracted economic crisis	This scenario does not provide for a rapid recovery and at least a transition to economic growth. This scenario could materialize if the coronavirus pandemic is not defeated in the coming months. In this case, lockdowns around the world will continue, and if they are canceled, there may be repeated outbreaks. However, the probability of such a negative development is still unlikely. This is evidenced by the experience of Wuhan, a city that became the first epicenter of the epidemic, which is now gradually returning to normal life. However, the L-recovery schedule can still be implemented for individual world economies. In the risk group of a country where it is difficult for the authorities to properly stimulate the economy, and at the same time they rely on the export of resources.

Under the L scenario, China will once again be ahead of everyone (losing half of its 2019 growth rate in a year), but the country will only recover by mid-2021. The US will lose more than 8% of GDP, and the EU – almost 10%. According to analysts, they will return to the level of 2019 only at the end of 2023. In developing countries, many of which have gone through similar deep crises in recent decades with the destruction of various spheres of human life will survive the new crisis a little easier.

The classic transfer of exogenous shocks to the real economy occurs through financial markets. When markets fall and household welfare declines, household saving rates increase and, consequently, consumption should fall. This effect should be strong, especially in developed economies. It requires a steep and steady decline. However, although financial market indices and consumer confidence are highly correlated, long-term data also show that consumer confidence may decline even as markets grow. COVID-19 has a negative effect on confidence, which is a pessimistic picture of the future.

Since the beginning of the pandemic, the world has become more conservative, which is evident in consumer behavior in many markets. People try to protect themselves and to keep social distancing. In the short and medium-term, people will save their financial resources to be ready for repeated lockdowns. In the future, many countries will form stocks of products (food, equipment, medicines). In particular, support is provided to producers of these goods in local markets. Global companies need to have reliable supply chains, devastated during the pandemic. Therefore, it is likely that a pandemic will force such companies to rethink their supply chains soon and possibly move certain supply chains closer to places where they are necessary to avoid future shutdowns (Donthu & Gustafsson, 2020).

Thus, the epidemic outbreaks form a particular case of the risks arising in supply chains in different markets since pandemics are characterized by long-term gaps, ripple effects and high uncertainty. In his study, Ivanov (2020) presents the results of a simulation study on the impact of COVID-19 on global supply chains. The author conducted a series of experiments to test the sensitivity of the model parameters for different scenarios. It illustrated the change in model behavior, which is essential for those who make decisions in changing market conditions caused by pandemics. Such research is useful for predicting the short-term and long-term macroeconomic impact of epidemic outbreaks and developing pandemic response plans. For clarity of the analysis, the author modeled global supply chains for a company that sells lighting equipment (for five different products). The author obtained a multi-stage supply chain with suppliers, production, distribution centers and customers located in different areas. The model contains two producers from China, whose suppliers are contractors from the regions affected by the epidemic outbreak, where quarantine was introduced, and production stopped. Producers deliver the product by ships and freight trains to the United States, Brazil, and Germany with an average transportation time of 30 days. Then, in the United States, production is distributed from Houston main distribution center or through four regional distribution centers. If orders are delivered within 4-9 days, the delivery is considered timely; otherwise, it is considered that there is a delay in delivery of products. The author uses a coronavirus schedule spread for the period from January 2020 to March 12, 2020, which he found on the Internet. The author considers three possible scenarios of pandemic events:

Scenario 1. Localization of the epidemic in China.

Scenario 2. Outbreaks and closures of businesses around the world.

Scenario 3. Further spread of epidemics to other markets and falling demand to 50%.

The author uses the methodology of modeling discrete events. The model has a set of tools that can be optimized using Logistix software using the standard "Global SIM Expertise" function. One of the conclusions is that the closure and opening of facilities can be a significant factor in determining the impact of outbreaks on supply chains efficiency. Other essential factors are the speed of epidemics and the duration of disruptions in supply chains.

Scientists widely use the modernized SIR model to predict economic indices affected by pandemics. Thus, Alvarez et al. (2020) analyzed the possibilities of developing an optimal blocking policy to reduce mortality from COVID-19 and minimize blocking costs, using a combination of the SIR epidemic model and linear economy elements. They concluded that the optimal set of measures in this area depends on the share of infected people and the susceptible population. They added parameters to the model using pandemic data and economic coverage of the blockade. The quantitative analysis enabled to determine the factors influencing the intensity and duration of optimal blocking. The authors note that the optimal blocking policy must begin two weeks after the outbreak and cover 60% of the population with a gradual easing of quarantine measures covering only 20% of the population. However, they mention that the lack of testing increases the expenditures for blocking and reduces the optimal blocking duration, ending not as smoothly as in the previous case. The welfare of a country's population with an optimal testing policy is higher, equivalent to a one-time payment of 2% of GDP.

Acemoglu et al. (2020) argue that the most compromise option is differentiated blocking according to various risk groups if there is a need for quarantine measures in pandemics. They use the Pareto principle by establishing the boundaries between economic and human losses, influencing management decisions when adopting specific blocking measures. Graphically, the authors' opinions are shown in Fig. 3.1. At some point in the figure, the line is pointing upwards, indicating the absence of quarantine easing by the government and an increase in economic losses and deaths. This situation is since economic damage includes productivity loss due to illness and declining productivity due to rising deaths. The dotted line shows a situation closer to the ideal. It confirms the authors' view that a meaningful blocking policy can save a significant number of lives since the same economic losses are maintained, but the mortality from infection is significantly reduced.

Besides, the authors analyze other options for blocking policy. Mainly, they consider the group distancing policy. They prove that this policy is a powerful tool to reduce mortality among people, complementing targeted blockades. For example, the authors note that group distancing can reduce mortality by 0.2% and economic costs by about 16% of GDP per year.

Another set of measures to improve pandemic control in countries includes testing and contact tracking. The authors analyze the model of virus spread under the condition of applying two measures at once - group distancing and testing and contact tracking (Fig. 3.2).

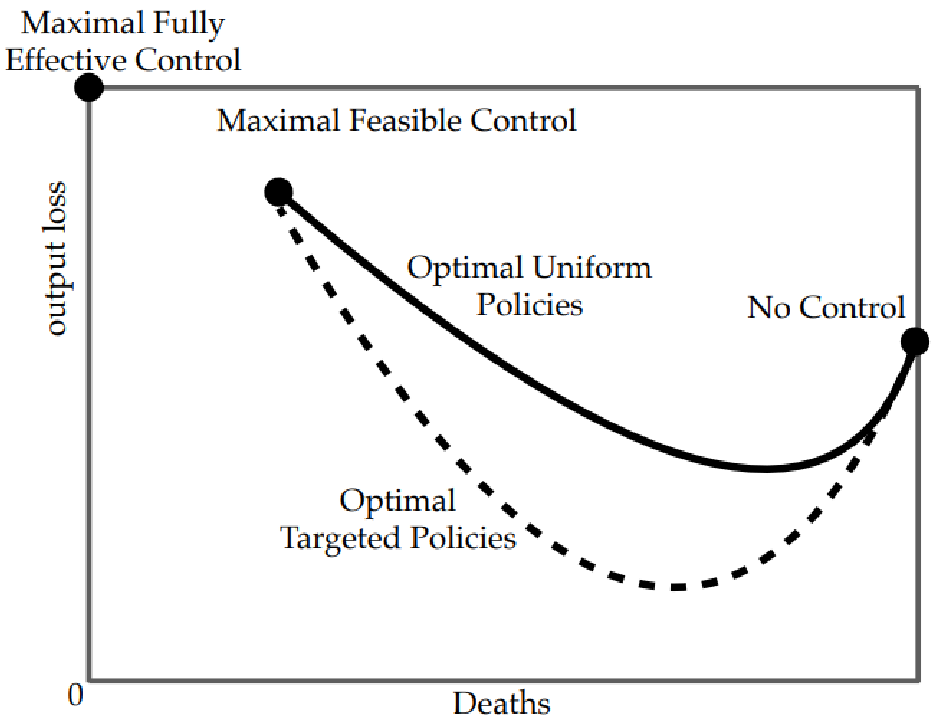

Figure 3.1 – Economic losses and mortality rate without additional measures to prevent the virus spread (Acemoglu et al., 2020)

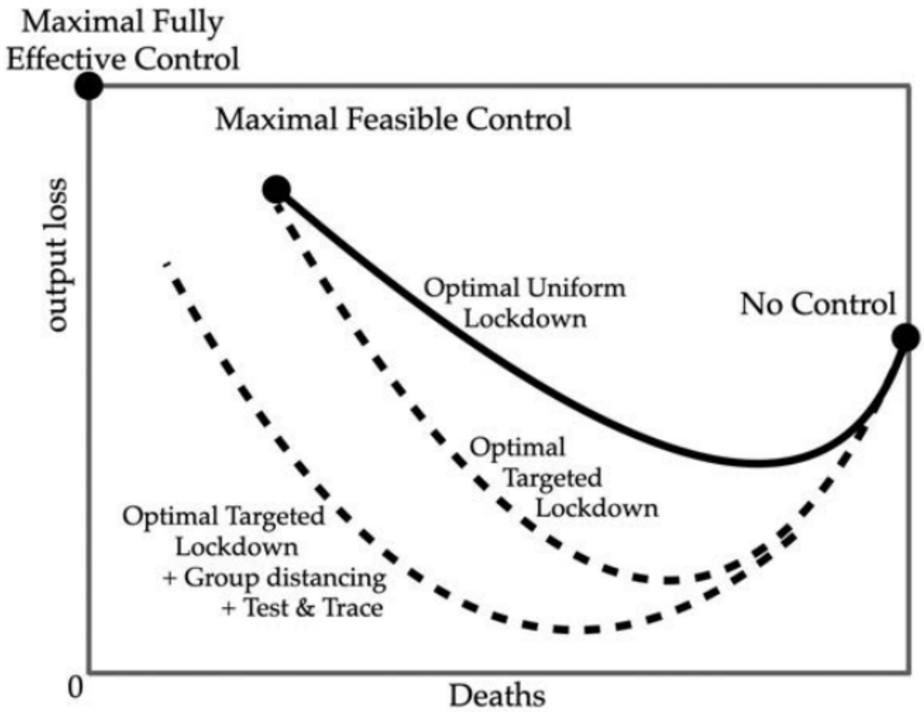

Figure 3.2 – Economic losses and mortality rate with additional measures to prevent the virus spread (Acemoglu et al., 2020)

Bayraktar et al. (2020) investigated the SIR model of the COVID-19 pandemic, which considers the cumulative immunity in society, the transmission rate depending on the behavior, remote workers, and indirect external factors causing a lockdown. The authors' study provides two blocking levels for different groups of the population - those in the low-risk group (aged 20-64) and those in the high-risk group (aged 65). These levels are defined by optimizing the target function, which considers the dependence of macroeconomic losses on the blockage level and the number of deaths. The authors see the economic slowdown as the most noticeable result of blocking measures. Many workers who are not necessary for quarantine or cannot work remotely become out of work because companies lose income. As in (Acemoglu et al., 2020), the authors consider the average salary of a full-time employee and normalized it to 1. It was assumed that those workers who are in the high-risk group do not receive a salary at all. In their calculations, the authors do not consider the existence of an "immunity passport" issued to those who recover and have immunity. So, the parameter p is equal to one. It also considers a particular share h of labor who can work from home. Finally, the authors marked the expenses for blocking through wages as follows:

$$\omega jLj(t)(Sj(t) + Ij(t) + Rj(t))(1 - h). \qquad (3.1)$$

The authors observe losses caused by blockages as losses in production volumes caused by people who do not work. Initial losses are expressed as follows:

$$\int_0^{\sigma} e^{-(r+v)t} \sum_j \omega jLj(t)(Sj(t) + Ij(t) + p\,Rj(t))(1 - h). \qquad (3.2)$$

The value obtained by formula (3.2) is compared with the annual standard production rate. This basic income is calculated as the amount of products produced before the expected time of the vaccine arrival.

This output is calculated as the amount of product produced before the expected time of vaccine arrival. If there is no blockage, the annual income is calculated according to the scheduled time of the vaccine arrival. The following formula can demonstrate it:

$$\int_0^{\sigma} e^{-(r+v)t} \sum_j w_j N_j dt = \frac{v}{r+v} \sum_j w_j N_j. \qquad (3.3)$$

The authors then calculate the cost of death from COVID-19 in group j using the approach described in (Acemoglu et al., 2020). The parameter χ describes the intangible living cost, which authors considered the impact of mortality from COVID-19 on society. The value of χ in 0.2 / r corresponds (Acemoglu et al., 2020), where $\chi = 20$ and $r = 0.01$. The parameter Δj shows the number of years left in an individual's career. The authors find the values Δ1 = 20 and Δ2 = 0. Therefore, the cost of death from COVID-19 is defined as

$$\chi + \frac{w_j}{r}\left(1 - e^{-\Delta_j r}\right). \quad (3.4)$$

Authors do not count fatalities indirectly caused by blockage. For this reason, they do not include χ in the cost of these deaths, but only consider the productivity loss. The authors take into consideration similar future deaths caused by the lack of preventive medical care using the constant parameter F (the number of indirect fatalities in the future in relation to those that occurred during the blockage). These fatalities are not reflected in the dynamics since they have not yet occurred, but they must be considered when calculating the losses from blockage:

$$\frac{w_j}{r}\left(1 - e^{-\Delta_j r}\right)\xi\left(L_j\right)\left(F + R_j(t) + S_j(t)\right). \quad (3.5)$$

Another addition to the model identifies the long-term economic consequences of the economic slowdown. Many large multinational companies have become bankrupt (The Hertz Corporation (although demand for car rental services of this company decreased long before the coronavirus since many consumers began to prefer the services of such companies as Uber and Lyft; retailer JCPenney, etc.) (Monica, 2020). Measures provided by national governments may alleviate the situation of companies. However, they are not able to fully compensate for the current decline in consumption. The adverse effects of a pandemic can be shown in different ways. The authors expressed them as job loss in the future when one blocking day leads to several αE days of job loss (on average). Its value is 0.42 (it reflects the current 14.7% unemployment rate as of April 2020) (BLS, 2020) and an average of three days of unemployment per blocking day, based on the average unemployment duration of 25.2 weeks (six months) in 2010 (Great recession, 2018). The authors modeled the following future unemployment cost:

$$\alpha_E w_j L_j(t)Sj(t) + Ij(t) + pRj(t)). \qquad (3.6)$$

Zhurovskyi et al. (2020) study common factors of pandemics in the world. They point out that over the past two decades, various epidemics have become more frequent, affecting the health of the world's population and the economies of regions and entire countries. An analysis of the effects of the SARS, swine flu, Ebola, and COVID-19 pandemics over the past 18 years on the development of the world economy has shown that they are cyclical with a return period of approximately five to six years. They significantly affect macroeconomic indices, leading to breaks in economic chains and slowing down economic development and society for months or even years. The authors developed a mathematical model and computer simulations of this phenomenon in pessimistic and optimistic scenarios to study the impact of the COVID-19 pandemic on the European countries' economies. The authors predict the probability of pandemics and their effects on economic development by putting them on the axis together with such fundamental periodic processes as:

– 40-50-years economic cycles of M. Kondratiev, based on changes in the technological culture of society;

– 7-11-years cycles of K. Zhuglyar, related to fluctuations in the capacity utilization levels and investment in fixed assets;

– Dow Jones Industrial Average, reflecting the total capitalization of 30 largest companies, the activity of which collectively defines the world economic trends.

Fig. 3.3 demonstrates that in 2020-2021 the downward wave of the fifth Kondratiev cycle ends and switches to the upward wave of the sixth cycle. Simultaneously, the economic recovery in the period 2020-2021 is significantly weakened by breaking economic chains caused by the COVID-19 pandemic, significant defocusing of investments in various types of business. It leads to the bottom of the Juglar cycle and falls by 30-40 % of the Dow Jones index. According to Zhuglyar, this reduction will last for about a year, during which investments will be redirected to business types that correlate with the sixth technological mode according to Kondratiev's cycles. The recovery of the global economy should begin with increasing the contribution to world GDP by over 5-7% thanks to the sixth mode of technologies.

Keogh-Brown et al. (2020) assessed the potential impact of COVID-19 on the UK economy, including the direct effects of the disease, preventive public action and related policies. The researchers linked the sectoral macroeconomic model to the epidemiological, demographic picture to assess the potential macroeconomic impact of COVID-19 and preventive measures (self-isolation, school closures, social distancing, business closures). In general, studies showed that COVID-19 could lead to unprecedented economic losses in the UK. The financial support package should be proportionate to the cost for mitigating COVID-19, but economic support can be insufficient without alternative measures to halt the spread.

Although previous outbreaks of SARS and MERS coronavirus have not had a significant economic impact on the UK, macroeconomic simulations of disease outbreaks were conducted about ten years ago, in the context of the UK pandemic, to assess the potential impact of prevention measures (Smith et al., 2011). Previous macroeconomic models have considered the direct and indirect economic impact of pandemics, school closures, and short-term preventive absences of employees at work. The simulation results show that depending on the pandemic severity, if 30% of the workforce is absent at workplaces and schools are closed for 13 weeks; the indirect negative economic consequences can ten times go beyond the direct economic effects directly related to citizens' health.

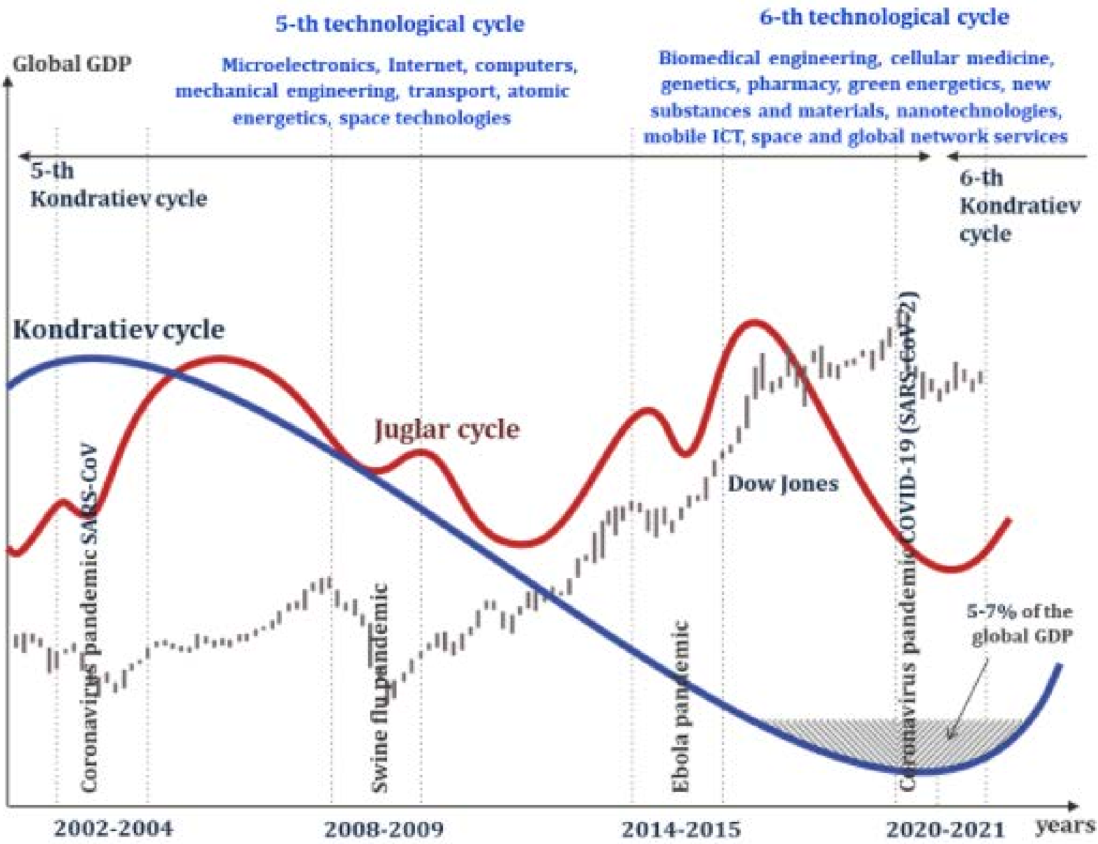

Figure 3.3 – The impact of pandemics on the development of the world economy (Zhurovskyi et al., 2020)

Keogh-Brown et al. (2020) used a Computable General Equilibrium (CGE) model in their study to analyze the potential macroeconomic impact of a coronavirus outbreak for the UK comprehensively. The CGE is a comprehensive model used to analyze indices in different economic sectors that correlate with a country's health care system. This model has been used to analyze previous government programs to curb the spread of flu pandemics worldwide (Lee & McKibbin, 2012). This model is quite flexible and can be used simultaneously to assess the direct and indirect impact of public health on labor market supply, consumption and specific economic sectors. These models can also analyze government macroeconomic policy in more detail and fix changes in the businesses and consumers' behavior. The CGE model is based on recording the behavior of various economic agents: firms, consumers, government and foreign agents. It considers the fact that firms seek to combine and multiply invested resources to maximize profits. Consumers divide their income between consumption and savings to maximize welfare. The government sets and collects taxes, distributes benefits, and buys goods. Foreign agents interact with domestic agents through trade in goods and services in the framework of export-import operations, foreign transfers and external borrowings and loans. The agents' behavior is based on economic theory laws. The set of equations define it mathematically. The model includes numerous producing sectors and commodity markets, the state budget. The authors used various CGE models, namely the standard IFPRI CGE model, first proposed by the International Food Policy Research Institute (Lofgren et al., 2001). The equations for this statistical model are formed using economic data, the Social Accounting Matrix. The model was built from 2015 to 2020 using data on real and nominal GDP, including 2020, when there was a negative impact of the coronavirus outbreak in the UK economy.

Vasiev et al. (2020) model macroeconomic processes for China using Python 3.4 software. The analysis is performed according to the seasonal model of the autoregressive integrated moving average (SARIMA). This study allowed scientists to identify the economic, social, and environmental factors most affected by a virus attack. A total of 23 factors were tested. The author's research methodology includes factor analysis, determination of the most influential factors for stable indices of Chinese provinces, construction of SARIMA regression model. Four scenarios have been predicted for the post-coronavirus economy in Chinese provinces using the "net-science" methodology (Suarez et al., 2015). The sequence of the author's research is as follows:

1) Introduction of scenario parameters for reducing economic activity in Hubei Province.
2) Modeling the redistribution of resources.
3) Assessing the lack of security for each of the 31 provinces in China.

4) Determining the level of decline in production for each sector.
5) Distribution of underproduction according to the scenario.
6) Changing the level of production.
7) Getting results according to a particular scenario.

After determining a set of parameters to reduce the production level in Hubei Province, according to each scenario, the redistribution of assets and the level of deficit for all regions are projected. Then, according to each scenario, the redistribution of resources for each province is estimated.

The financial flows and the migration index between regions were analyzed using the cost-output matrices. The authors found the correlation degree between the local product and the population migration index. According to OLS regression results, the minimum relationship between financial flows and the migration index is 1.099147e + 06 and is very close. The redistribution of the virus from a particular province primarily affects closely related regions. The analysis showed that during the epidemic, economic activity declined in all provinces. The researchers also calculated the cross-regional entropy of the migration index proximity during the pandemic and post-viral period. The higher the economic entropy for a province, the higher its stability, stronger relationship, and coronavirus susceptibility. Gössling et al. (2020) modeled possible scenarios of developments in the world economy, reflected in Fig. 3.4.

The transmission of economic and financial consequences between economic sectors and regions is called "spill-over." International spill-over effects are mostly studied using multi-regional input-output analysis (MRIO) (Auer et al., 2017). This type of analysis was developed by Nobel Prize winner V. Leontief (Leontief, 1936). Since then, it has been widely used to track economic and environmental impacts through complex supply chain networks, including the health care system impact. The main element of MRIO analysis is the N * N intermediate demand matrix, reflecting the links between all world economy sectors. The sectors can provide other industries or final consumers.

The intermediate and final demand is summed up. For example, when y is a household, the total output is x = T1 + y, where the vector 1 = {1,1,. . ., 1} is the summation operator. Determining the matrix of the technical coefficient A≔Txˆ-1 allows obtaining the basic calculated Leontief identity x = Txˆ-1 + y ↔ x = (I - A) -1y, where I - is the identity matrix. The variable (I - A) -1 is a well-known Leontief statement providing information about complex relationships between geographically remote producers and consumers.

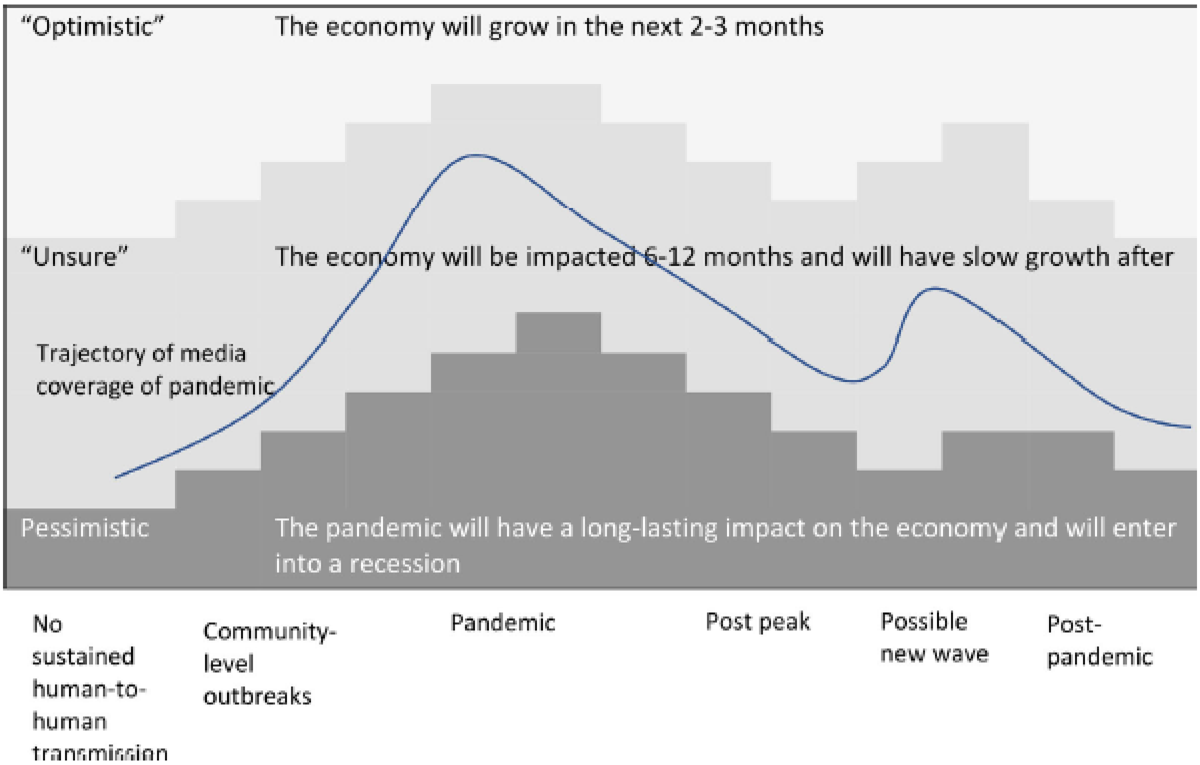

Figure 3.4 – Scenarios for the development of the world economy after the COVID-19 pandemic according to Gössling et al. (2020)

A disaster analysis is one of the MRIO analyses studying the impact of shocks on the economy. This type of analysis considers the direct and indirect consequences of disasters that lead to production loss and reduced business activity. Over the years, several variants of such an input-output analysis have been developed for various emergent events. The variations deal with expanding the possibilities for formal analysis using the econometric model "input-output."

A relatively new version of the model - hypothetical extraction (HEM) is based on the hypothetical scenarios assessment in the economy when industries stop to operate, e.g., the study of Xia et al. (2019) on the closure of the IT industry in the UK caused by the natural hazards.

Lenzen et al. (2020) set a goal to quantify the real impact of the global COVID-19 pandemic on human existence. These authors focus on the disaster analysis, which considers the consumption possibilities after a disaster. This method uses a matrix of events G, in which the diagonal elements G_{ii} describe the relative losses of the branches i = 1,. . ., N as a direct result of the catastrophe. The parameter $(\bar{x} - x)^2$ of the output $\bar{x}$ after the accident from the output x before the catastrophe is minimized, provided that two conditions are met:

– it is established that $\bar{x} \leq (I - G)x$;

– the final demand after the catastrophe is $\bar{y}=(I - A)\bar{x} \geq \min(0, y_{St})$. Here $y_{St} \leq 0$ contains information on stocks that industries can count on to continue their sales, despite the decline in production.

Thus, the initial conditions of the model suggest that the final demand may not be negative for sectors that do not have stocks. Decreased consumption after the disaster (including the pandemic) reduces the employment rate and household incomes. According to calculations in (Leontief, 1936), the economic and environmental consequences of F disaster can be calculated based on consumption losses as the difference in previous and subsequent consumption opportunities $\bar{y}$-y-asF=$Q\hat{x}^{-1}(I-A)^{-1}(\bar{y}-y)$.

Erokhin & Gao (2020) assess the relationship between food security, health and macroeconomic variables. They introduce variable Y into the calculation, which indicates the number of people with insufficient food intake. Besides, the authors used the following variables in calculations:

– X_1 – the number of confirmed cases of COVID-19;

– X_2 – balance of food trade as the value of food and agricultural products exports excluding imports of food and agricultural products;

– X_3 – food inflation as a monthly percentage change in the price of a standard food basket;

– X_4 – exchange rate.

Variable X_1 is used to demonstrate the direct impact of the pandemic on food security. The authors conducted an analysis consisting of four stages. In the first stage, a stationary test is performed to check the relationship between the selected variables. The autoregressive distributed lag method (ARDL) was used to analyze the short-term and long-term interactions between variables in the second stage. The Yamamoto test is then used to identify causal relationships between variables. In the last stage, the authors tried to predict the future relative strengths of causal relationships between variables using the variance decomposition method. The equation for ARDL analysis is as follows:

$$\Delta Y_t=\delta_0+\sum_{i=1}^{1}\delta_{1i}\Delta Y_{t-i}+\sum_{i=1}^{1}\delta_{2i}\Delta YX1_{t-i}+\sum_{i=1}^{1}\delta_{3i}\Delta YX2_{t-i}+\sum_{i=1}^{1}\delta_{4i}\Delta YX3_{t-i}+\sum_{i=1}^{1}\delta_{5i}\Delta YX4_{t-i}+\omega ECT_{t-1}+\varepsilon_{t-I}, \quad (3.7)$$

where Δ – the first difference operator; δ_0 – constant element; δ_1, δ_2, δ_3, δ_4 and δ_5 – short-term indicators of variables elasticity; *i* – the order of the ARDL model; ωECT_{t-1} – correction coefficient; ε_t = error coefficient; t – time.

Fan et al. (2018) define the pandemic risks r(s) in terms of the pandemic annual probability with a severity exceeding s standard mortality rates and time s as the expected number of years before a pandemic occurs with a severity at least such as s. If t(s) is the return time, then t(s) = r(s) -1. For example, if the pandemic annual probability is 1%, the return time is 100 years. As in other economic studies of pandemic influenza, the authors distinguish two main pandemic development scenarios: moderate and severe. The probability estimation function and empirically derived mortality values were used to find the economic loss in moderate and severe influenza pandemic scenarios.

In the studies regarding the impact of the pandemic on the countries' economies, Kazimi & Mackenzie (2016) rely on work (Verikios et al., 2015). It models the impact of a global influenza pandemic in two different scenarios. A high number of deaths but a low level of infection characterize the first scenario. The second scenario is characterized by a low mortality rate but a high infection rate. The second scenario has more initial global losses, but the losses in the first scenario exceed the losses in the second after the first year of the pandemic. The authors use a modified version of the GTAP model to represent influenza pandemic consequences (Hertel & Tsigas, 1997). GTAP is a multi-regional comparative statistical model of CGE in world trade and investment. Formal GTAP can be represented by a set of equations that define behavioral and definition relationships. We assume that there are m relations with the total number of p variables written in matrix form:

$$A_v = 0, \tag{3.8}$$

where A – m*p matrix of coefficients, v – p*1 a percentage changes vector in the variable models, and 0 is a zero-vector m*1. *e* variables are exogeneous among p variables. Typically, *e* variables describe changes in the economic structure and policy (e.g., tariff rates, technology). Variables *e* can be used to simulate changes in (p - e) endogenous variables. Many functions, which are the basis for (3.8) are nonlinear. Writing a system of equations like (3.8) allows the researcher to avoid unambiguous forms for nonlinear functions. It is possible to write the percentage fluctuations of variables (p - e) as linear functions of the percentage fluctuations of *e* variables. It helps to increase computational efficiency. Although the model is linear, exact solutions are generated using multi-step procedures.

Using the GTAP model, it is possible to represent the economic activity within regional economies. A local economy can be either a single country or an entire region consisting of many countries (for example, the European Union).

Each region is a producer of a particular product. The region's production is influenced by five main factors: skilled and unskilled labor force, capital, land, and natural resources. In the GTAP model, the fixed capital used by companies in each region is a fixed value. The authors add an equation that connects the capital stock at the beginning of the analyzed period and the capital stock at the end of the analyzed period to move to a dynamic index:

$$KE_r^t = KB_r^t + I_r^t - D_r^t, \tag{3.9}$$

where KB_r^t and KE_r^t – the amount of available capital in the region r at the beginning and end of the year t; I_r^t – the amount of new created capital (i.e., investments) in the region r during the year t; D_r^tr – depreciation of capital in the region r.

The authors add a new equation to the model to find the quarterly rate of capital accumulation (we denote the variables by the index q instead of t) without changing the variables in (3.9):

$$KE_r^q = KB_r^q + I_r^q - D_r^q, \tag{3.10}$$

The generated equation (3.10) demonstrates the quarterly values of depreciation (D_r^q) and investment (I_r^q), providing the capital amount KE_r^q, accumulated quarterly.

Planned investment in each region I_r ^ t is a function of the relative rate of the profit:

$$I_r^t = F_r(\frac{ROR_r}{ROR})^{\gamma}, \tag{3.11}$$

where ROR_r - net (depreciation) rate of return on capital in r-region; ROR – the average rate of return in the world; γ is a positive parameter; F_r is an exogenous scaling factor that ensures that the two sides of equation (3.11) are equal, considering the selected value of γ and the input values of ROR_r and ROR. Equation (3.11) provides an increase in investment in regions with higher profit rates of return and vice versa. The authors set the value of γ equal to one, giving a unitary elasticity rate of return on investment for all regions. The real investment in every region I_r^q is equal to $I_r^t/4$.

Martin et al. (2020) build an economic model at the household level. The model considers two periods: 1) the crisis period, which represents the loss of income and falling macroeconomic indices; 2) the recovery period in the economy. It is assumed that during the crisis, affected entities lose income depending on their belonging to a particular sector and use their savings to continue consumption. This situation continues until the full recovery of the economy. During the recovery period, it is assumed that the income level is fully restored to pre-crisis levels. Household recovery time is defined as the time required to replenish savings to the level before the crisis.

The authors describe the pre-crisis income, i_0, in the model in the following way:

$$i_0=i_0^L + i_0^{oth} + i_0^h = i_0^L + \pi k_0^{oth} + \pi k_0^h \quad (3.12)$$

where i_0^L, i_0^{oth}, i_0^h – initial pre-crisis amounts of income from labor, investment and housing (the authors understand the income from housing as rent to homeowners, considered as capital income); k_0^{oth}, k_0^h – capital reserves for investment and management, respectively; π – average capital productivity in the country.

Total income as a function of time, i(t), is:

$$i(t)=i_0-\Delta i(t)=i_0-\Delta i^L(t)+i^{UI}(t), \quad (3.13)$$

where $\Delta i^L(t)$ – loss of income from work caused by the crisis; $i^{UI}(t)$ – unemployment insurance as the government aid.

Pre-crisis level of household consumption is expressed via the equation:

$$c_0=i_0-p_0^{rent}-p_0^{mort}, \quad (3.14)$$

where p_0^{rent}, p_0^{mort} – rent and mortgage payments, respectively. It is assumed that all income not invested in housing, is consumed, to simplify the calculations.

The model assumes that households have savings from the beginning. They have current liquid assets that they can use in the crisis. It is assumed that the containment phase continues during T_C. At the end of this period, revenues may return to pre-crisis levels. The recovery period begins lasting T_R. It is assumed that people who are not affected by falling incomes or job losses have a fixed income. In the long run, the crisis affects all employees and firms. Negative consequences appear in the country's economic system. During the crisis and recovery period, households use and then recover their savings and consumption levels as a function of time, c(t), reflected in the model as follows:

$$c(t)=\begin{cases} c_0-\Delta i(t)+\frac{S_0-S_f}{T_C} & if\ 0\le t\le T_C, \\ c_0-\frac{S_0-S_f}{T_R} & if\ T_C<t\le T_C+T_R \end{cases}, \quad (3.15)$$

where S_o and S_f – initial and final amounts of savings, respectively; T_c та T_R – the duration of the crisis and the recovery periods.

The authors express the adjusted consumption via:

$$c_{adj}(t)=\max(c(t), c_{min}), \quad (3.16)$$

where c_{min} = 1e^{-3} shows the consumption preservation level with the assumption that people always have access to humanitarian aid (for example, food banks). Household savings as a function of time, S(t), is as follows:

$$S(t)=\begin{cases} S_0 - t\frac{S_0-S_f}{T_C} \;\; if \;\; 0 \le t \le T_C, \\ S_f + \frac{t-T_C}{T_R}\left(S_0 - S_f\right) \; if \; T_C < t \le T_C + T_R \end{cases}, \qquad (3.17)$$

where t – the time set at the beginning of the crisis t_0=0. Other variables are defined above. Recovery time is based on the exogenous ability to save, which is constant for all households:

$$T_R=\frac{S_f-S_0}{\gamma c_0}, \qquad (3.18)$$

where γ – the savings coefficient during the recovery period until the savings level returns to pre-crisis levels. The authors suppose that the value of this parameter is 0.10.

The developed model with time series of consumption and savings for households of a certain country is shown in Fig. 3.5.

Researchers in this study suggest that the population benefits from consumption, u(t), and savings, v(t). Moreover, the savings usefulness can be interpreted either as a "peace of mind" phenomenon when a person has liquid assets, or as preventing the cost of future savings for any negative shock that may occur in the future:

$$u(t)=\frac{1}{1-\eta}c(t)^{1-\eta},$$
$$v(t)=\frac{\alpha}{1-\beta}S(t)^{1-\beta}, \qquad (3.19)$$

where η – elasticity of consumption marginal utility, α and β are statistically calibrated savings utility parameters.

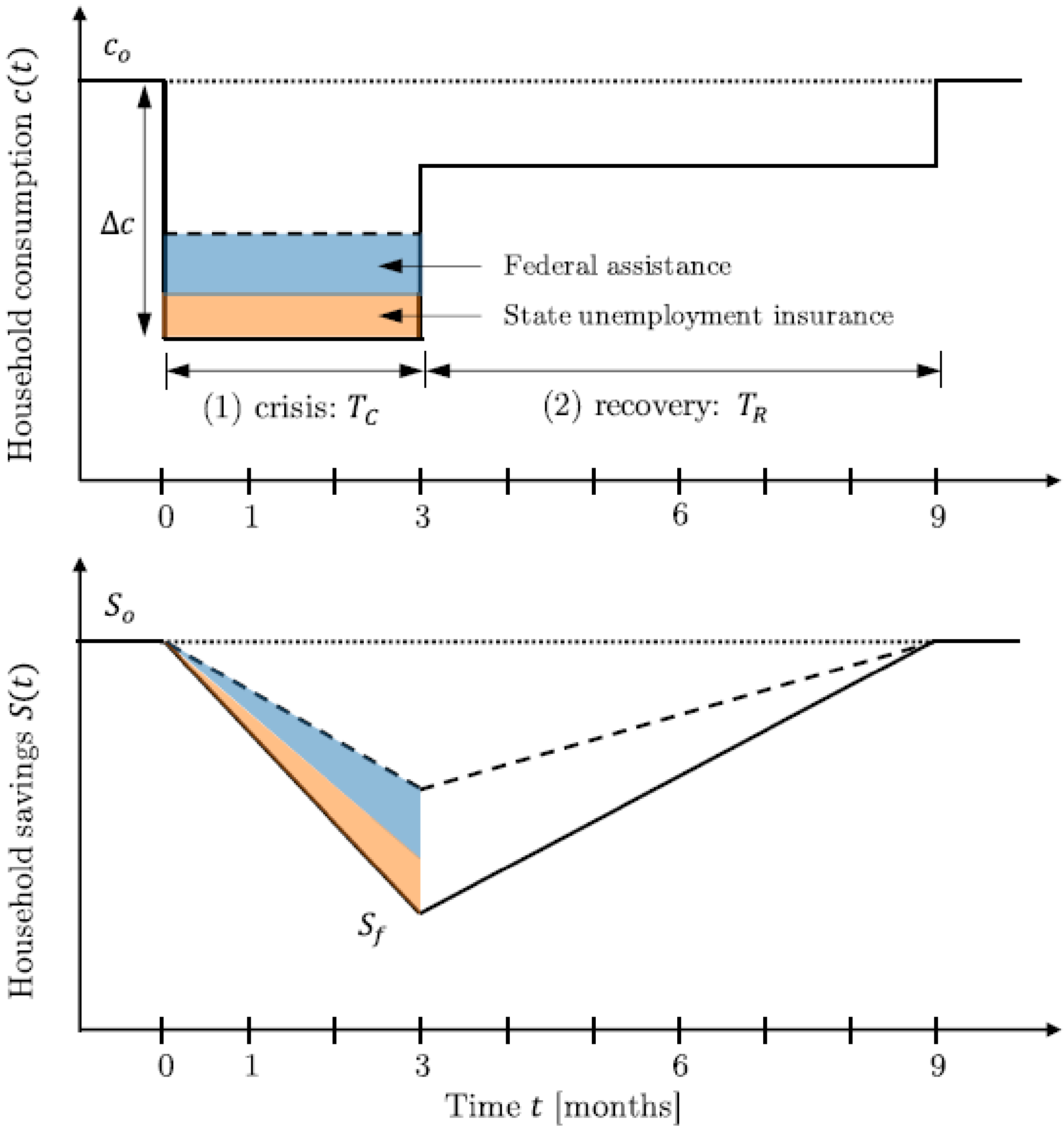

Figure 3.5 – Household consumption and savings model in crisis (pandemic) and recovery period (Martin et al., 2020)

Household welfare, W, is the sum of household welfare during the crisis, W_c, and recovery, W_R. Household welfare losses (ΔW) are calculated as follows:

$$\Delta W = W_0 - W, \tag{3.20}$$

where W_0 the initial level of the population welfare is defined as:

$$W_0=\int_0^{T_c+T_R} e^{-pt}(u_0+v_0)dt = \int_0^{T_C+T_R} e^{-pt}\left(\frac{1}{1-\eta}c_0^{1-\eta} + \frac{\alpha}{1-\beta}S_0^{1-\beta}\right)dt. \quad (3.21)$$

In their study, McKibbin & Fernando (2020) forecast seven scenarios for the global macroeconomic impacts of COVID-19 (Figure 3.6). However, in their work they use a global model of temporal general equilibrium with different agents - G-Cubed Multi-Country Model. This model is a hybrid of dynamic stochastic general equilibrium (DSGE) and computational general equilibrium (CGE) models.

Scenario	Countries Affected	Severity	Attack Rate for China	Case Fatality Rate China	Nature of Shocks	Shocks Activated	Shocks Activated
						China	Other countries
1	China	Low	1.0%	2.0%	Temporary	All	Risk
2	China	Mid	10.0%	2.5%	Temporary	All	Risk
3	China	High	30.0%	3.0%	Temporary	All	Risk
4	Global	Low	10.0%	2.0%	Temporary	All	All
5	Global	Mid	20.0%	2.5%	Temporary	All	All
6	Global	High	30.0%	3.0%	Temporary	All	All
7	Global	Low	10.0%	2.0%	Permanent	All	All

Figure 3.6 – Scenario assumptions about the global macroeconomic impacts of the COVID-19 pandemic (McKibbin & Fernando, 2020)

Czech et al. (2020) investigate the macroeconomic impact of the COVID-19 pandemic on the countries of the Visegrad Group (Czech Republic, Hungary, Poland, Slovakia). The authors analyze changes in market expectations based on volatility indices provided in option prices. Researchers use a reverse risk strategy to assess market perceptions of the risk related to high exchange rate appreciation or severe currency depreciation. The following equation describes the allowable volatility of the option:

$$\delta_{RR}=\delta_{25call} - \delta_{25\Delta put}, \quad (3.22)$$

where δ_{RR} – predicted reverse risk volatility; Δ - the rate of of the option price change regarding changes in the basic instrument.

The survey was conducted for the exchange rates EUR/CZK (Czech koruna), EUR/HUF (Hungarian forint) and EUR/PLN (Polish zloty), and the leading indices of the blue-chip stock market, i.e., Prague PX (Czech Republic), Budapest BUX (Hungary), Warsaw WIG20 (Poland) and Bratislava SAX (Slovakia). Data from the period from January 1, 2014, to May 7, 2020, were analyzed to define the short-term effects of COVID-19 on the financial markets in the selected countries, reflecting as percentage changes. 2014 is the year of the analysis. It is explained by the fact that there is a need to eliminate the effects of the previous global crisis in the Visegrad Group's financial markets.

The authors formed exchange rates and stock prices using the GARCH model, described in detail (Gunay, 2020). It is a convenient tool for modeling changes in the instability structure in financial markets over time. Given that the coronavirus pandemic period is interpreted in the scientific literature as a typical crisis period, the asymmetric GARCH model was used to illustrate the impact of COVID-19 cases on exchange rates and significant stock market indices in the Visegrad Group. Czech et al. (2020) use an improved TGARCH model, which allows fixing the asymmetry by adding a fictitious multiplicative variable to the equation and investigating whether there is a statistically visible difference between cases of positive and negative shocks. The authors describe the TGARCH (q, p) model as follows:

$$\begin{cases} Y_t = \beta COVID + \varepsilon_t \\ \varepsilon_t = \sqrt{h_t}\vartheta_t \\ h_t^2 = \alpha_0 + \sum_{i=1}^{q} a_i \varepsilon_{t-i}^2 + \sum_{k=1}^{l} \gamma k^{\varepsilon_{t-k}^2} I(\varepsilon_{t-k} < 0) + \sum_{j=1}^{p} \varphi_j h_{t-j}^2 , \\ \vartheta_t \sim GED(0, 1, \omega) \end{cases} \quad (3.23)$$

where Y_t – variable of the model; COVID – daily logarithmic changes in cases of COVID-19; ε_t – error, h_t^2 – conditional variance, β, α, γ, φ – coefficients of the model; ω - a generalized error distribution parameter.

Djurovic et al. (2020) confirm that since a pandemic leads to the cancellation of travel, meetings, and important events, it plunges the world economy into depression. The authors offer their econometric model as a production function:

$$GDP\_GAP_t=\beta_0+\beta_1 CapitalStock_t+\beta_2 logHumanCapital_t+\beta_3 E_{mp_t} + u_{t}, \quad (3.24)$$

where GDP_GAP_t – gross internal growth of HP filtered gap; $CapitalStock_t$ - gross fixed capital formation (% of GDP); logHumanCapitalt - the natural logarithm of human capital (includes employees with higher education that is crucial for economic growth); E_{mp_t} – employment (it is important for inclusive and sustainable development).

Time series are interpolated and seasonally adjusted. Since COVID-19 causes symmetrical shock on the economy, gross fixed capital formation has generalized the impact on demand. Human capital and employment are related to the effect on the supply of the Montenegrin economy. The authors use a new Keynesian macro-model, where GDP growth is modeled using a neoclassical production function using capital and labor as input (Roeger & Veld, 2004). They analyze employment and human capital from the supply side since the disease causes disability for those who care for the disabled. Thus, the analysis of economic models regarding the pandemic impacts, particularly COVID-19, showed that they are quite diverse, including different parameters to study the multidirectional effects of crises caused by such factors. Consideration of the findings obtained from these models can improve the effectiveness of decisions taken in the infection counteraction sphere and more quickly develop the necessary measures on time.

Conclusion

The authors analyzed several scientific sources, which contain studies of the impact made by COVID-19 on all aspects of public life, focusing on the economic sphere. Undoubtedly, the main negative aspect of pandemics is that they lead to human losses, a decline in the economic potential of the world's economies and a decline in the social parameters of life. According to the authors' research, governments' considerable efforts in many countries to counter pandemics, including COVID-19 infection, can level the playing field within states, somewhat mitigate the adverse effects, and stabilize economic performance. The answer to the question of the only useful model for predicting the coronavirus spread remains open. There are many studies in the scientific literature on mathematical models based on statistics, data on the peculiarities of transmission and course of the disease on COVID-19. Their analysis summarized the features of such models as SIR, SEIR, SEIRD, GLM, SEIAMPR, TARNN, SRID and others. As a result, one can conclude that it is advisable to combine artificial intelligence and statistical analysis to correctly form the sampling parameters of the whole set of different data to build an adequate model for predicting the pandemic spread as COVID-19. Simultaneously, there is no ideal model that, including all the calculated parameters, could predict future developments.

Such investigations as CGE in its variations, DSGE, GARCH and other specific models, which do not always have short abbreviations, deserve attention regarding economic models of epidemic spread. Consideration of the calculation results of such models can increase the effective decisions taken in the framework of countering pandemics.

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Modeling and forecasting the impact of the COVID-19 pandemic on socio-economic development

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The scientific monograph was performed within the framework of the research theme «Economic and mathematical modeling and forecasting of the COVID-19 influence on Ukraine development in national and regional contexts: public health factors and socio-economic and ecological determinants» (Application ID: 2020.01/0181),

1st Edition
Range 145 pg (6.31 Signatures)

Suggested citation:

Letunovska N., Vasilyeva T., Lyeonov S. (2020). Modeling and forecasting the impact of the COVID-19 pandemic on socio-economic development: monograph, Szczecin: Centre of Sociological Research, p. 145. 978-83-959336-3-9. DOI: 10.14254/ 978-83-959336-3-9/2020

ISBN 978-83-959336-3-9

9 788395 933639