Macroeconomics Analysis on COVID-19 Based on Mathematical Models

Lanxuan Xu *

School of Public Health, University of Washington, Washington, Seattle, United States

* Corresponding Author Email: Lanxux@uw.edu

Abstract. From the past century, humanity has never witnessed such a health crisis like the Covid-19 worldwide pandemic. Since it was declared a global health crisis in March 2020, country governments have put forth efforts to curb transmission of the disease and to manage the impacts on the economy. The forced measures have caused adverse and difficult to manage macroeconomic consequences. Many studies have been carried out in various regions and countries to explore these macroeconomic impacts. This paper offers a review of the research associated with the consequences of COVID-19 on macroeconomics. The author will use previous research studies that have applied various economic models (CGE, DSGE, and GEM) to quantify the macroeconomic results of the pandemic. The review concludes that the macroeconomic consequences of various pandemics can be quantified using economic models. It provides comprehensive and specific data on the consequences of COVID-19 on macroeconomics. It also exhibits information about carious economic modelling that can be used to estimate pandemic impacts.

Keywords: Macroeconomics, Computable General Equilibrium Model, Dynamic Stochastic General Equilibrium Model, Global Economic Model.

1. Introduction

The COVID-19 pandemic will go down in history as one of the biggest threats to humanity witnessed in this century. The viral disease spread across nations and affected almost every community, showing how the global economy is highly interconnected. According to WHO, over 599 million people have contracted the virus globally, and more than 6 million fatalities as of August 2022 [1]. The outbreak has been an issue of public health since 2020 and it has impacted the global economy to a large extent. Substantial economic effects have already been observed worldwide due to business closures, trade distractions, high death rates, and lower productivity. When a comparison is done between the impacts of the great depression in 2008, the effects of coronavirus outbreak on the economy worldwide is extra tremendous [2]. By 2020, many countries were undergoing a covid-related economic recession. According to the International Monetary Fund, global economic growth shrank by 3.2% in 2020, with a 5.9% growth forecast in 2019 and 4.9% fir 2022 [3]. Furthermore, a rise in viral infection cases and the development of new and more viral strains caused more countries to experience an economic downfall. Although developed nations benefited from high vaccination rates in 2021, developing countries struggled to get their people carinated and functioning economies. The global economy was projected to recover at different speeds, but governments are still experiencing continued economic problems into 2022. However, this would be at different rates due to the differences in access to vaccines, the strength of policy support, and other structural conditions. A critical factor in recovering the economy is determining the economic effects of the outbreak on macroeconomics.

The statistical method that will be used in data analysis is descriptive statistics. With descriptive statistical analysis, we will understand the trends in the economy before and after the Covid-19 outbreak. Coronavirus has affected the economy of countries in different phases and various ways. This research assumes that the Covid-19 pandemic persevered for many quarters but focuses on the first three quarters. Additionally, the use of descriptive statistics will help to make a comparison of the impacts of the outbreak on different regions globally.

The goal of this research is to evaluate two-dimensional effects of the coronavirus on the world economy. Firstly, Covid-19's effect on the level of geographical regions. Secondly, the coronavirus impact on the main economic sectors. Urbanization and globalization have made infectious disease outbreaks global threats that require a collective response. Evaluating the severity and magnitude of the economic impacts is essential in assessing the loss and the worst affected sectors, enabling governments to formulate appropriate recovery measures. Additionally, establishing the effects of the corona outbreak on the worldwide economy will be a signal for leaders worldwide to increase cooperation on pandemic preparedness and contribute efforts in global collective action. This paper will be sectioned into three parts. The following section is the data sourcing section and data pre-processing. Then, the author will show and analyse the main economic models. Finally, a significant and comprehensive discussion will be exhibited.

2. Data Sourcing

The effects of corona outbreak on the macroeconomies of countries will be established by reviewing existing information and literature. The data used in the study is secondary and obtained from credible websites, journal articles, magazines, newspapers, expert reports, and other literature relevant to the consequences of coronavirus on the international economy. The study will mainly utilize, but not be limited to, Google Scholar, one of the most widely accepted web search engines with scholarly articles. Another benefit of using this search engine is that it is freely accessible and searches for articles across various databases. Both empirical and theoretical papers will be taken into consideration. To identify the relevant data, documented reports will be explored by considering the title, abstract, and keywords appropriate for this research, including effects-both positive and negative of corona outbreak, global economy, economic growth, and resilience. After identifying relevant documents and articles, their content will be examined to establish their exclusions and inclusions depending on their relevance to the issue under investigation. The main data sourcing analyzed in this paper are displayed in Table 1.

Table 1. The representative data scouring in this study

Author	Economic modeling	Scope of study
Cho et al. [6]	Global CGE	Global
Shang et al. [4]	CGE	U.K, Australia, Canda, New Zealand, Japan, Sweden.
Robinson et al. [8]	CGE	U.S.
Zhang et al. [13]	NK-DSGE	China
Nguyan et al. [14]	DSGE	Vietnam
Eichenbaum et al. [11]	DSGE	U.S.
Eichenbaum et al. [12]	DSGE	U.S., France, Canada, Italy, U.K.
Chan et al. [15]	DSGE	China
Ibn-Mohammed et al. [18]	GEM	Japan, U.K., Italy, China, U.S., Korean, France
Pesenti [17]	GEM	U.S., China
Laxton & Pesenti [16]	GEM	Czech Republic

3. Data pre-processing

This research utilizes both quantitative and qualitative analysis. The key variables used as proxies in the analysis to evaluate the impacts of the outbreak on macroeconomics is economic growth, unemployment rate, government**,** investment, and working hours. The Gross Domestic Product (GDP) is economic indicator that will be used to establish impact of coronavirus on level of geographical regions. GDP is recognized as an economic indicator that measures the total output of a country's final products in each period (either quarterly or yearly) [4]. The economic indicator is used to compare nations' economic performance, but, in many cases, comparisons are used to assess and estimate the progress, social welfare, or living standards among countries. Data on the GDP of different regions will be obtained from the World Economic Outlook (WEO). The WEO is an article

that is usually published by International Monetary Fund (IMF) each year. Real GDP growth will be divided into seven regions to cover the global economy. Advanced Economies, Euro Region, Asian-5, Middle East, Central Asia, Sub-Sahara and South Africa region, Latin America, the Caribbean, and underdeveloped and developing countries [5]. In efforts to understand the consequences of the corona outbreak on the main economic sectors, we shall focus on the three main economic sectors: primary, secondary sectors, and tertiary sectors. Primary sectors include the industries that extract raw materials: agriculture, petroleum, and oil. Secondary sectors are industries involved in converting raw materials to finished products, that is, manufacturing. Tertiary sectors are the industries that provide services such as education, hospitality, tourism, and transport.

Previous studies highlighted the importance of general equilibrium models instead of partial equilibrium models to analyze the effects of pandemics on the multi-sectoral and multi-faceted effects of viral infection outbreaks. Hence, this research examines the macroeconomic impacts of Covid-19 using three simulation models: Computable General Equilibrium, Dynamic Stochastic General Equilibrium, and Global Economic models.

4. Computable General Equilibrium Model

Over the past two decades, Computable General Equilibrium (CGE) models have become a tool for empirical economic analysis. Data availability, computer technology, and model specification improvements have lowered the prices of policy analysis and improved payoffs based on CGE models, promoting their use worldwide. This dynamic model underpins growth and mobility across various sectors and regions [6]. The CGE model uses accurate economic data to examine the changes experienced in an economy due to external changes. It assumes that nations have zero barriers and frequently engage in trade with perfectly competitive markets. Additionally, the model assumes foresight in every economic entity through which all current and future choices are made.

CGE models are numerical models that combine economic data with economic theory to compute the effects of shocks or policies in an economy, as shown in Fig. 1. These models place financial data to several equations that intend to capture the economic structure and behavioral reactions of agents such as government, firms, and households. This establishes a framework to simulate policy variations and evaluate the effect on main economic variables, including expenditure and income flows. The macroeconomic impact of the economic shock or policy being modeled is assessed by comparing the economy before and after the economic shock. The policy baseline before is produced by fitting the behavioral parameters and the model equations to the year of the base data. This means that the base year in which the economic shock is experienced will depict the present economic structure. The baseline assumes that the economy begins from an equilibrium position. When a shock is presented, the economy moves to a new equilibrium, administered by the economic relationships indicated in the equations. The model identifies a solution by allocating goods and factors and finding new prices to return the economy to equilibrium.

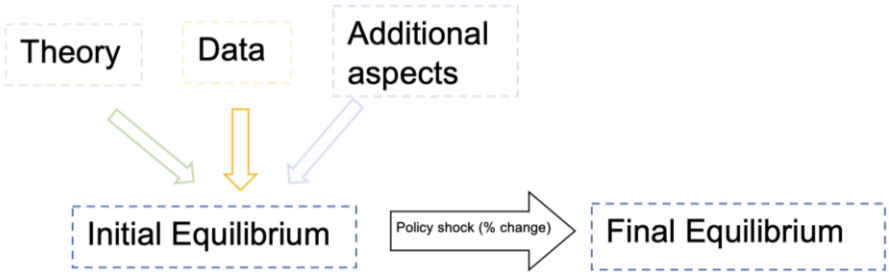


Figure 1. The layout of Computable General Equilibrium (CGE) model

5. Computable General Equilibrium Modeling Framework

Smith et al., state that the shockwaves to a country with different outbreaks can be assessed by CGE using macroeconomic data and information about behavioral changes during past epidemics [7]. Robinson & Roland-Holst (1988) use the CGE model to analyze Jacobian multipliers and show macro, institutional and sectoral associations in a SAM (social accounting matrices) framework [8]. Cho et al. in 2021 use the Global CGE model in analyzing the consequences of coronavirus on macroeconomics [6]. The Global CGE model is a Multisector and Multiregional Fully Dynamic CGE model. In this model, households decide on spending, leisure, and savings to maximize intertemporal value. Savings result in investment which leads to capital accumulation in the following period. The institutions are represented by the administration, households, and the entire world. The families make an income from the production factors and transmissions from other institutions. The households utilize their revenue by paying taxes, saving, consuming, and making transfers. The government obtains taxes and acquires transmissions from other institutes. The government operates this revenue by purchasing commodities for its use and transferring them to other institutes. The final institute is the ROW (rest of the world), whereby transfer costs between domestic organizations and the ROW are all used in international currency. The findings implied that the Covid-19 shockwave may distress the short-range economic development and the upcoming economic growth owing to its pre-pandemic movement. Shang et al. evaluated the consequences of the corona outbreak on economies using the CGE model. The findings were that LME economies were more responsive to the outbreak compared to CME economies where the outbreak was contained by the governments [9].

6. Dynamic Stochastic General Equilibrium Model

Dynamic stochastic general equilibrium (DSGE) models have become a famous macroeconomic analysis tool. Macroeconomics emphasizes aggregated sectors in the economy and examines aspects like employment, economic output, and the general price level. With macroeconomics research (and macroeconomics), DSGE models are understood as good indicators of how an economy works. These models provide an alternative method to the traditional depictions of the economy and can be applied for various uses.

DSGE models are founded upon three interrelated features for analysis of the economy: supply, demand, and monetary policy. The equations that constitute DSGE models are acquired from crucial assumptions concerning the behavior of main economic agents. These are households, the government, and firms [10]. These agents interact over time until they reach a general equilibrium point. According to this model, the household is the agent that consumes the final product produced by different firms. There are two kinds of firms since there are two kinds of goods. The firms producing intermediate goods have a particular good and then pass it to the firm creating the final good. This firm packs differentiated products and then takes them to the market to be sold. Apart from these interrelated components of DSGE models, another aspect is their stochastic nature. This indicates that there is some model part that is randomly established. Stochastic events do not have a definite order or pattern, and they are unpredictable. This, thus, adds economic uncertainty and produces economic fluctuations. In DSGE models, the objectives of the economic agents must be stated. The household is expected to maximize utility, assuming more consumption increases utility and working hours red utility. The firm's goal is to maximize profits despite operating in a perfectly competitive market. A perfectly competitive market is assumed because it symbolizes ideal scenarios and capably serves markets.

$$V_t = \mathbb{E}_t \sum_{s=t}^{\infty} \beta^s \left(H_{C,s} \frac{c_s^{1-\sigma_C}}{1-\sigma_C} - \mu_L \frac{L_S^{1+\varphi}}{1+\varphi} \right) \quad (1)$$

Investigating the how the coronavirus has affected on macroeconomics of nations through the Dynamic stochastic general equilibrium model has received global recognition. Eichenbaum et al.

examined epidemic influences in the New-Keynesian and Neoclassical Models. These are the main frameworks of DSGE model. The findings showed rise-to-fall instability in output, consumption, and savings during the coronavirus outbreak [11]. Eichenbaum stretched the DSGE model to examine the linkage between epidemics and economic decision-making [12]. The findings illustrated that individuals reduce employment and consumption to lower the risk of infection. Another study examined the effects of Covid-19 on income inequality, government liability, and sustainable economic growth using the NK-DSGE model in China [13]. The findings illustrated that the consequences of the corona outbreak on labor demand and aggregate demand have caused many difficulties in the sustainability and development of the country and uneven communities. In Vietnam, vast research has also been undertaken to examine the consequences of corona outbreak on the Vietnam economy. Nguyan et al. assessed the approximations of the consequences of the corona outbreak on the economy of Vietnam by applying the Bayesian approach to approximate dynamic stochastic general equilibrium models [14]. The findings showed that inflation, exchange rate changes, and refinancing interest rates suddenly declined after the Covid-19 shock. However, the scale of the decrease was moderately small. Another study utilized the SIR-DSGE model to investigate macroeconomic impacts of coronavirus in China [15]. SIR (susceptible-infected-removed) model is a famous model made in the 1900s and is used to illustrate the spread of infectious diseases. Combining the DSGE and SIR models forms the assumption that the respective disease can affect an economy's supply and demand. The results found the Ramsey social planner decreases output considerably during the Covid-19 outbreak, in efforts for a quicker recovery of the economy.

7. Global Economic Model

Global Economic Model (GEM) is a model that was built on current theoretical developments in monetary economics and international finance. The model seeks to provide an optimal framework to address basic policy queries entailing international policy transmissions and shocks while producing main elements of macroeconomic dependence among nations and regions. Like the DSGE models, the GEM design links short-term Keynesian dynamics with long-run features of actual business cycle models. GEM is founded on explicit micro-foundations, enabling an integrated treatment of welfare considerations and positive elements. Just like other models, GEM models have a wide range of features present in the economy's key sectors.

The first component is the household sector. Every household consumes a final product and offers labor to every local company. Some households lack admittance to capital markets and pay for what they consume mainly through nonrefundable labor returns. The other households are the owners of the collection of local companies, the local assets stock. They then lease this stock to domestic companies. Additionally, the household purchases and trades a local bond designated in local money and a transnational bond allotted in zero disposable supply globally. When households decide to buy or sell global bonds, they provide a premium to financial intermediaries. Physical capital and labor are immovable internationally. On production, firms create the final products and a range of differentiated intermediate products and offer intermediation services. Every nation has two types of final goods- an investment product and a consumption product- created by companies with perfect competition. The consumption product is used by the government or local households. Investment demand is divided between the public sector and private agents. Final products are formed by utilizing all intermediate products as inputs. A single firm creates different varieties of intermediate products under monopolistic competition. Every intermediate product is created using local capital and labor inputs. Intermediate products are either traded internationally or nontraded. The intermediate goods that are nontraded can be bought by the government or used to produce final goods. The last component is the government which buys two final goods and nontrade able services. Through treasure, the country's government sources funds from levies obtained from the local private segment. Through the central bank, the central administration evaluates the interest rate. Monetary policy that is expressed as a promise to maintain price stability.

GEM has been used in various studies to examine international macroeconomics and finance. Laxton & Pesenti used GEM to examine how monetary rules in small emerging markets might differ from the ones in large industrial nations [16]. The study showed how the GEM model can extend analyses through better estimation of benefits and concepts. Presenti examined the use of the fully integrated GEM in macroeconomic countries [17]. According to the study, the global economy is composed of $\mathcal{D}$ countries or regions. Ibn-Mohammed et al. investigated the consequences of the corona outbreak on the worldwide economy utilizing the international GEM model designed by a rectilinear economy system [18]. The study outlined specific recommendations on CE-related options to catalyze international economic growth and develop resilience in the post-Covid era.

8. Discussion

The CGE model is fitting because it is a general equilibrium model. Therefore, it analyses the macroeconomic impacts of a pandemic given the multi-sectoral and multi-faceted effects of highly transmittable diseases like the coronavirus outbreak. The CGE model is also very flexible. The studies in this review that have applied CGE models have modified them to accommodate a wide range of assumptions specific to macroeconomic policies. The model has also modified COVID-19 as an economic shock and assessed its impacts on the macro economy of countries. A disadvantage of CGE models is that they only focus on an economic shock's short-term impacts.

Examining the consequences of corona outbreak on the macroeconomy of different nations through the dynamic stochastic general equilibrium model has been used in most studies. This is because examining the effects of shocks through the dynamic stochastic general equilibrium model can provide a synopsis of those effects on macro indicators of respective country. Furthermore, the DSGE model is developed under idea of business cycle and displays reaction of every economic sector to shocks. The findings from the DSGE models are relatively uniform with the actual condition and robust empirical proof supports it. DSGE models are less disaggregated and allow random variation to account for uncertainty compared to CGE models. Like CGE models, DSGE models capture business cycle fluctuations, so they focus more on the short-term effects, not the long-lasting ones.

On the other side, the application of GEM in Covid-19 studies is limited. This can be attributed to its complex nature and alternative features. The model uses many variants across sectors and countries. The model, however, joins the long-term features of real business cycle theories with short-term Keynesian subtleties allowing it to analyze integrated treatment and welfare considerations. The implications of the models provide information about the interaction between epidemics and macroeconomic decisions. Future developments in this field should aim at creating macro policies that can stabilize and recover the economy.

9. Conclusion

In summary, this paper offers a comprehensive review about positive and negative consequences of coronavirus outbreak on macroeconomics. The author draws data from previous studies that have applied the CGE, DSGE and GEM economic models. The economic models provided insights into the effects of Covid-19 on economies and society’s responses. From the review, it can conclude that the COVID-19 pandemic impacted macroeconomic variables, including consumption, investment, total output, wages, employment, inflation, price, deposit interest rate and loan interest rate. Generally, the pandemic reduced total output, investment, consumption, employment, loan interest rates and price level, and increased inflation and deposit interest rates. Additionally, the findings indicate that the impacts of the pandemic were phased. The economic models concentrated on the impacts in the short run making the long-term impacts insignificant. Since the economic sector is crucial in handling the COVID-19 pandemic shock, policy analysts, economists, and future scholars can utilize this information in efforts to recover the economy.

References

[1] WHO (World Health Organization). (2021). *WHO Coronavirus (COVID-19) 2*.

[2] J. Mou, "Research on the Impact of COVID19 on Global Economy," *IOP Conference Series: Earth and Environmental Science*, 546 (3), (2020), p. 032043.

[3] International Monetary Fund (IMF). (2021). *World Economic Outlook*.

[4] Y. Shang, H. Li, and R. Zhang, "Effects of Pandemic Outbreak on Economies: Evidence from Business History Context," *Frontiers in Public Health*, 9 (2021).

[5] Akram, Muhammad, Alqahwachi, Nazar and Muhammad, "The Impact of (COVID-19) on Global Economy," 10.13140/RG.2.2.27514.41921 (2021).

[6] G. L. Cho, K. Minsuk, and Y. K. Kim, "The Global Economic Impact of the COVID-19 Pandemic: The Second Wave and Policy Implications," (2021).

[7] R. D. Smith, and J. Richardson, "Can we estimate the 'social' value of a QALY? Four core issues to resolve, "*Health policy (Amsterdam, Netherlands)*, *74* (1), 77 – 84 (2005).

[8] S. Robinson, and D. W. Roland-Holst, "Macroeconomic structure and computable general equilibrium models," *Journal of Policy Modeling*, 10 (3), pp. 353 – 375 (1988).

[9] Y. Shang, H. Li, and R. Zhang, "Effects of pandemic outbreak on economies: evidence from business history context," *Frontiers in Public Health*, *9*, 632043 (2021).

[10] L. J. Christiano, M. S. Eichenbaum, and M. Trabandt, "On DSGE Models," *Journal of Economic Perspectives*, 32 (3), pp. 113 – 140 (2018).

[11] M. S. Eichenbaum, S. Rebelo, and M. Trabandt, "Epidemics in the New Keynesian model," *Journal of Economic Dynamics and Control*, 140, p. 104334 (2022).

[12] Eichenbaum, Martin, Sergio Rebelo, and Mathias Trabandt. The Macroeconomics of Epidemics. Review of Financial Studies 34: 5149 – 87 (2021).

[13] X. Zhang, Y. Zhang, and Y. Zhu, "Covid-19 pandemic, sustainability of macroeconomy, and choice of monetary policy targets: A nk-dsge analysis based on china," *Sustainability*, *13* (6), 3362 (2021).

[14] T. D. Nguyen, 'The Impact of the COVID-19 Pandemic on Economic Growth and Monetary Policy: An Analysis from the DSGE Model in Vietnam', *Economies*, 10 (7) (2022).

[15] Y. T. Chan, "The macroeconomic impacts of the COVID-19 pandemic: An SIR-DSGE model approach, "*China Economic Review*, 71, p. 101725 (2022).

[16] D. Laxton, and P. Pesenti, "Monetary rules for small, open, emerging economies," *Journal of* Monetary *Economics*, 50 (5), pp. 1109 – 1146 (2003).

[17] P. Pesenti, "The Global Economy Model: Theoretical Framework," *IMF Staff Papers*, 55 (2), pp. 243 – 284 (2008).

[18] T. Ibn-Mohammed, "A critical analysis of the impacts of COVID-19 on the global economy and ecosystems and opportunities for circular economy strategies," *Resources, Conservation and Rec*ycling, 164, p. 105169 (2021).