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Dynamics of Covid-19 Pandemic, Health Infrastructure, and Economic Growth: An Endogenous Growth Model

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Abstract:
The impact of health infrastructure on economic growth in the framework of endogenous growth models has been studied in a few research pieces; however, the impact of the Covid-19 pandemic on economic growth in the endogenous growth models has not yet been studied. The present article expands the existing pieces of literature in several ways. First, investigating the impact of the Covid-19 pandemic on economic growth in a steady-state situation. Second, identifying the threshold level of health infrastructure impact on long-term economic growth by considering the Covid-19 pandemic. Third, modeling of population dynamics and the Covid-19 pandemic. Fourth, modeling the level of following the protocols and public awareness of the Covid-19 pandemic and examining their impact on long-term economic growth. The developed model was calibrated using the information of a transition country, Iran. Results show if the health infrastructure is higher than the threshold level of 0.87, the output level will have an upward trend in the presence of the Covid-19 pandemic. Otherwise, the output trend will be downward. The increasing output could lead to the spread of the Covid-19 pandemic even in the long run in the Iranian economy. At a certain level of income, with the improvement of the health infrastructure, the level of Covid-19 pandemic release will decrease.

1. Introduction

The Covid-19 pandemic is a severe shock to the supply and demand of the economy in all countries. The impact of this pandemic on the economy can be analyzed from both micro and macro aspects. From a micro perspective, its

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impact on companies and businesses can be examined. In this respect, supply shocks have increased the cost of transportation, labor force, investment, raw materials, and the cost of converting inputs into outputs (transformation costs). Demand shocks have also reduced domestic and foreign demand; Thus, the micro-level impact of these shocks is falling demand, rising production costs, the closure of many of the activities, and the spread of unemployment and deepening recession. However, at the macro-level, Covid-19 pandemic affects aggregate demand, consumption, private investment, the government budget (revenues and expenses), foreign trade (exports and imports), and overall economic growth (in different economic sectors and the entire economy).

Because economic growth is a long-term phenomenon, an endogenous growth model has been proposed to investigate the impact of the COVID-19 pandemic on economic growth. However, the impact of health infrastructure on economic growth in the form of economic growth models has been considered in studies such as *Agénor (2008), Gupta and Barman (2010)*, and *Klarl (2016)*. Therefore, the present study has expanded the existing pieces of literature in several ways. The first contribution is that it has examined the impact of the Covid-19 pandemic on social welfare. The second contribution is that it examines the threshold level health infrastructure's impact on long-term economic growth by considering the Covid-19 pandemic. The third contribution is that it has modeled the population dynamics and pandemics of Covid-19. The fourth contribution is that the level of compliance with the protocols and public awareness of the Covid-19 pandemic has been taken into account in modeling.

The present article is organized into six parts. In the second part, studies related to the impact of pandemic COVID-19 on macroeconomic variables and the impact of health infrastructure on economic growth are reviewed, and the novelty of the present paper is clarified. In the third part, an endogenous growth model is developed. In the fourth part, the developed model is calibrated using the information of a transition country (Iran). The fifth section is dedicated to discussion. The last section is dedicated to summarizing the results.

2. Literature Review

Although the study of the impact of the Covid-19 pandemic on macroeconomic variables, including economic growth, has little history, much attention has been paid to the impact of health infrastructure on economic growth. On the other hand, different techniques have been used to examine these effects. The purpose of this section is to briefly review the existing studies and identify the contributions of the present article. Accordingly, the existing studies can be divided into two groups according to the purpose of the present study: the impact of the Covid-19 pandemic on macroeconomic variables and the impact of health infrastructure on economic growth. The following is a summary of the findings of some existing studies.

2.1. Covid-19 Pandemic and Macroeconomics Variables

With the spread of the Covid-19 pandemic, numerous studies have been conducted in all fields, including health economics. Most studies in this group have focused on production and economic growth (e.g., *Chudik et al., 2020; McKibbin and Fernando,2020; Ludvigson et al.,2020; Bonadio et al., 2020; Baqaee and Farhi, 2020; Abo-Zaid and Sheng, 2020;Milani, 2021*). However, in some studies, other variables such as unemployment, asset value (e.g., *Ludvigson et al., 2020; CÈspedes et al., 2020; Milani, 2021),* and the co-movement of financial markets (e.g., *Samadi et al., 2020*) have been considered. The subject matter of most studies (e.g., *Chudik et al., 2020; McKibbin and Fernando, 2020; Bonadio et al., 2020; Milani, 2021*) has been worldwide; however, in some studies (e.g., *Samadi et al., 2020; Baqaee and Farhi, 2020; Ludvigson et al., 2020; Abo-Zaid and Sheng, 2020; Milani, 2021*), the focus has been on examining the impact of the Covid-19 pandemic on macroeconomic variables in a particular country.

Chudik et al. (2020) used a threshold-augmented dynamic multi-country model (TGVAR) to quantify the effect of the Covid-19 pandemic on macroeconomic variables. The results of this study showed that Covid-19 pandemic significantly reduces global output. Nevertheless, this effect is different among the countries of the world. This effect is more severe and prolonged in the United States, the United Kingdom, and several other advanced economies than in China and other emerging Asian countries. *CÈspedes et al. (2020)* have developed a minimalist macroeconomic model of an epidemic. The theoretical results of this study showed that the occurrence of adverse shocks due to rising unemployment and declining asset value has a significant impact on the economy. There is also the possibility of multiple equilibria. Using the Hybrid Global DSGE/CGE Model, *McKibbin and Fernando (2020)* examined global macroeconomic outcomes from different scenarios of how Covid-19 will evolve next year. They emphasized the importance of spillover effects and showed that even a limited outbreak could significantly affect the short-term's global economy. *Bonadio et al. (2020)* studied the effect of Covid-19 on production growth in 64 countries and examined the contribution of global supply chains to these adverse effects. The results showed a 29% drop in average real GDP in response to the Covid-19 shock. *Milani (2021)* also sought to examine the economic and social response to the Covid-19 pandemic in 41 countries using the Global Vector Autoregressive (GVAR) model. This study showed that social networks help explain the spread of the disease and explain the spillover between countries in understanding coronavirus risk. Another finding of the study was that unemployment also responded to health shocks, particularly in the United States and Spain.

The focus of limited studies has been on the impact of the Covid-19 pandemic on macroeconomic variables in a particular country. *Ludvigson et al. (2020)*

investigated the macroeconomic impact of the Covid-19 pandemic on the United States using a VAR technique. The study predicted that the Covid-19 pandemic would lead to a 20% drop in industrial production and a 39% drop-in service sector employment over the next 12 months.

Baqaee and Farhi (2020) have used nonlinear production networks. They have considered the effect of supply shock and shocks of final demand components on total production in a multi-segment neoclassical model with input-output relationships. The results of this model for the US economy show that considering the nonlinear relationship (depending on the analysis horizon and the exact size of the shocks) may increase the Covid-19 pandemic effect by 10 to 100%.

Abo-Zaid and Sheng (2020) developed a multi-sector dynamic stochastic general equilibrium (DSGE) model in which the Covid-19 pandemic shock affected both supply and demand. The results of calibration using US data showed that the effects of the demand-side and the supply-side are more robust in the short-run (between 2 to 4 seasons) and long-run, respectively. *Samadi et al. (2021)* also used the Wavelet Coherence and Segmented Regression methods to investigate the effect of the Covid-19 pandemic on the co-movements of financial markets and concluded that the Covid-19 pandemic did not affect the co-movement of financial markets in Iran.

2.2. Health Infrastructure and Economic Growth

In several studies, the impact of variables has been investigated in the health sector, including health infrastructure on economic growth and different techniques. However, few studies have included the variables representing the health sector in endogenous growth models. In the following, several important studies related to the present article have been reviewed.

Van Zon and Muysken (2001), in the framework of Lucas (1988)'s endogenous growth model, considered a household utility function of the level of health and consumption. In this model, a trade-off between health and human capital accumulation was assumed. Also, health services production had a decreasing return, and human capital accumulation had an increasing return to scale. This study showed that health is a complement to economic growth, and any re-allocation of labor from the health sector to human capital accumulation activities will lead to reduced economic growth.

Agénor (2008) studied the optimal allocation of government spending between economic infrastructure and the health sector by adding health to Barro (1990)'s endogenous growth model. This model assumed that health has a positive effect on both labor productivity and household utility. The main feature of the model designed by *Agénor (2008)* is that it considers the effect of economic infrastructure on the production of goods and services and the supply of health services. The level of health services was considered an input in the function of health goods production, and health expenditures were considered input in the

function of health production. *Agénor (2008)* first solved the model by considering health as a flow variable and then as a stock variable in the production and utility function. This researcher has sought to find the optimal allocation of government investment between economic infrastructure and health.
Gupta and Barman (2010) extend this model by adding environmental pollution to *Agénor (2008).* In an endogenous growth model, the researchers focused on the role of public infrastructure spending, health spending, and environmental pollution. The production function in the model of these researchers was similar to the production function of *Agénor (2008)*; the utility function was considered only as a function of consumption. The results of this study show that economic growth leads to environmental pollution, and as a result, the quality of the environment decreases, and the rate of accumulation of health capital decreases.
Hosoya (2014) designed an endogenous growth model concerning health infrastructure and investigated policy implications and dynamic equilibrium characteristics. In this model, health infrastructure was considered a stock variable. It was assumed that health infrastructure would be improved only through government investment in health. The household utility function was also considered a non-separable function, including consumption, leisure, and public health infrastructure level. This study showed that public health infrastructure plays a vital role in the development policies of low-income countries.
Klarl (2016), like *Gupta and Barman (2010),* incorporated pollution and health into the endogenous growth model; the difference was that he had also included the health status in the function of utility. In this study, it has been assumed that health status increased directly with increasing investment in health and decreased with increasing pollution. The model was calibrated using OECD countries' data. This study showed that in an economy with a relatively high value to health and the change in environmental tax is more than the marginal amount, welfare differences are obvious. *Schön et al. (2017),* by adding the health sector, have developed an overlapping generations model with endogenous growth to explain three stylized facts in the US economy: increasing life expectancy, increasing the share of GDP allocated to health spending, as well as increasing medical goods prices.
Zhang (2018) has also developed a dynamic general equilibrium model with endogenous wealth and health. He considered health care as a function of health services and the time spent on health care. By simulating his model for three types of households, he was able to identify the existence of a locally stable equilibrium point.
How health sector variables are included in the endogenous growth model in the mentioned studies is presented in Table 1.

In sum, not many studies have been conducted on the subject of health and endogenous growth models. *Van Zon and Muysken's (2001)* study was one of the first studies to incorporate health into Lucas (1988) 's endogenous growth model. The study of *Agénor (2008)* was another study in this field, which has been the basis of the studies of *Gupta and Barman (2010)* and *Klarl (2016)*. *Hosoya (2014)* was also one of the researchers who have considered health a function of utility and production. *Schön et al. (2017),* in an overlapping generations model with endogenous growth, have focused more on investing in health and producing health goods along with consumption goods. *Zhang (2018)*, on the other hand, has more broadly incorporated health into growth models, as health services were considered in the production function, and health care was considered in the welfare function; additionally, health care was considered a function of health services.

Table 1. Summary of Health Studies in the Context of Endogenous Growth Models

Authors	How to model health in endogenous growth models
Van Zon & Muysken (2001)	The utility function includes the health variable, and a trade-off between health and human capital is considered.
Agénor (2008)	The level of health services is considered an input in the function of production of health goods. Health expenditures, is considered an input in the function of the production of health. The utility is considered a function of consumption and health services. It is assumed that government expenditure is spent on both infrastructure and health services.
Gupta and Barman (2010)	Health capital is considered an input in the function of the production of goods and services. A health capital accumulation function is also considered a direct function of government spending on health infrastructure. In this function, depreciation due to environmental pollution is added, which reduces the accumulation of health capital.
Hosoya (2014)	The health stock is entered in the final goods production function. It is assumed that the health infrastructure will be improved only through government investment in health. The household utility function is also considered a non-separable function, including consumption, leisure, and public health infrastructure level.
Klarl (2016)	Like *Gupta and Barman (2010)* has introduced pollution and health into the endogenous growth model. The difference is that he has also included the health status in the function of utility.
Schön et al (2017)	The utility function is considered a function of consumption only, and the price of health relative to the consumer good is included in the household budget. Goods produced in the economy are considered two types of consumer goods and health goods.
Zhang (2018)	Production is considered to include capital goods, consumer goods, and health services. The labor supply function, in addition to population, human capital, and working hours, including health. In addition to leisure and consumption, health care is also included in the household utility function. Health care is a function of health services and the time spent on health care.

Source: Our own elaboration

The present paper has modeled health infrastructures such as *Agénor (2008)*, *Gupta and Barman (2010)*, and *Klarl (2016)*; However, it has expanded the existing studies in several ways. First, it has analyzed the impact of the Covid-19 pandemic on social welfare. Second, it examines the threshold level of health infrastructure's impact on long-term economic growth by considering the Covid-19 pandemic. Third, the population dynamics and pandemics of Covid-19 are modeled. Fourth the level of following the protocols and the level of public awareness of the Covid-19 pandemic has been taken into account in modeling.

3. Model

3.1. Welfare function

The most common form used to formulate the welfare function in most economic studies is a function in relation (1):

$$Max J = \left\{ \int_0^T U(C_t) e^{-\rho t} dt \right\} \quad (1)$$

where $U(C_t)$ is instantaneous utility function and has a positive relationship with the level of consumption (C_t); ($U_C > 0$). The marginal utility elasticity must be constant over time to derive the optimal steady-state at a positive rate. Accordingly, in most studies on sustainable growth, the instantaneous utility function is considered $U(C_t) = \frac{C^{1-\sigma}}{1-\sigma}, \sigma > 0$(*Boucekkine and Fabbri, 2013,* and *Barro and Sala-i-martin, 1995: p 114)*. In this function, $\frac{1}{\sigma} > 0$ is the amount of intertemporal elasticity of substitution of private consumption and $\rho > 0$ is the discount rate.

We assume that the Covid-19 pandemic reduces the level of social well-being in each period. Accordingly, in the present paper, the instantaneous utility function is considered as Equation 2:

$$U(C_t) = \left(\frac{C_t}{(1+\Theta_t)^{\tau}} \right)^{1-\sigma} / \left(\frac{1}{\sigma}\right) \quad (2)$$

where Θ_t, is the prevalence of Covid-19 [1] (number of patients), and τ (between 0 and 1) is a sensitivity of the community to this pandemic. According to Equation

[1] The prevalence of the disease was a stock variable; however, the incidence of the disease is a flow variable. Given that in this paper, we seek to write the equation of motion for the Covid-19 pandemic, the prevalence of the disease is included in the modeling.

(2), if the Covid-19 pandemic is completely gone ($\Theta_t \to 0$), the instantaneous utility function (2) will become the utility function in the absence of this pandemic (Equation (1)). If the epidemic is very widespread ($\Theta_t \to \infty$), then the utility tends to zero, and welfare of society will be in the minimum possible amount.

The parameter τ is also called "community sensitivity to the Covid-19 pandemic". Depending on the sensitivity of the people to this pandemic, this parameter will be between 0 and 1. If society does not show any sensitivity to the pandemic (when this pandemic does not exist, people will not develop sensitivity), the value of this parameter will be zero. Therefore, in this case, the instantaneous utility function (2) becomes a standard form (Equation 1) and will be only a function of consumption.

Figure (1) shows the instantaneous utility function (2). In optimizations, the defined utility function must be concave. Figure (1) shows that such a condition is met by considering the instantaneous utility function (2).

It is assumed that the social planner seeks to maximize intertemporal utility between zero and infinite times. Therefore, the social welfare function can be considered as relation (3) :

$$Max \int_0^\infty \frac{C_t^{1-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)}}{1-\sigma} e^{-\rho t} dt \tag{3}$$

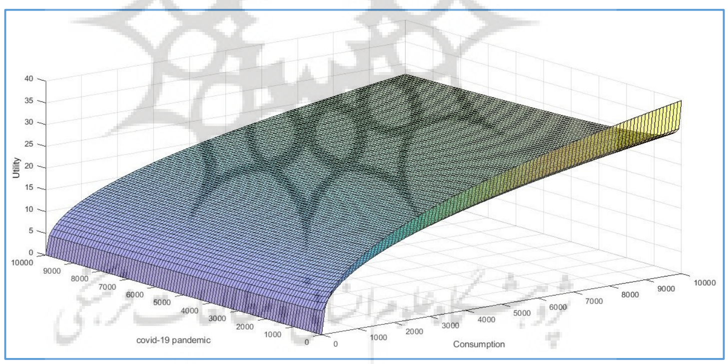

Figure 1. The effect of Covid-19 emission and consumption on the utility process
Source: Research Finding

3.2. Equations of Motion

To maximize intertemporal utility, households, firms, and social planners face some constraints. These constraints can be written in the form of equations of motion. The household budget constraint can be written as equation (4):

$$\dot{K}_t = Y_t - C_t - CC_t - \delta K_t \quad (4)$$

where $\dot{K}_t$ is a change in capital stock during the time. δ is depreciation rate, C_t is aggregate consumption, and CC_t is public health costs to deal with the Covid-19 pandemic[1]. For simplicity, we assume that the cost of dealing with the Covid-19 pandemic is a fixed amount of revenue:

$$CC_t = \ell Y_t \quad (5)$$

where ℓ is a parameter that shows the percentage of revenue that is spent against Covid-19. By replacing Equation 5 in Equation 4, we have:

$$\dot{K}_t = Y_t - C_t - \ell Y_t - \delta K_t \quad (6)$$

In most existing growth studies, the population growth rate is assumed to be a fixed value such as $(b - d)$, where b is the birth rate and d is the death rate. However, the equation of population growth can be written as equation (7):

$$\dot{N}_t = (b - d)N_t \quad (7)$$

This equation can be easily solved and show that the population is growing exponentially at $b - d$ rate over time ($N_t = N_0 e^{(b-d)t}$). One of the effects of any pandemic, including the Covid-19 pandemic, is that it inevitably affects death rate. Therefore, the population growth equation (Equation 7) must be adjusted. Under such circumstances, population growth will be a function of the Covid-19 pandemic. The death rate is assumed to have increased due to the presence of the Covid-19 pandemic, and the death rate is in the form of $d\wp(\Theta_t)$.

Therefore, in this study, instead of the usual equation of motion for population (Equation (7)), we have Equation (8):

$$\dot{N}_t = bN_t - d\wp(\Theta_t)N_t \quad (8)$$

The functional form of $\wp(\Theta_t)$ can be considered $\wp(\Theta_t) = \Theta_t^{\omega}$, where 1-$\omega$ is "health infrastructure development rate." So, we will have:

[1] Given that the cost of treating the Covid-19 pandemic does not affect reducing the number of patients, in Equation (4), the amount of these costs is ignored.

$$\dot{N}_t = bN_t - d\Theta_t^{\ \omega} N_t \tag{9}$$

If ω is equal to zero, $\Theta_t^{\ \omega}$ will be equal to one, and Equation (9) will be a typical dynamic relationship for the population. This means that the Covid-19 epidemic did not affect death rate. If ω is equal to one, we will have the largest impact of Covid-19 on the death rate. This rate can also be considered a criterion for evaluating the performance of the country's health infrastructure.

Another favorite equation of motion in this paper is the equation of motion for Θ_t. It is assumed that the prevalence of the disease (number of patients) in period t + 1 (Θ_{t+1}) is equal to the level of this epidemic in period t (Θ_t) plus factors that lead to its decrease or increase. Therefore, the prevalence variable (number of patients) can be written as a recursive equation ($\Theta_{t+1} = \Theta_t + f(L_t, CC_t)$) and as a function of CC_t (the amount of cost allocated to control Covid-19) and L_t (the amount of labor as a proxy variable for the level of individuals economic and social activities). Inevitably, the higher the level of social activity at the time of the epidemic, the greater its spread. It is important to note that the spread of the Covid-19 epidemic also depends on the extent to which individuals follow health protocols. We assume:

$$f(L_t, CC_t) = \psi L_t^{\ \varsigma} CC_t^{\ -\vartheta} \tag{10}$$

where ς can be called "*rate of non-compliance with protocols*" (percentage of people who do not follow health protocols) and ϑ is a parameter can be called "*level of awareness and knowledge of the virus*." ψ is also the constant ratio of labor to population. The equation of motion for the prevalence of the disease (number of patients) can be written as Equation (11):

$$\dot{\Theta}_t - \Im L_t^{\ \varsigma} (CC_t)^{-\vartheta} - \zeta \Theta_t \tag{11}$$

where ζ can be referred to as the "*Covid-19 pandemic attenuation parameter*" (or disease depreciation rate), if the protocol is fully complied with, ς will go to zero, and we will have: ($\dot{\Theta}_t = \Im (CC_t)^{-\vartheta} - \zeta \Theta_t$). This means that the protocols are running at a high level and social activities have no effect on the spread of the virus. If people do not follow the protocols, ς tends to one, and we will have ($\dot{\Theta}_t = \Im L_t (CC_t)^{\vartheta} - \zeta \Theta_t$). In this case, social activities have the greatest impact on the spread of the virus, and anyone can easily transmit the virus and spread the epidemic.

On the other hand, if we know a lot about viruses, ϑ is assumed to be one. The costs of controlling a virus have the most significant impact on controlling it. If this parameter is assumed to be zero, the cost of controlling the virus has virtually no effect on controlling the epidemic, and we will $\dot{\Theta}_t = \Im L_t^{\varsigma} - \zeta \Theta_t$. By replacing the labor relation ($L_t = \psi N_t$) as well as the cost to control the Covid-19 ($CC_t = \ell Y_t$) in (11), we will have:

$$\dot{\Theta}_t = \Im \psi^{\varsigma} \ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} - \zeta \Theta_t \qquad (12)$$

3.3.The General Form of the Production Function

In this paper, a Cobb-Douglas function is considered in the form of equation (13):

$$Y_t - A L_t^{\alpha} K_t^{\beta} \qquad (13)$$

where K_t is the capital stock, L_t is labor force, and A is transfer parameter. Labor can be considered a percentage of the total population ($L_t = \psi N_t$) to simplify the model. Therefore, ψ is another control variable that the social planner determines according to the state of the economy.

3.4.Solving

The summary of our model is in the form of equations 14:

$$Max \int_0^{\infty} \frac{C_t^{1-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)}}{1-\sigma} e^{-\rho t} dt$$

$$\dot{\Theta}_t = \Im \psi^{\varsigma} \ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} - \zeta \Theta_t \qquad (14)$$

$$\dot{N}_t = bN_t - d\Theta_t^{\omega} N_t$$

$$\dot{K}_t = Y_t - C_t - \ell Y_t - \delta K_t$$

$$Y_t = A L_t^{\alpha} K_t^{\beta}$$

In equations (14), we have three control variables; consumption, percentage of the labor force to the total population, and percentage of income to control the epidemic (C_t, ψ, ℓ) and three state variables; physical capital, disease prevalence (number of patients), and population (K_t, Θ_t, N_t).

The purpose of solving the model is to calculate the rate of economic growth and population growth rate in steady-state in the presence of Covid-19 pandemic. To solve the model, we form the current Hamiltonian function as Equation 15:

$$H = \frac{C_t^{1-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)}}{1-\sigma} + \lambda_1 N_t (b - d\Theta_t^{\omega}) + \lambda_2[(1-\ell)Y_t - C_t - \delta K_t] +$$

$$\lambda_3[\Im \psi^{\varsigma} \ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} - \zeta \Theta_t] \tag{15}$$

where $\lambda_1, \lambda_2, \lambda_3$ are the co-state variables, and the other variables are the same as before. By differentiating the current Hamiltonian function with respect to the control variables; consumption ($\frac{\partial H}{\partial C_t} = 0$), a percentage of the revenue allocated to the Covid-19 pandemic control ($\frac{\partial H}{\partial \ell} = 0$), and a percentage of the population that makes up the workforce (ψ), we have:

$$\frac{\partial H}{\partial C_t} = 0 \Rightarrow C_t^{-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)} - \lambda_2 = 0 \tag{16}$$

$$\frac{\partial H}{\partial \ell} = 0 \Rightarrow -\lambda_2 Y_t + \lambda_3[-\vartheta \Im \psi^{\varsigma} \ell^{-\vartheta-1} N_t^{\varsigma} Y_t^{-\vartheta}] = 0 \Rightarrow$$

$$-\lambda_3(\vartheta \Im \psi^{\varsigma} \ell^{-\vartheta-1} N_t^{\varsigma}) = \lambda_2 Y_t^{\vartheta+1} \tag{17}$$

$$\frac{\partial H}{\partial \psi} = 0 \Rightarrow \lambda_2\left[(1-\ell)\alpha\frac{Y_t}{\psi}\right] + \lambda_3\left[\varsigma \Im \psi^{\varsigma-1} \ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} - \vartheta \Im \psi^{\varsigma} \ell_t^{-\vartheta} N_t^{\varsigma} \alpha \frac{Y_t}{\psi} Y_t^{-\vartheta-1}\right] = 0 \tag{18}$$

According to the type of concave utility function, the transversality condition will be established in this maximization. By solving the 16-18 relationships, we can calculate the percentage of revenue allocated to control the Covid-19 pandemic

(ℓ^*), the steady-state economic growth rate in the presence of the Covid-19 pandemic (g^*), and the population growth rate (g_n). These variables are calculated in Equations 19-21, respectively.

$$\ell^* = \frac{\vartheta\alpha}{\varsigma} \quad (19)$$

Equation (19) shows that as the level of household awareness (science) of the Covid-19 pandemic and ways to prevent it increases (ϑ increases), the percentage of revenue that should be allocated to deal with the Covid-19 pandemic in the steady-state. On the other hand, compliance with health protocols by the community (ς) will reduce the percentage of revenue for pandemic control. If society wants to maintain its output, it is necessary to use its labor force before the outbreak of this pandemic. In this case, more money should be spent on fighting this pandemic. This effect is also included in the form of production sensitivity to labor (α).

The steady-state rate of economic growth in the presence of Covid-19 pandemic level can be written as Equation (20):

$$g^* = \frac{(b - d\Theta_t^{\ \omega})\alpha}{1-\beta} \quad (20)$$

On the other hand, the relationship between output and prevalence of the disease (number of patients) can be written as equation (21):

$$\Theta_t = \Re Y_t^{\ \aleph} \quad (21)$$

where;

$$\Re = \frac{\Im\psi^{\varsigma}\ell^{-\vartheta}}{\zeta}\left[\frac{\Lambda^{-\frac{1}{\alpha}}}{\psi}\left(\frac{(\varsigma - 2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{-\frac{\beta}{\alpha}}\right]^{\varsigma}$$

$$\aleph = \frac{(1-\beta)\varsigma - \vartheta\alpha}{\alpha}$$

By replacing Equation (21) in Equation (20), the amount of steady-state economic growth rate for the Covid-19 pandemic level can be calculated from Equation (22):

$$g^* = \frac{\alpha}{1-\beta}\left(b - d\Re^{\omega} Y_t^{\ \omega\aleph}\right) \quad (22)$$

Also, the path of production in the steady-state (Y_t) can be calculated through Equation (23):

$$Y_t = \left[\frac{\lambda}{\hbar} + \left(\frac{\hbar Y_0{}^{1-\wp} - \lambda}{\hbar}\right) e^{(1-\wp)\hbar(t-t_0)}\right]^{\frac{1}{1-\wp}} \qquad (23)$$

where;

$$\hbar = b\frac{\alpha}{1-\beta}$$

$$\wp = \frac{\omega[(1-\beta)\varsigma - \vartheta\alpha] + \alpha}{\alpha}$$

$$\lambda = \frac{\alpha}{1-\beta} d \left[\frac{\Im \psi^{\varsigma} \ell^{-\vartheta}}{\zeta}\left[\frac{A^{-\frac{1}{\alpha}}}{\psi}\left(\frac{(\varsigma \quad 2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{-\frac{\beta}{\alpha}}\right]^{\varsigma}\right]^{\omega}$$

Lemma (1)*: Increasing production does not necessarily lead to an increase in the prevalence of the disease (number of patients).*

Proof: According to the equation (23) with the increase of production, the prevalence of the disease (number of patients) can be decreasing or increasing. We had:

$$\aleph = \frac{(1-\beta)\varsigma - \vartheta\alpha}{\alpha}$$

Increased production leads to a decrease in the prevalence of the disease (number of patients) when $\aleph$ is negative. In other words:

$$\aleph = \frac{(1-\beta)\varsigma - \vartheta\alpha}{\alpha} \leq 0 \rightarrow (1-\beta)\varsigma < \vartheta\alpha \Rightarrow (1-\beta) < \frac{\vartheta\alpha}{\varsigma} \xrightarrow{\ell^* = \frac{\vartheta\alpha}{\varsigma}(A16)} \ell^* > 1-\beta$$

This means that if public health costs to deal with the Covid-19 pandemic are more than $1-\beta$, then the incidence of the disease (number of patients) will decrease as production increases. In other words, if the elasticity of production to physical capital (β) is higher than the share of other household expenditures ($1-\ell^*$), then increasing production will reduce the prevalence of the disease (number of patients) and otherwise will increase it.

Steady-state population growth rate can also be written in terms of economic growth rate as equation (24)[1]:

$$g_n = \left(\frac{1-\beta}{\alpha}\right) g^* \qquad (24)$$

4. Calibration: The Case of Iran

4.1. Data

The data required to calibrate the model are presented in Table 2.

4.2.Health infrastructure, population, and economic growth

In this section, the relationship between the level of health infrastructure and economic growth, as well as population growth in the presence of Covid-19 pandemic in steady-state is analyzed.

Figure 2 shows the relationship between health infrastructure and economic growth in the presence of Covid-19 pandemic. It is clear from this figure that the higher the health infrastructure index $(1-\omega)$, the lower the impact of the Covid-19 pandemic on economic growth in steady-state; So that in the worst case (value of the index of health infrastructure equal to zero), economic growth is 14%. In the best case (health infrastructure index equal to 1), the long-term economic growth rate (steady-state) will be equal to 1.8%. According to the Central Bank of Iran reports, in 2020, Iran's economic growth rate was -3.5%. As mentioned, the state of Iran's health infrastructure is not good, and the expansion of the Covid-19 pandemic has had a significant negative impact on economic growth.

[1] See Equation A18 in Appendix.

Table 2. Parameters Required for Model Calibration

Parameters	Definition	Value	Source
Reverse intra-periodic substitution elasticity	σ	0.92	*(Eslamuliyan, Harati, & Ostadzad, 2013)*
Discount rate	ρ	0.024	*(Eslamloueyan & Ostadzad, 2014)*
Birth rate	b	0.182	Statistical center of Iran *https://www.amar.org.ir/english*
Death rate	d	0.17	Statistical center of Iran *https://www.amar.org.ir/english*
Health infrastructure index	$1-\omega$	-	Parameter for Sensitivity analysis
Capital depreciation rate	δ	0.1	*(Ostadzad & Behpour, 2015)*
Elasticity of Labor	α	0.779	Research Findings[1]
Elasticity of capital stock	β	0.462	Research Findings[1]
Labor / population ratio	ψ	0.261	Research Findings[2]
Observance parameter of health protocols	$1-\varsigma$	0.56	Calibration assumption
Knowledge about Covid-19	ϑ	0.4	Calibration assumption
Covid-19 depreciation rate	ζ	.5	Calibration assumption

Notes:

1. Production elasticity relative to labor and capital in Iran has been estimated using data from the period 1967-2018.
2. According to the relationship between labor and population ($L_t = \psi N_t$), and data from 1967-2018, the value of the parameter ψ for the Iranian economy has been estimated. The value of this ratio was between 0.24 and 0.29. The average of this variable was 0.261.

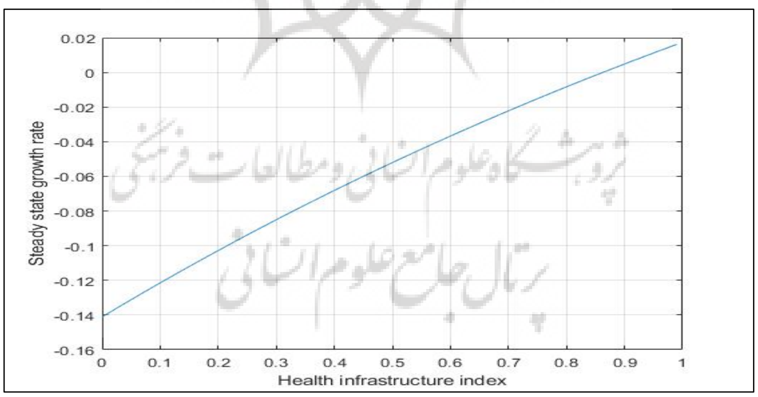

Figure 2. The Relationship between health infrastructure and economic growth

Source: Research Findings

Figure 3 shows the relationship between the level of health infrastructure and population growth in the presence of Covid-19 pandemic in steady-state. At best (health infrastructure equals one), the long-term population growth rate will be 1.45%, and at worst (health infrastructure equals zero), the population growth rate will be -9% in a steady state. This means that the state of health infrastructure can play an effective role in eliminating the destructive effects of the Covid-19 pandemic, including on the population. In 2020, Iran's population growth rate was 1.24%.

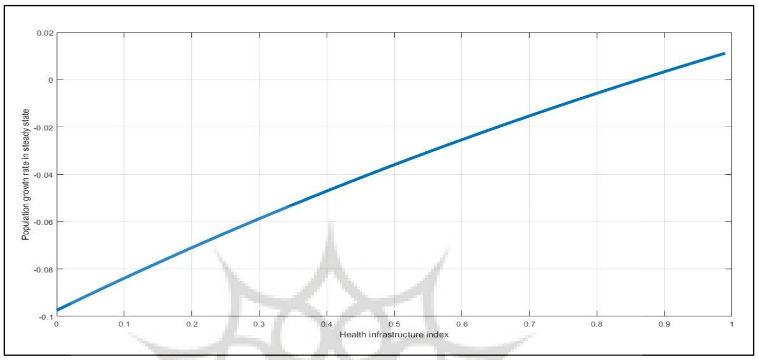

Figure 3. Health infrastructure and population growth

Source: Research Findings

4.3. Covid-19 pandemic, Health infrastructure, and economic growth

This section answers two critical questions: (1) Does production increase lead to the spread of a pandemic or not? (2) At what level of health infrastructure can the expansion of the Covid-19 pandemic increase economic growth?

The path of production and the extent of the Covid-19 pandemic spread at different levels of health infrastructure are plotted in Figures (4) and (5). As can be seen from Figure 4, if the level of health infrastructure is greater than 0.87, the level of production will have an upward trend in the presence of the Covid-19 pandemic, and if it is smaller than that, the overall trend of production will be downward. Lemma 1 also showed that increased production could expand or decrease the level of Covid-19.

Since the total expenditure of households in control of the Covid-19 and the elasticity of production with respect to capital is less than 1; ($\ell^* + \beta < 1$), it can be expected that the increase in production could lead to the expansion of the Covid-19 pandemic even in the long run in the Iranian economy. One reason for this can be attributed to poor infrastructure in health. Figure (5) also proves this.

The relation between the Covid-19 pandemic and the production and level of health infrastructure is shown in Figure 6. As is evident, at a certain level of income, with the increase of health infrastructure (a decrease in the value of the x-axis), the prevalence of Covid-19 will decrease. On the other hand, at lower levels of the horizontal axis, the level of Covid-19 will not increase much as GDP increases. This means that health infrastructure is an important factor in preventing the spread of the Covid-19 pandemic despite increased production.

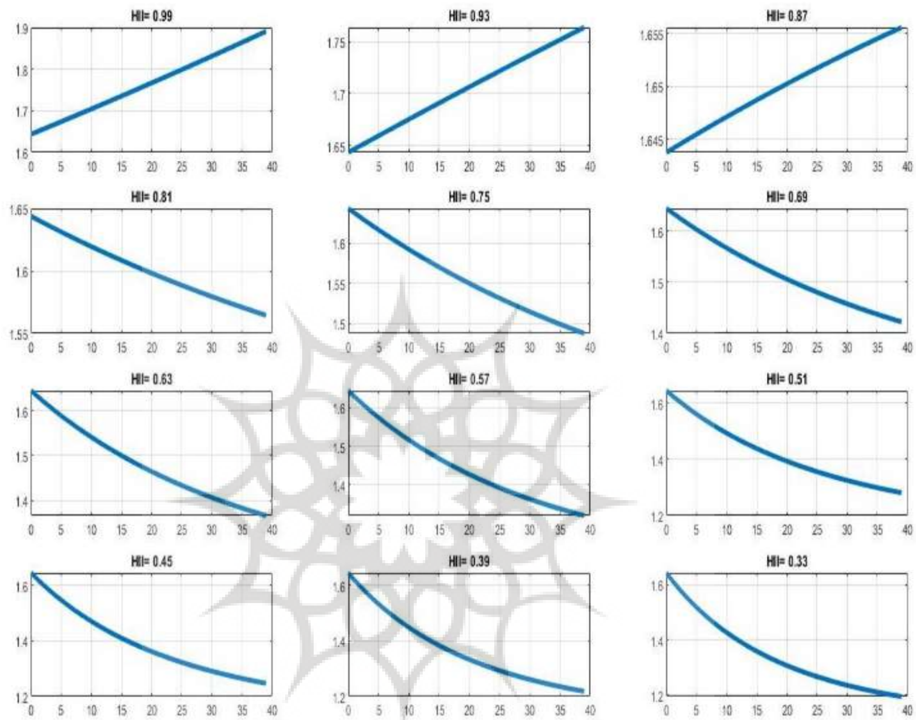

Figure 4. Trend of Production (Y)

Source: Research Findings

Note: Vertical axis is Y and Horizontal axis is Time

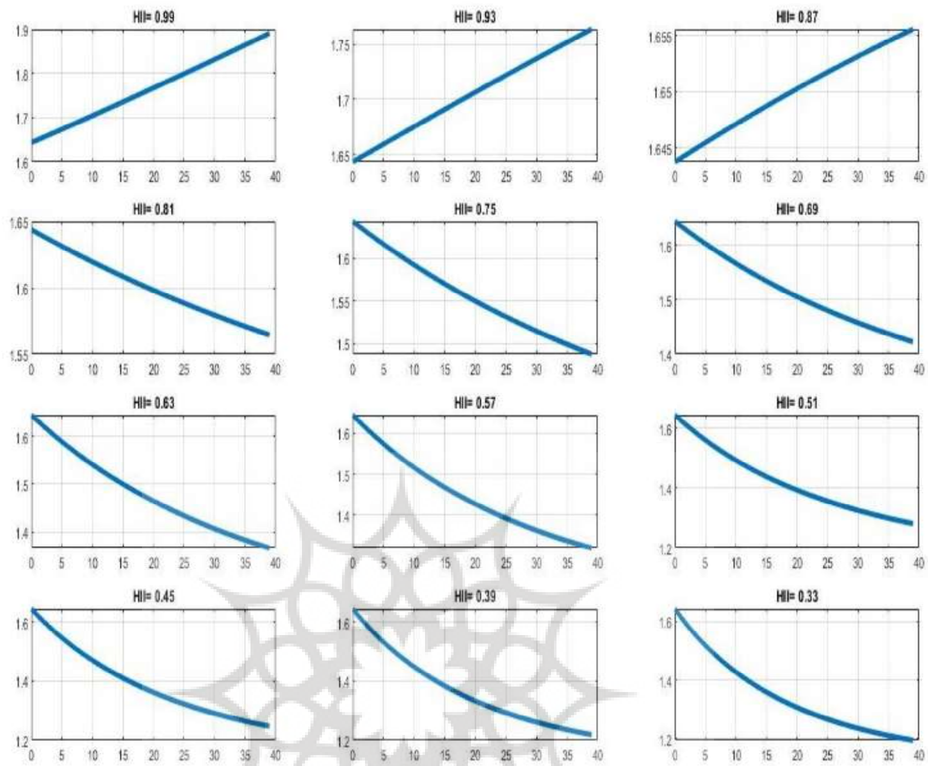

Figure 5. Trend of Covid-19 pandemic

Source: Research Findings
Note: Vertical axis is Covid-19 and Horizontal axis is Time

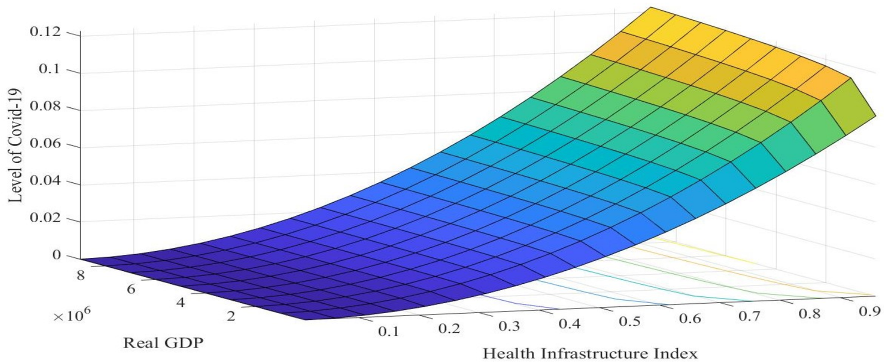

Figure 6. Covid-19 Pandemic, Health infrastructure and economic growth

Source: Research Findings

5. Discussion

In the first months of 2020, the COVID-19 pandemic made a global shock on the world economy. Assessments showed that gross domestic product (GDP) growth would be between 3-6 % in the best scenario, and 10-15 % fall in the worst scenario (*Fernandes, 2020*). Despite its consequences on the population's health and high numbers of mortalities, it highly affected the market's supply and demand (*Rainisch et al., 2020*).

Lack down caused decreasing working time, unemployment, and many businesses' failure (*Chudik et al.*, 2020). Both mentally and physically Ill-health consequences of COVID-19 lead to a decrease in labour force productivity and a decrease in both households and businesses income *(Pfefferbaum and North, 2020, Gorlick, 2020*), as well as reduce household consumption and the ability to purchase commodities (*Martin et al., 2020*). The economic recession was a critical effect of the COVID-19 pandemic, which caused a decrease in the GDP of affected countries *(Chudik et al., Nicola et al., 2020*). However, countries' output losses due to the COVID-19 pandemic are not consistent with each other *(König and Winkler, 2020*). They are highly related to the development status of the country (higher developed countries GDPs are more affected by a health emergency), the extent of the government intervention for controlling the pandemic, and the incidence rate of the pandemic in the country, and preparedness of the country for dealing with communicable diseases emergencies like the COVID-19 pandemic *(König and Winkler, 2020; Sousa Júnior et al., 2020*).

Preparedness of the countries is related to the availability of health infrastructure in each country (*Gilbert et al., 2020*). These infrastructures contain physicians, hospital beds, ICU beds, ventilators, and population health literacy. These factors are very different, even in developed countries *(Jee, 2020; San Lau et al., 2020; Kapoor et al., 2020*). For example, the number of ICU beds was 5.2 per 100000 populations in Japan (2019) while it was 33.9, 8.5, and 3.6 in Germany, Norway, and New Zealand in 2017, respectively. In 2018, the number of hospital beds was 13.05 per 1000 population in Japan, 5.9 in France, 3.1 in Italy, and 2.61 in Denmark (*Organisation for Economic Co-operation and Development, 2020*). These differences might explain the diverse effects of COVID-19 pandemic and economic growth. In the present study, due to the lack of data about the dynamic relationship between economic growth, health infrastructures, and COVID-19 pandemic, we decided to find new evidence pieces to show the dynamic relationships between these factors.

Iran is the 18^{th} largest country in the world. It has near 80 million populations. Iran has a mixed health system financing multiple resources like public and private health insurances, social security, taxation, oil revenues, and charities are gathering money for health and medical care. However, primary health care services are totally provided by the government, and the private sector does not contribute to service providing (*Khosravi et al., 2017*). Health governance is highly centralized, and the Ministry of Health (MoH) is responsible for each country's health intervention. However, medical universities have the authority to deliver health and medical care services to the people of each province. The ministry of health is responsible for policymaking, planning, supervision of health and medical organizations, gathering health standards and medical guidelines, and training health professions (*Almaspoor-Khangah et al., 2017; Sajadi et al., 2019*).

The number of hospital beds in Iran was 1.72 per 1000 population in 2017, which was low compared to other middle eastern countries. Besides, for every 900 populations, the country had one physician (population-physician ratio), which was at an average rate in the middle eastern countries. The life expectancy of the population has been increased during the past decades (67.7 in 1984 for men to 75.47 in 2017 and 71 for women in 1984 to 79.36 in 2017) (*World Health Organization, 2019; World Bank Group, 2020*). Access to primary health care has been increased highly during this period, and now 99% of the population in rural areas access primary healthcare (PHC). The family physician plan was implemented in 2005 in rural and small cities, but the ministry of health could not find an effective model to be implemented in the cities higher than 20000 populations.

Despite the government's efforts to achieve universal health coverage (UHC), people paid 59.5% of their health and medical costs in the out-of-pocket form, and health insurances supported only 40% of costs. 3.82% of the population faced catastrophic health expenditures in 2015, and the utilization of medical services did not increase after the plan (*Doshmangir et al., 2019; Lozano et al.,2020*). The United States economic sanctions to Iran have been augmented, and the country is faced with a deficiency in the governmental budget, decrease in per capita GDP, high inflation rates, and increase in unemployment. Local currency value has been decreased to one-third in 4 years, and foreign health and medical equipment prices have been increased highly (*Sashi and Bhavish, 2019; Fotourehchi,2020; Iran, C.B.o.I.R.o., 2020*).

Iran was one of the first countries faced with the Covid-19 pandemic in the world. Due to official reports, the number of confirmed Covid-19 patients was 654936 until 6 November 2020; 36985 were dead during the period. Iran faced four epidemic peaks during the period, and all of the provinces of the country were faced with Covid-19. The country faced 438 deaths per one million populations (*World Health Organization, 2020*). On the first days of the entrance of the Covid-19 to the country, the government did not react effectively to restraint the spreading of the virus. The first intervention (lack down and controlling travels and closing offices, schools, and businesses) was implemented at least three weeks after the entrance of the virus (*Kaffashi, and Jahani, 2020; Zeinali et al., 2020*). Government and society alliance in managing the outbreak was not sufficient in the first weeks of entrance the Covid-19 (*Raoofi et al.,2020*). However, this intervention was highly effective and helped to decrease the spread of Covid-19. After four weeks, the government started to decrease the level of lack down, and the strategies were changed into social distancing strategies and face mask utilization. Lifesaving and protective equipment were inadequate, and effective policymaking was highly delayed (*Raoofi et al.,2020*). The United States economic sanctions resulted in catastrophic economic conditions, especially for the poor, increase in medicine prices and higher inabilities to import essential commodities (*Gorji, 2013; Danaei et al., 2019; Murphy et al.,2020*) and implementation of new lack down strategies will decrease the government revenues highly (*Samadi et al., 2020*). In addition, inter-sectoral collaborations for decreasing the spread were very low, and other organizations did not help the Ministry of Health in controlling the epidemic (*Raoofi et al.,2020; Bazrafshan and Delam, 2020*).

The present article investigates the impact of health infrastructure on economic growth in the framework of endogenous growth models. In this study we first, investigate the impact of the Covid-19 pandemic on economic growth in a steady-state situation. Second, we identify the threshold level of health infrastructure impact on long-term economic growth by considering the Covid-19 pandemic. Third, we mode the population dynamics and the Covid-19 pandemic. Fourth, we mode the level of following the protocols and public awareness of the Covid-19 pandemic and examining their impact on long-term economic growth. Finally, the developed model was calibrated using the information of a transition country, Iran. Our results shows If the health infrastructure is higher than the threshold level of 0.87, the output level will have an upward trend in the presence of the Covid-19 pandemic. Otherwise, the output trend will be downward. The increasing output could lead to the spread of the Covid-19 pandemic even in the long run in the Iranian economy. At a certain level of income, with the improvement of the health infrastructure, the level of Covid-19 pandemic release will decrease. Our results are consistent with *Hosoya (2014)*. He showed that public health infrastructure plays a vital role in the development policies of low-income countries.

6. Conclusions

The Covid-19 pandemic should be considered the cause of the deepest recession in the world's history; therefore, it is necessary to study its impact on economic growth and welfare.

Economic growth is a long-term phenomenon. The Covid-19 pandemic is also predicted to have short-term and long-term destructive effects. Also, depending on the state of the health infrastructure in countries, the pandemic effects on economic growth will be drastically different. Accordingly, this article seeks to answer these questions in order to evaluate the impact of the Covid-19 pandemic on economic growth: Does this effect depend on the level of the country's health infrastructure or not? Also, given the unknown dimensions of this pandemic, what will be the population dynamics? Does the level of people's awareness of the pandemic and following protocols reduce its impact on economic growth?

An endogenous growth model has been developed and solved to achieve this goal and answer the questions. Given that the impact of this pandemic on the economic growth of developing, underdeveloped, and transition countries are expected to be greater than that of developed countries, the developed model has been calibrated with the information of a transition country (Iran). The results of this article show that the Covid-19 pandemic will hurt economic growth and population in the country in a steady-state, but by improving the health infrastructure, its negative impact can be reduced. Another finding of this study is that health infrastructure has led to the threshold of 0.87 to increase production in the presence of the Covid-19 pandemic.

This result shows that the impact of this pandemic is very destructive, and the country's policymakers and international organizations such as the World Health Organization must think about financial assistance to these countries to repair and improve their health infrastructure.

Declarations

***Authors' contributions**:*

Ali Hossein Ostadzad: Writing- Original draft preparation, solving the model, Software.

***Ali Hussein Samadi*:** Conceptualization, Methodology, Writing- Reviewing and Editing, Supervision.

***Enayatollah Homaie Rad**:* Funding acquisition; Investigation, Data curation.

Consent for publication

Not applicable

Availability of data and material

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Appendix:

Equation (15):

The problem of optimal control is as follows:

$$Max \int_0^{\infty} \frac{C_t^{1-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)}}{1-\sigma} e^{-\rho t} dt$$

$$\dot{\Theta}_t = \Im \psi^{\varsigma} \ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} - \zeta \Theta_t$$

$$\dot{N}_t = bN_t - d\Theta_t^{\omega} N_t$$

$$\dot{K}_t = Y_t - C_t - \ell Y_t - \delta K_t$$

$$Y_t = AL_t^{\alpha} K_t^{\beta} \quad \text{(A1)}$$

The current Hamiltonian function will be in relation A (2):

$$H = \frac{C_t^{1-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)}}{1-\sigma} + \lambda_1 N_t(b - d\Theta_t^{\omega}) + \lambda_2[(1-\ell)Y_t - C_t - \delta K_t] + \lambda_3[\Im \psi^{\varsigma} \ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} - \zeta \Theta_t] \quad \text{(A2)}$$

We had 16-18 Equations:

$$\frac{\partial H}{\partial C_t} = 0 \Rightarrow C_t^{-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)} - \lambda_2 = 0 \quad \text{(A3)}$$

$$\frac{\partial H}{\partial \ell} = 0 \Rightarrow -\lambda_2 Y_t + \lambda_3[-\vartheta \Im \psi^{\varsigma} \ell^{-\vartheta-1} N_t^{\varsigma} Y_t^{-\vartheta}] = 0 \Rightarrow -\lambda_3(\vartheta \Im \psi^{\varsigma} \ell^{-\vartheta-1} N_t^{\varsigma}) = \lambda_2 Y_t^{\vartheta+1} \quad \text{(A4)}$$

$$\frac{\partial H}{\partial \psi} = 0 \Rightarrow \lambda_2\left[(1-\ell)\alpha \frac{Y_t}{\psi}\right] + \lambda_3\left[\varsigma \Im \psi^{\varsigma-1} \ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} - \vartheta \Im \psi^{\varsigma} \ell_t^{-\vartheta} N_t^{\varsigma} \alpha \frac{Y_t}{\psi} Y_t^{-\vartheta-1}\right] = 0 \quad \text{(A5)}$$

Now we can extract Equation 19 using relations A1-A3 and other functions:

$$\xrightarrow{A5} \lambda_2\left[(1-\ell)\alpha \frac{Y_t}{\psi}\right] + \lambda_3[\varsigma \Im \psi^{\varsigma-1} \ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} - \vartheta \Im \psi^{\varsigma-1} \ell^{-\vartheta} N_t^{\varsigma} \alpha Y_t^{-\vartheta}] = 0 \Rightarrow$$

$$\lambda_2\left[(1-\ell)\alpha \frac{Y_t}{\psi}\right] + \lambda_3 \Im \psi^{\varsigma-1} \ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta}[\varsigma - \vartheta\alpha] = 0$$

$$\rightarrow \lambda_2\left[(1-\ell)\alpha \frac{Y_t}{\psi}\right] = \lambda_3 \Im \psi^{\varsigma-1} \ell^{-\vartheta}[\vartheta\alpha - \varsigma] N_t^{\varsigma} Y_t^{-\vartheta} \rightarrow$$

$$\lambda_2(1-\ell)\alpha Y_t^{\vartheta+1} = \lambda_3 \Im \psi^{\varsigma} \ell^{-\vartheta}[\vartheta\alpha - \varsigma] N_t^{\varsigma} \quad \text{(A5)}$$

$$\dot{\lambda}_1 = \rho\lambda_1 - \frac{\partial H}{\partial N_t} \Rightarrow \dot{\lambda}_1 - \rho\lambda_1 - \left[\lambda_1(b - d\theta_t{}^{\omega}) + \lambda_2\left((1-\ell)\alpha\frac{Y_t}{N_t}\right) + \lambda_3\left[\Im\psi^{\varsigma}\ell^{-\vartheta}\left(\varsigma N_t{}^{\varsigma-1}Y_t{}^{-\vartheta} - \vartheta N_t{}^{\varsigma}Y_t{}^{-\vartheta-1}\alpha\frac{Y_t}{N_t}\right)\right]\right] \Rightarrow$$

$$\dot{\lambda}_1 = \rho\lambda_1 - \left[\lambda_1(b - d\theta_t{}^{\omega}) + \lambda_2\left((1-\ell)\alpha\frac{Y_t}{N_t}\right) + \lambda_3\left[\Im\psi^{\varsigma}\ell^{-\vartheta}\left(\varsigma N_t{}^{\varsigma-1}Y_t{}^{-\vartheta} - \vartheta N_t{}^{\varsigma-1}Y_t{}^{-\vartheta}\alpha\right)\right]\right] \Rightarrow$$

$$\dot{\lambda}_1 = \lambda_1[\rho - (b - d\theta_t{}^{\omega})] - \lambda_2\left((1-\ell)\alpha\frac{Y_t}{N_t}\right) - \lambda_3\left[\Im\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma-1}Y_t{}^{-\vartheta}(\varsigma - \vartheta\alpha)\right] \tag{A6}$$

$$\dot{\lambda}_2 = \rho\lambda_2 - \frac{\partial H}{\partial K_t} \Rightarrow \dot{\lambda}_2 = \rho\lambda_2 - \left[\lambda_2\left((1-\ell)\beta\frac{Y_t}{K_t} - \delta\right) + \lambda_3\left(-\vartheta\Im\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma}Y_t{}^{-\vartheta-1}\beta\frac{Y_t}{K_t}\right)\right]$$

$$\Rightarrow \dot{\lambda}_2 = \rho\lambda_2 - \left[\lambda_2\left((1-\ell)\beta\frac{Y_t}{K_t} - \delta\right) + \lambda_3\left(-\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma}Y_t{}^{-\vartheta}\frac{1}{K_t}\right)\right] \Rightarrow$$

$$\dot{\lambda}_2 = \lambda_2\left(\rho - (1-\ell)\beta\frac{Y_t}{K_t} + \delta\right) - \lambda_3\left(\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma}Y_t{}^{-\vartheta}\frac{1}{K_t}\right) \tag{A7}$$

$$\dot{\lambda}_3 = \rho\lambda_3 - \frac{\partial H}{\partial \theta_t} \Rightarrow \dot{\lambda}_3 = \rho\lambda_3 + \tau C_t{}^{1-\sigma}(1+\theta_t)^{-\tau(1-\sigma)-1} + \lambda_1 d\omega N_t\theta_t{}^{\omega-1} + \zeta\lambda_3 \tag{A8}$$

$$Y_t = A\psi^{\alpha}N_t{}^{\alpha}K_t{}^{\beta}$$

$$\lambda_2 = C_t{}^{-\sigma}(1+\theta_t)^{-\tau(1-\sigma)}$$

$$\lambda_3\left(\vartheta\Im\psi^{\varsigma}\ell^{-\vartheta-1}N_t{}^{\varsigma}\right) = \lambda_2 Y_t{}^{\vartheta+1}$$

$$\lambda_2(1-\ell)\alpha Y_t^{\vartheta+1} = \lambda_3\Im\psi^{\varsigma}\ell^{-\vartheta}[\vartheta\alpha - \varsigma]N_t{}^{\varsigma}$$

$$\dot{\lambda}_1 = \lambda_1[\rho - (b - d\theta_t{}^{\omega})] - \lambda_2\left((1-\ell)\alpha\frac{Y_t}{N_t}\right) - \lambda_3\left[\Im\psi^{\varsigma}\ell^{-\vartheta}(\varsigma - \vartheta\alpha)N_t{}^{\varsigma-1}Y_t{}^{-\vartheta}\right]$$

$$\dot{\lambda}_2 = \lambda_2\left(\rho - (1-\ell)\beta\frac{Y_t}{K_t} + \delta\right) - \lambda_3\left(\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma}Y_t{}^{-\vartheta}\frac{1}{K_t}\right)$$

$$\dot{\lambda}_3 = (\rho + \zeta)\lambda_3 + \tau C_t{}^{1-\sigma}(1+\theta_t)^{-\tau(1-\sigma)-1} + \lambda_1 d\omega N_t\theta_t{}^{\omega-1}$$

$$\dot{N}_t = bN_t - d\theta_t{}^{\omega}N_t$$

$$\dot{K}_t = Y_t - C_t - \ell Y_t - \delta K_t \Rightarrow \frac{\dot{K}_t}{K_t} = (1-\ell)\frac{Y_t}{K_t} - \frac{C_t}{K_t} - \delta \Rightarrow g_K = (1-\ell)\frac{Y_t}{K_t} - \frac{C_t}{K_t} - \delta$$

$$\dot{\theta}_t = \Im\psi^{\varsigma}\ell^{-\vartheta}N_t^{\varsigma}Y_t^{-\vartheta} - \zeta\theta_t$$

In the steady state, we expect shadow prices (co-state variables) to have a zero-growth rate, Therefore, according to the relations (A6-A9) we will have:

$$\xrightarrow{\dot{\lambda}_1=0,(A6)} 0 = \lambda_1[\rho - (b - d\theta_t^{\omega})] - \lambda_2\left((1-\ell)\alpha\frac{Y_t}{N_t}\right) - \lambda_3[\Im\psi^{\varsigma}\ell^{-\vartheta}(\varsigma - \vartheta\alpha)N_t^{\varsigma-1}Y_t^{-\vartheta}] \Rightarrow$$

$$\lambda_1[\rho - (b - d\theta_t^{\omega})] = \lambda_2\left((1-\ell)\alpha\frac{Y_t}{N_t}\right) + \lambda_3[\Im\psi^{\varsigma}\ell^{-\vartheta}(\varsigma - \vartheta\alpha)N_t^{\varsigma-1}Y_t^{-\vartheta}] \qquad (A9)$$

Now we consider the co- state variable $\dot{\lambda}_2$ to be equal to zero. In this case we will have:

$$\xrightarrow{\dot{\lambda}_2=0,(A7)} 0 = \lambda_2\left(\rho - (1-\ell)\beta\frac{Y_t}{K_t} + \delta\right) - \lambda_3\left(\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t^{\varsigma}Y_t^{-\vartheta}\frac{1}{K_t}\right) \Rightarrow$$

$$\lambda_2\left(\rho + \delta - (1-\ell)\beta\frac{Y_t}{K_t}\right) = \lambda_3\left(\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t^{\varsigma}Y_t^{-\vartheta}\frac{1}{K_t}\right) \Rightarrow$$

$$\lambda_2\left(\frac{(\rho+\delta)K_t - (1-\ell)\beta Y_t}{K_t}\right) = \lambda_3\left(\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t^{\varsigma}Y_t^{-\vartheta}\frac{1}{K_t}\right) \Rightarrow$$

$$\lambda_2\left((\rho+\delta)K_t - (1-\ell)\beta Y_t\right) = \lambda_3\left(\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t^{\varsigma}Y_t^{-\vartheta}\right) \Rightarrow$$

$$\lambda_2 = \lambda_3\left(\frac{\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t^{\varsigma}Y_t^{-\vartheta}}{(\rho+\delta)K_t - (1-\ell)\beta Y_t}\right) \qquad (A10)$$

Finally, in relation (A8), we set the third co-state variable ($\dot{\lambda}_3$) to zero and simplify relation A10:

$$\xrightarrow{\dot{\lambda}_3=0} 0 = (\rho+\zeta)\lambda_3 + \tau C_t^{1-\sigma}(1+\theta_t)^{-\tau(1-\sigma)-1} + \lambda_1 d\omega N_t\theta_t^{\omega-1} \qquad (A11)$$

By placing the relation (A10) in (A9) and slightly simplifying:

$$\xrightarrow{A10 in A9}$$

$$\lambda_1[\rho \quad (b \quad d\theta_t^{\omega})] = \lambda_3\left(\frac{\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t^{\varsigma}Y_t^{-\vartheta}}{(\rho+\delta)K_t - (1-\ell)\beta Y_t}\right)\left((1-\ell)\alpha\frac{Y_t}{N_t}\right) + \lambda_3[\Im\psi^{\varsigma}\ell^{-\vartheta}(\varsigma - \vartheta\alpha)N_t^{\varsigma-1}Y_t^{-\vartheta}] \Rightarrow$$

$$\lambda_1[\rho-(b-d\Theta_t{}^{\omega})] = \lambda_3(1-\ell)\alpha\left(\frac{\vartheta\mathfrak{Z}\beta\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma-1}Y_t{}^{-\vartheta+1}}{(\rho+\delta)K_t-(1-\ell)\beta Y_t}\right) + \lambda_3\left[\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta}(\varsigma-\vartheta\alpha)N_t{}^{\varsigma-1}Y_t{}^{-\vartheta}\right] \Rightarrow$$

$$\lambda_1[\rho-(b-d\Theta_t{}^{\omega})] = \lambda_3\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma-1}Y_t{}^{-\vartheta}\left(\frac{(1-\ell)\alpha\vartheta\beta Y_t}{(\rho+\delta)K_t-(1-\ell)\beta Y_t}+\varsigma-\vartheta\alpha\right) \Rightarrow$$

$$\lambda_1 = \lambda_3\frac{\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma-1}Y_t{}^{-\vartheta}\left(\frac{(1-\ell)\alpha\vartheta\beta Y_t}{(\rho+\delta)K_t-(1-\ell)\beta Y_t}+\varsigma-\vartheta\alpha\right)}{[\rho-(b-d\Theta_t{}^{\omega})]} \qquad \text{(A12)}$$

$$\xrightarrow{(A11),(A12)}$$

$$0 = (\rho+\zeta)\lambda_3+\tau C_t{}^{1-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)-1} + \lambda_3\frac{\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma-1}Y_t{}^{-\vartheta}\left(\frac{(1-\ell)\alpha\vartheta\beta Y_t}{(\rho+\delta)K_t-(1-\ell)\beta Y_t}+\varsigma-\vartheta\alpha\right)}{[\rho-(b-d\Theta_t{}^{\omega})]}d\omega N_t\vartheta_t{}^{\omega-1}$$

$$0 = +\tau C_t{}^{1-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)-1} + \lambda_3\left[\frac{\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta}d\omega\Theta_t{}^{\omega-1}N_t{}^{\varsigma}Y_t{}^{-\vartheta}\left(\frac{(1-\ell)\alpha\vartheta\beta Y_t}{(\rho+\delta)K_t-(1-\ell)\beta Y_t}+\varsigma-\vartheta\alpha\right)}{[\rho-(b-d\Theta_t{}^{\omega})]} + \rho+\zeta\right]$$

$$\Rightarrow \lambda_3 = -\frac{\tau C_t{}^{1-\sigma}(1+\Theta_t)^{-\tau(1-\sigma)-1}}{\left[\frac{\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta}d\omega\Theta_t{}^{\omega-1}N_t{}^{\varsigma}Y_t{}^{-\vartheta}\left(\frac{(1-\ell)\alpha\vartheta\beta Y_t}{(\rho+\delta)K_t-(1-\ell)\beta Y_t}+\varsigma-\vartheta\alpha\right)}{[\rho-(b-d\Theta_t{}^{\omega})]}+\rho+\zeta\right]} \qquad \text{(A13)}$$

The following is according to the relations (A10-A13):

$$\begin{cases} -\lambda_3\left(\vartheta\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta-1}N_t{}^{\varsigma}\right) = \lambda_2 Y_t{}^{\vartheta+1} \Rightarrow -\dfrac{\lambda_2}{\lambda_3} = \dfrac{\vartheta\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta-1}N_t{}^{\varsigma}}{Y_t{}^{\vartheta+1}} \\ \lambda_2(1-\ell)\alpha Y_t{}^{\vartheta+1} = \lambda_3\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta}[\vartheta\alpha-\varsigma]N_t{}^{\varsigma} \Rightarrow -\dfrac{\lambda_2}{\lambda_3} = \dfrac{\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta}[\varsigma-\vartheta\alpha]N_t{}^{\varsigma}}{(1-\ell)\alpha Y_t{}^{\vartheta+1}} \Rightarrow \\ \lambda_2 = \lambda_3\left(\dfrac{\vartheta\mathfrak{Z}\beta\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma}Y_t{}^{-\vartheta}}{(\rho+\delta)K_t-(1-\ell)\beta Y_t}\right) \Rightarrow \dfrac{\lambda_2}{\lambda_3} = \dfrac{\vartheta\mathfrak{Z}\beta\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma}Y_t{}^{-\vartheta}}{(1-\ell)\beta Y_t-(\rho+\delta)K_t} \end{cases}$$

$$\frac{\vartheta\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta-1}N_t{}^{\varsigma}}{Y_t{}^{\vartheta+1}} = \frac{\mathfrak{Z}\psi^{\varsigma}\ell^{-\vartheta}[\varsigma-\vartheta\alpha]N_t{}^{\varsigma}}{(1-\ell)\alpha Y_t{}^{\vartheta+1}} = \frac{\vartheta\mathfrak{Z}\beta\psi^{\varsigma}\ell^{-\vartheta}N_t{}^{\varsigma}Y_t{}^{-\vartheta}}{(1-\ell)\beta Y_t-(\rho+\delta)K_t} \qquad \text{(A14)}$$

In relation A14, we equate the relations in pairs. In this case we will have:

$$\frac{\Im\psi^{\varsigma}\ell^{-\vartheta}[\varsigma-\vartheta\alpha]N_t^{\varsigma}}{(1-\ell)\alpha Y_t^{\vartheta+1}}=\frac{\vartheta\Im\beta\psi^{\varsigma}\ell^{-\vartheta}N_t^{\varsigma}Y_t^{-\vartheta}}{(1-\ell)\beta Y_t-(\rho+\delta)K_t}\Rightarrow\frac{[\varsigma-\vartheta\alpha]}{(1-\ell)\alpha Y_t^{\vartheta+1}}=\frac{\vartheta\beta Y_t^{-\vartheta}}{(1-\ell)\beta Y_t-(\rho+\delta)K_t}\Rightarrow$$

$$[\varsigma-\vartheta\alpha][(1-\ell)\beta Y_t-(\rho+\delta)K_t]=\vartheta\beta Y_t^{-\vartheta}(1-\ell)\alpha Y_t^{\vartheta+1}\Rightarrow$$

$$[\varsigma-\vartheta\alpha][(1-\ell)\beta Y_t-(\rho+\delta)K_t]=\vartheta\beta(1-\ell)\alpha Y_t \Rightarrow(1-\ell)(\varsigma-\vartheta\alpha)\beta Y_t-(\rho+\delta)(\varsigma-\vartheta\alpha)K_t=\vartheta\beta(1-\ell)\alpha Y_t\Rightarrow$$

$$(1-\ell)(\varsigma-\vartheta\alpha)\beta Y_t-\vartheta\beta(1-\ell)\alpha Y_t=(\rho+\delta)(\varsigma-\vartheta\alpha)K_t\Rightarrow(1-\ell)\beta Y_t[(\varsigma-\vartheta\alpha)-\vartheta\alpha]=(\rho+\delta)(\varsigma-\vartheta\alpha)K_t\Rightarrow$$

$$(1-\ell)\beta Y_t(\varsigma-2\vartheta\alpha)=(\rho+\delta)(\varsigma-\vartheta\alpha)K_t\Rightarrow$$

$$Y_t=\frac{(\rho+\delta)(\varsigma-\vartheta\alpha)}{(1-\ell)(\varsigma-2\vartheta\alpha)\beta}K_t \qquad \text{(A15)}$$

Equation (A15) shows that the amount of production at steady state is a constant coefficient of capital. (This result is common in Ramsey model). By placing in relation A14 we will have:

$$\frac{\vartheta\Im\psi^{\varsigma}\ell^{-\vartheta-1}N_t^{\varsigma}}{Y_t^{\vartheta+1}}=\frac{\Im\psi^{\varsigma}\ell^{-\vartheta}[\varsigma-\vartheta\alpha]N_t^{\varsigma}}{(1-\ell)\alpha Y_t^{\vartheta+1}}\longrightarrow\frac{\vartheta\ell^{-1}}{1}=\frac{[\varsigma-\vartheta\alpha]}{(1-\ell)\alpha}\Rightarrow\frac{\vartheta}{\ell}=\frac{[\varsigma-\vartheta\alpha]}{(1-\ell)\alpha}\longrightarrow$$

$$\vartheta\alpha(1-\ell)=[\varsigma-\vartheta\alpha]\ell\Rightarrow(\vartheta\alpha-\ell\vartheta\alpha)=[\varsigma\ell-\vartheta\alpha\ell]\Rightarrow\varsigma\ell=\vartheta\alpha\Rightarrow$$

$$\ell^*=\frac{\vartheta\alpha}{\varsigma} \qquad \text{(A16)}$$

which is the same as the Equation (19) and represents the percentage of revenue that should be spent on controlling the Covid-19 pandemic.

***Equation* (20):**

By placing the relation (A16) in (A15) we have:

$$Y_t=\frac{(\rho+\delta)(\varsigma-\vartheta\alpha)}{\left(1-\frac{\vartheta\alpha}{\varsigma}\right)(\varsigma-2\vartheta\alpha)\beta}K_t\Rightarrow Y_t=\frac{(\rho+\delta)(\varsigma-\vartheta\alpha)}{\left(\frac{\varsigma-\vartheta\alpha}{\varsigma}\right)(\varsigma-2\vartheta\alpha)\beta}K_t\Rightarrow Y_t=\frac{\varsigma(\rho+\delta)}{(\varsigma-2\vartheta\alpha)\beta}K_t\Rightarrow$$

$$g_y=g_K=g^* \qquad \text{(A17)}$$

Now, according to the production function and the relation (A17), the population growth rate has been calculated in terms of the steady state economic growth rate.

$$Y_t = A\psi^{\alpha} N_t^{\alpha} K_t^{\beta} \xrightarrow{g_y = g_k = g^*} g^* = \alpha g_n + \beta g^* \xrightarrow{g_n = \frac{\dot{N}_t}{N_t}} g_n = \left(\frac{1-\beta}{\alpha}\right) g^* \qquad \text{(A18)}$$

The following is according to the population dynamic equation:

$$\dot{N}_t = bN_t - d\Theta_t^{\omega} N_t \longrightarrow \frac{\dot{N}_t}{N_t} = b - d\Theta_t^{\omega} \Rightarrow g_n = b - d\Theta_t^{\omega} \Rightarrow g_n = b - d\Theta_t^{\omega}$$

$$\xrightarrow{g_n = \left(\frac{1-\beta}{\alpha}\right) g^*} \left(\frac{1-\beta}{\alpha}\right) g^* = b - d\vartheta_t^{\omega} \Rightarrow$$

$$g^* = \frac{(b - d\Theta_t^{\omega})\alpha}{1-\beta} \qquad \text{(A19)}$$

Equation (A19) shows the rate of economic growth given the level of the Covid-19 pandemic. Given the dynamic equation of Covid-19 and the fact that we expect the growth rate of Covid-19 to be zero at steady state, we have the Equation (A20).

$$\dot{\Theta}_t = \Im\psi^{\varsigma}\ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} \quad \zeta\Theta_t \quad \Im\psi^{\varsigma}\ell^{-\vartheta} N_t^{\varsigma} Y_t^{-\vartheta} = \zeta\Theta_t \Rightarrow$$

$$\frac{\Im\psi^{\varsigma}\ell^{-\vartheta}}{\zeta} N_t^{\varsigma} Y_t^{-\vartheta} = \Theta_t \qquad \text{(A20)}$$

On the other hand, according to the production function, the Equation (A15) and with a little simplification, we have:

$$Y_t = A\psi^{\alpha} N_t^{\alpha} K_t^{\beta} \xrightarrow{K_t = \frac{(\varsigma - 2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)} Y_t} Y_t = A\psi^{\alpha} N_t^{\alpha} \left(\frac{(\varsigma - 2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)} Y_t\right)^{\beta} \Rightarrow$$

$$Y_t = A\psi^{\alpha} N_t^{\alpha} \left[\frac{(\varsigma - 2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right]^{\beta} Y_t^{\beta} \Rightarrow Y_t^{1-\beta} = A\psi^{\alpha} N_t^{\alpha} \left[\frac{(\varsigma - 2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right]^{\beta}$$

$$Y_t^{1-\beta} = A\psi^{\alpha} \left(\frac{(\varsigma - 2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{\beta} N_t^{\alpha}$$

$$Y_t - \left[A\psi^{\alpha} \left(\frac{(\varsigma - 2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{\beta}\right]^{\frac{1}{1-\beta}} N_t^{\frac{\alpha}{1-\beta}} \qquad \text{(A21)}$$

With a little simplification in Equation (A21) we will have the population in terms of production:

$$N_t = \frac{A^{-\frac{1}{\alpha}}}{\psi} \left(\frac{(\varsigma - 2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{-\frac{\beta}{\alpha}} Y_t^{\frac{1-\beta}{\alpha}} \qquad \text{(A22)}$$

Next, we place Equation (A22) in Equation A20:

$$\frac{\Im\psi^{\varsigma}\ell^{-\vartheta}}{\zeta}N_t^{\varsigma}Y_t^{-\vartheta}=\Theta_t\xrightarrow{N_t=\frac{A^{-\frac{1}{\alpha}}}{\psi}\left(\frac{(\varsigma-2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{-\frac{\beta}{\alpha}}Y_t^{\frac{1-\beta}{\alpha}}}\Theta_t$$

$$=\frac{\Im\psi^{\varsigma}\ell^{-\vartheta}}{\zeta}\left(\frac{A^{-\frac{1}{\alpha}}}{\psi}\left(\frac{(\varsigma-2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{-\frac{\beta}{\alpha}}Y_t^{\frac{1-\beta}{\alpha}}\right)^{\varsigma}Y_t^{-\vartheta}\longrightarrow$$

$$\Theta_t=\frac{\Im\psi^{\varsigma}\ell^{-\vartheta}}{\zeta}\left[\frac{A^{-\frac{1}{\alpha}}}{\psi}\left(\frac{(\varsigma-2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{-\frac{\beta}{\alpha}}\right]^{\varsigma}Y_t^{\frac{(1-\beta)\varsigma}{\alpha}}Y_t^{-\vartheta}\Rightarrow\Theta_t$$

$$=\frac{\Im\psi^{\varsigma}\ell^{-\vartheta}}{\zeta}\left[\frac{A^{-\frac{1}{\alpha}}}{\psi}\left(\frac{(\varsigma-2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{-\frac{\beta}{\alpha}}\right]^{\varsigma}Y_t^{\frac{(1-\beta)\varsigma}{\alpha}-\vartheta}$$

$$\Theta_t=\frac{\Im\psi^{\varsigma}\ell^{-\vartheta}}{\zeta}\left[\frac{A^{-\frac{1}{\alpha}}}{\psi}\left(\frac{(\varsigma-2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{-\frac{\beta}{\alpha}}\right]^{\varsigma}Y_t^{\frac{(1-\beta)\varsigma-\vartheta\alpha}{\alpha}} \qquad \text{(A23)}$$

According to the Equation (A23) and change the parameters

$\Re=\frac{\Im\psi^{\varsigma}\ell^{-\vartheta}}{\zeta}\left[\frac{A^{-\frac{1}{\alpha}}}{\psi}\left(\frac{(\varsigma-2\vartheta\alpha)\beta}{\varsigma(\rho+\delta)}\right)^{-\frac{\beta}{\alpha}}\right]^{\varsigma}$ and $\aleph=\frac{(1-\beta)\varsigma-\vartheta\alpha}{\alpha}$, we have:

$$\Theta_t=\Re Y_t^{\aleph} \qquad \text{(A24)}$$

This relationship indicates the relationship between production and the level of Covid-19.

Equation (23):

According to Equation (A19), the production equation can be calculated in terms of time:

$$g^*=\frac{(b-d\Theta_t^{\ \omega})\alpha}{1-\beta}\longrightarrow g^*=\frac{\alpha}{1-\beta}(b-d\Theta_t^{\ \omega})$$

$$\xrightarrow{\Theta_t=\Re Y_t^{\aleph}(A24)}g^*=\frac{\alpha}{1-\beta}\left(b-d\left(\Re Y_t^{\aleph}\right)^{\omega}\right)\Rightarrow g^*=\frac{\alpha}{1-\beta}\left(b-d\Re^{\omega}Y_t^{\ \omega\aleph}\right)$$

$$\Rightarrow\frac{\dot{Y}_t}{Y_t}=\frac{\alpha}{1-\beta}\left(b-d\Re^{\omega}Y_t^{\ \omega\aleph}\right)\Rightarrow$$

$$\frac{\dot{Y}_t}{Y_t}=b\frac{\alpha}{1-\beta}-\frac{\alpha}{1-\beta}d\Re^{\omega}Y_t^{\ \omega\aleph} \qquad \text{(A25)}$$

we change $\begin{cases}h=b\frac{\alpha}{1-\beta}\\ \lambda=\frac{\alpha}{1-\beta}d\Re^{\omega}\end{cases}$ in (A25). So, we have:

$$\frac{\dot{Y}_t}{Y_t} = \hbar \quad \lambda Y_t^{\omega\aleph} \Rightarrow \dot{Y}_t = \hbar Y_t \quad \lambda Y_t^{\omega\aleph+1} \tag{A26}$$

In order to find the standard shape of the differential equation, we also change the parameter $\wp = \omega\aleph + 1$ on the Equation (A26).

$$\dot{Y}_t = \hbar Y_t - \lambda Y_t^{\wp} \tag{A27}$$

Equation (A27) is a standard Bernoulli differential equation. Due to the variable change, we solve this differential equation according to the initial conditions:

$$\xrightarrow{\times Y_t^{-\wp}} Y_t^{-\wp}\dot{Y}_t = \hbar Y_t^{-\wp} Y_t - \lambda Y_t^{-\wp} Y_t^{\wp} \Rightarrow Y_t^{-\wp}\dot{Y}_t = \hbar Y_t^{1-\wp} - \lambda$$

$$Y_t^{-\wp}\dot{Y}_t = \hbar Y_t^{1-\wp} - \lambda \Rightarrow \frac{Y_t^{-\wp} dY_t}{\hbar Y_t^{1-\wp} - \lambda} = dt \Rightarrow \int \frac{Y_t^{-\wp} dY_t}{\hbar Y_t^{1-\wp} - \lambda} = \int dt \Rightarrow$$

$$\Xi = Y_t^{1-\wp} \Rightarrow d\Xi = (1-\wp) Y_t^{-\wp} dY \Rightarrow dY = \frac{1}{(1-\wp)} Y_t^{\wp} d\Xi$$

$$\int \frac{Y^{-\wp} \frac{1}{(1-\wp)} Y_t^{\wp} d\Xi}{\hbar \Xi - \lambda} = \int dt \Rightarrow \frac{1}{(1-\wp)} \int \frac{d\Xi}{\hbar\Xi - \lambda} = \int dt \Rightarrow \frac{1}{(1-\wp)\hbar} Ln\,(\hbar\Xi - \lambda)\Big]_{\Xi_0}^{\Xi} = t\Big]_{t_0}^{t}$$

$$\frac{1}{(1-\wp)\hbar} Ln\left(\frac{\hbar\Xi - \lambda}{\hbar\Xi_0 - \lambda}\right) = (t - t_0) \Rightarrow Ln\left(\frac{\hbar\Xi - \lambda}{\hbar\Xi_0 - \lambda}\right) = (1-\wp)\hbar(t - t_0)$$

$$\Rightarrow \frac{\hbar\Xi - \lambda}{\hbar\Xi_0 - \lambda} = e^{(1-\wp)\hbar(t-t_0)} \longrightarrow \frac{\hbar\Xi - \lambda}{\hbar\Xi_0 - \lambda} = e^{(1-\wp)\hbar(t-t_0)} \xrightarrow{\Xi = Y_t^{1-\wp}} \frac{\hbar Y_t^{1-\wp} - \lambda}{\hbar Y_0^{1-\wp} - \lambda} = e^{(1-\wp)\hbar(t-t_0)} \Rightarrow$$

$$\hbar Y_t^{1-\wp} - \lambda = \left(\hbar Y_0^{1-\wp} - \lambda\right) e^{(1-\wp)\hbar(t-t_0)} \Rightarrow \hbar Y_t^{1-\wp} = \left(\hbar Y_0^{1-\wp} - \lambda\right) e^{(1-\wp)\hbar(t-t_0)} + \lambda \Rightarrow$$

$$Y_t^{1-\wp} = \left(\frac{\hbar Y_0^{1-\wp} - \lambda}{\hbar}\right) e^{(1-\wp)\hbar(t-t_0)} + \frac{\lambda}{\hbar} \longrightarrow Y_t = \left[\frac{\lambda}{\hbar} + \left(\frac{\hbar Y_0^{1-\wp} - \lambda}{\hbar}\right) e^{(1-\wp)\hbar(t-t_0)}\right]^{\frac{1}{1-\wp}}$$

$$Y_t = \left[\frac{\lambda}{\hbar} + \left(\frac{\hbar Y_0^{1-\wp} - \lambda}{\hbar}\right) e^{(1-\wp)\hbar(t-t_0)}\right]^{\frac{1}{1-\wp}} \tag{A28}$$

پویایی های همه گیری کووید-۱۹، زیرساخت های سلامت و رشد اقتصادی: یک الگوی رشد درون زا

چکیده:
تأثیر زیرساخت‌های سلامت بر رشد اقتصادی در چارچوب الگوهای رشد درون‌زا در چند مطالعه بررسی شده است. با این حال، تأثیر همه‌گیری کووید-۱۹ بر رشد اقتصادی در قالب الگوهای رشد درون‌زا، هنوز مورد مطالعه قرار نگرفته است. مقاله حاضر ادبیات موجود را از چند جهت گسترش می‌دهد. اول، بررسی تأثیر همه‌گیری کووید-۱۹ بر رشد اقتصادی در یک وضعیت پایا. دوم، شناسایی سطح آستانه تأثیر زیرساخت های سلامت بر رشد اقتصادی درازمدت با در نظر گرفتن همه‌گیری کووید-۱۹. سوم، الگوسازی پویایی جمعیت و همه‌گیری کووید-۱۹. چهارم، الگوسازی سطح پیروی از پروتکل‌ها و آگاهی عمومی از همه‌گیری کووید-۱۹ و بررسی تأثیر آنها بر رشد اقتصادی درازمدت. الگوی بسط داده شده در این مقاله، با استفاده از اطلاعات یک کشور در حال گذار، ایران کالیبره شد. نتایج نشان می‌دهد اگر زیرساخت‌های سلامت بالاتر از سطح آستانه ۰٫۸۷ باشد، سطح تولید در حضور همه‌گیری کووید-۱۹ روند صعودی خواهد داشت. در غیر این صورت روند خروجی نزولی خواهد بود. افزایش تولید می تواند منجر به گسترش همه گیری کووید-۱۹ حتی در درازمدت در اقتصاد ایران شود. در سطح معینی از درآمد، با بهبود زیرساخت‌های سلامت، میزان انتشار همه‌گیری کووید-۱۹ کاهش می‌یابد.

کلمات کلیدی: همه گیری کووید-۱۹، زیرساخت های بهداشتی، رشد اقتصادی، مدل رشد درون زا.