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Vulnerability of Renewable and Fossil Fuel Energy from COVID-19

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ABSTRACT

COVID-19 has hurt the world economy since its global spread. So various economic sectors, particularly the energy sector, have been impacted negatively. Statistical analysis has been used in numerous research to assess the effects and repercussions of COVID-19 on the energy sector. However, the influence of its interaction with other sectors, such as households and businesses, on the energy sector has not been studied. The DSGE model provides a framework for analyzing the effect of COVID-19 on the energy sector in dealing with households, businesses, government, and central bank policymakers. The energy sector is separated into two parts in this paper: renewable energy and fossil fuel energy. The impact of COVID-19 on consumption, production, investment in renewable energy, and investment in fossil fuels was then studied using the DSGE framework. The results indicated a decline in production and investment in these two sectors, as well as a rise in consumption. The results also indicate that the fossil fuel energy sector has had a greater decline in production, a greater increase in production costs, a greater loss in investment, and a greater increase in consumption than the renewable energy sector.

Introduction

The coronavirus known as "COVID-19" was reported in mid-December 2019 in the central Chinese city of Wuhan. Initially referred to as pneumonia, the Chinese national health authority formally announced the outbreak of the virus in China on December 30, 2019. The World Health Organization underlined at a conference on Wednesday, March 12, 2019, that the term pandemic should not be used carelessly due to its sensitivity, but that the organization's evaluations identify and declare the coronavirus as global [1].

COVID-19 has several effects on the energy sector. As with any other disease, COVID-19 has had no direct impact on the energy sector. However, it has an indirect impact. The energy sector faces issues such as supply chain delays, tax payments, and the possibility of not receiving government incentives [2]. COVID-19 has had diverse effects on energy consumption and production. Travel and transportation reduced energy demand. Additionally, COVID-19 has decreased energy consumption in several economic sectors, including the commercial and industrial sectors. By contrast, with increased consumption in the residential sector, global energy consumption has decreased overall [2]. COVID-19 harmed employment and liquidity in the energy sector resulting in a decline in energy sector output [3-6]. However, COVID-19 has varying effects on different subsectors of the energy sector. Increasing investments have

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been made in renewable energy [7, 8]. If government incentives in the renewable energy sector are not aligned with clean energy goals, clean energy investment will drop [8]. During COVID-19, wind energy production declined [9], therefore in some countries, facilities related to wind power plants were shut down, along with the fabrication of wind turbine blades, installation of wind turbines, and delivery of associated parts [10-16]. COVID- 19 has decreased the number of solar workers, slowed construction in the solar, supply chain, and equipment sectors, and diminished the number of customers. During COVID-19, the electricity demand has increased [17-23]. COVID-19 causes environmental waste to grow [13]. COVID-19 predominance reduces greenhouse gas emissions. Wind energy consumption has decreased [13, 23].

The literature review is divided into two groups. The first group consists of studies that employ statistical analysis to investigate the impact of COVID-19 on energy pricing, consumption, production, and policymaker actions in the energy sector, but do not model the consequences [2, 10, 15, 17]. The second group of articles examines renewable and fossil fuel energy in the framework of DSGE models, but their models do not investigate the impact of COVID-19 on these two energy sources [1, 4, 5, 6, 7, 24]. The literature research revealed that governments prefer to employ renewable energy, thereby delaying the environmental problems caused by the use of fossil fuels. It is necessary, therefore, to enhance access to renewable energy while minimizing environmental problems and health concerns as a means of job creation [1]. Some nations' short-term responses to COVID-19 include free electricity, exemption/suspension of bill payments, and VAT exemptions on electricity bills [2]. Environmental policies based on the application of technology in the energy sector have greater dynamic effects than demand-side policies, such as tax and subsidy policies. Therefore, technological advancement can raise the energy sector produced more than demand-side measures [1, 5]. By paying taxes and earning revenue from the sale and export of energy, the energy sector influences the government sector. Likewise, government fiscal policies have an impact on the energy sector [16]. The energy sector influences household behavior via the impact of energy prices on the consumer price index and the household employment rate. In addition, the energy sector influences the enterprise's behavior through energy production and consumption [4, 7, 9, 23]. Through monetary policy, the central bank can also control and mitigate the impact of energy shocks [16, 24].

In Iran, renewable energy is evaluated for use in electricity production due to the availability of fossil fuels and the desire to reduce pollution. Considering that energy statistics in Iran are classified into two categories, namely electricity and oil, gas, and petroleum products, renewable energy in this article refers to electricity.

Based on Alege et al. [1], Eroglu [4], and Argentieri et al. [5], this article has analyzed the renewable and fossil fuel energy sectors in the DSGE model, as well as the influence of COVID-19 on the modeled energy sector in terms of the labor force channel. This article's contributions are: The utility function for COVID-19 shock is the shock function. The impact of COVID-19 on non-energy, renewable energy, and fossil fuel energy is evaluated independently. Separate studies have been conducted on the effects of COVID-19 on the consumption of non-energy items, renewable energy, and fossil fuels, as well as the effects of COVID-19 on investment in all three sectors. This research involves multiple steps. This article began by describing the structure of the model. Then, a discussion of technique and stylized facts follows.

Model Structure

In this paper, a micro-founded DSGE model including energy sectors is constructed by the recent literature [1, 4].

Models have been designed with the following considerations in mind:

- Developing utility function through labor COVID-19 shock.

- Examining COVID-19's impact on the capital of the non-energy, renewable energy, and fossil fuel energy sectors.
- Consumption and labor force are divided into three categories: non-energy, renewable energy, and fossil fuel energy.

Households

According to Blazquez et al. [8] and Duncan [11], it is assumed that consumption and work together drive household utility. Blazquez et al. [8] and Duncan [11] assume household driving utility is derived from money, but we constructed these models assuming a combination of money and bond. In this paper such as Eroglu [4], labor is divided into three categories. Eroglu [4] divides labor into final, renewable, and fossil fuel energy, but this study has developed Eroglu [4], and the non-energy sector labor force has been substituted for the final labor force in the utility function. This research has developed Blazquez et al. [8], Duncan [11], and Eroglu [4] models by separating non-energy, renewable, and fossil fuel energy consumption. In addition, the COVID shock has been introduced to the utility function. The domestic utility function is:

$$\sum_{s=0}^{\infty}(\beta^h)^s\, E_t\left[\sigma_c \ln c_t - e_t^{covid}\ \sigma_n \ln N_t + \vartheta ln x_t\right] \tag{1}$$

Where β is the inter-temporal discount factor, c_t is total consumption, and σ_c is the inverse of inter-temporal substitution elasticity of consumption.
N_t is labor supply that:

$$N_t = (N_t^{non})^{\sigma_{nnon}}(N_t^{re})^{\sigma_{nre}}\left(N_t^{ff}\right)^{\sigma_{nff}} \tag{2}$$

N_t^{non}, is the supply of labor in the non-energy sector, N_t^{re}, is the supply of labor in the renewable energy sector, and N_t^{ff} supply of labor in fossil fuel energy sector. x_t is a combination of m_t money, and bond b_t, σ_{nnon} is the share of non-energy labor in the labor force, σ_{nre} is the share of renewable energy labor in the labor force, σ_{nff} is the share of fossil fuel energy labor in the labor force that $\sigma_{nnon} + \sigma_{nre} + \sigma_{nff} = 1$. e_{tcovid} is the shock of the labor force to model the impact of COVID on the supply labor force. This shock has been modeled as an autoregressive process [24]:

$$e_t^{covid} = \rho_{covid} e_{t-1}^{covid} + \varepsilon_{tcovid}$$
$$\rho_{covid} \epsilon (0,-1) \tag{3}$$
$$\varepsilon_{tcovid} \sim (0, \sigma_{\varepsilon_{covid}})$$

ϑ is the elasticity of x_t and x_t is:

$$x_t = m_t^{v_1} b_t^{1-v1} \tag{4}$$

v_1 is the shared parameter for the money-holding index.

Households utilize non-energy, renewable, and fossil fuel products that are interchangeable, c_t is:

$$c_t = c_{tnon}^{w_{non}} c_{tre}^{w_{re}} c_{tff}^{w_{ff}} \tag{5}$$

Where c_{tnon} is non-energy consumption, c_{tre} is renewable energy consumption and c_{tff} is fossil fuel energy consumption. w_{non}, w_{re}, w_{ff} are shares of non-energy, renewable, and fossil fuel energy goods in the consumption basket. That $w_{non} + w_{re} + w_{ff} = 1$.
The implied price index is:

$$P_t = w_{non}(P_t^{non}) + w_{re}(P_t^{re}) + w_{ff}(P_t^{ff}) \quad (6)$$

The price of non-energy goods is P_t^{non}, P_t^{re} is the price of renewable, and P_t^{ff} is the price of fossil fuel energy.
The sectoral capital formation is:

$$k_{t+1}^i = (1 - \delta^i)k_t^i + i_t^i \quad (7)$$

Where k_t^i is capital inventory in t with (i= non-energy, renewable energy, fossil fuel energy), and δ^i is capital depreciation in every sector.

The representative household maximizes the utility function within the restrictions of its budget. The fiscal restriction is as follows:

$$\begin{aligned} m_t + c_t^{non} + c_t^{re} + c_t^{ff} + b_t + i_t^{re} + i_t^{ff} + i_t^{non} \\ = w_t^{re}N_t^{re} + w_t^{ff}w_t^{ff} + w_t^{non}N_t^{non} + (1 + r_t^b)\frac{b_{t-1}}{\pi_t} + r_t^{kre}k_t^{re} \\ + r_t^{kff}k_t^{ff} + r_t^{knon}k_t^{non} + \frac{m_{t-1}}{\pi_t} + \frac{\pi_t^f}{\pi_t} \end{aligned} \quad (8)$$

Where b_t is the bond, and r_t^b is the interest rate of the bond. r_t^k is payment to capital. π_t^f is the profit of firms.

Let's obtain first-order conditions concerning $c_t^{non}, c_t^{re}, c_t^{ff}$ $N_t^{re}, N_t^{non}, N_t^{ff}, k_t^{re}, k_t^{ff}$ k_t^{non}, b_t.

Firms

The production sector includes four types of businesses. There are one final good company and three intermediate goods companies that produce non-energy, renewable, and fossil fuel energy, respectively.

Final Goods Firms

The ultimate good producer purchases intermediate products indicated by *j* in sector *i* and produce the final good by using [7].

$$Y_t = \left[\int_0^1 Y_{jt}^{\left(\frac{\theta-1}{\theta}\right)}\right]^{\left(\frac{\theta-1}{\theta}\right)} \quad \theta > 1 \quad (9)$$

Where Y_{jt} is intermediate good (*j* represents non-energy, renewable, and fossil fuel), θ is the constant elasticity of substitution between intermediate products. To maximize profit, producers of final items decide their purchases of intermediate goods based on varying pricing. The demand function for a differentiated product produced by any intermediate producer can be determined using Eq. 10:

$$Y_{jt}^{i} = \left(\frac{P_{jt}^{i}}{P_t}\right)^{-\theta} Y_t \quad (10)$$

The price of the final good is:

$$P_t = \left(\int_0^1 \left(P_{jt}^{i}\right)^{1-\theta} d_j\right)^{\frac{1}{1-\theta}} \quad (11)$$

Intermediate Good Firms

The non-energy producing firms combine capital k_t^{non}, labor N_t^{non}, renewable energy y_t^{re}, and fossil fuel energy y_t^{ff} as input, subject to productivity shocks.

$$Y_t = A_t^{non}(N_t^{non})^{\alpha_{ynon}}(k_t^{non})^{\beta_{ynon}}\left(y_t^{ff}\right)^{\gamma_{ynon}}(y_t^{re})^{1-\alpha_{ynon}-\beta_{ynon}-\gamma_{ynon}} \quad (12)$$

Where $\alpha_{ynon}\epsilon\ (0,1)$ is the share of the labor force in the non-energy sector production, $\beta_{ynon}\epsilon\ (0,1)$ is the share of capital, $\gamma_{ynon}\epsilon(0,1)$ $(1-\alpha_{ynon}-\beta_{ynon}-\ \gamma_{ynon})\epsilon(0,1)$ is the share of energy. A_t^{non} is technology shock in non-energy.

$$A_t^{non} = \rho_{Anon}A_{t-1}^{non} + \varepsilon_{tanon}$$
$$\rho_{Anon}\epsilon(0,1) \quad (13)$$
$$\varepsilon_{tanon}\sim(0,\sigma_{\varepsilon_{tanon}})$$

The renewable energy producing firms combines capital k_t^{re} and labor N_t^{re}subject to productivity shocks.

$$y_t^{re} = A_t^{re}(N_t^{re})^{1-\alpha_{yre}}(k_t^{re})^{\alpha_{yre}} \quad (14)$$

Where $\alpha_{yre}\epsilon(0,1)$ is the share of capital in renewable energy sector production. A_t^{re} is technology shock in renewable energy.

$$A_t^{re} = \rho_{Are}A_t^{re} + \varepsilon_{tare}$$
$$\rho_{Are}\epsilon(0,1) \quad (15)$$
$$\varepsilon_{tare}\sim(0,\sigma_{\varepsilon_{tare}})$$

The fossil fuel energy-producing firms combine capital k_t^{ff} and labor N_t^{ff}subject to productivity shocks.

$$y_t^{ff} = A_t^{ff}\left(N_t^{ff}\right)^{1-\alpha_{yff}}\left(k_t^{ff}\right)^{\alpha_{yff}} \quad (16)$$

Where $\alpha_{yff}\ \epsilon\ (0,1)$ is the share of capital in fossil fuel energy. A_t^{ff} is technology shock in fossil fuel energy.

$$A_t^{ff} = \rho_{Aff}A_t^{ff} + \varepsilon_{taff}$$
$$\rho_{Aff}\epsilon(0,1) \quad (17)$$
$$\varepsilon_{taff}\sim(0,\sigma_{\varepsilon_{taff}})$$

Adjustment costs in non-energy are:

$$PAC_t^{non} = \frac{\varphi_f}{2}\left(\frac{P_{jt}}{\bar{\pi}P_{jt-1}} - 1\right)Y_t^{\,2} \tag{18}$$

$\varphi_f \geq 0$ is the adjusted cost. $\bar{\pi}$ is the inflation rate in a steady state. Because pricing in the energy sector in Iran is assigned by the government, and firms have no role in pricing; therefore, energy firms do not have adjustment costs. So, $PAC_t^{re} = PAC_t^{ff} = 0$. The marginal cost in non-energy firms is:

$$mc_t^{non} = \frac{{w_t}^{\alpha_{ynon}} {r_t^k}^{\beta_{ynon}} {P_t^{ff}}^{\gamma_{ynon}} {P_t^{re}}^{1-\alpha_{ynon}-\beta_{ynon}-\gamma_{ynon}}}{\alpha_{ynon}^{\alpha_{ynon}} \beta_{ynon}^{\beta_{ynon}} \gamma_{ynon}^{\gamma_{ynon}} (1-\alpha_{ynon}-\beta_{ynon}-\gamma_{ynon})^{1-\alpha_{ynon}-\beta_{ynon}-\gamma_{ynon}} A_t^{non}} \tag{19}$$

The marginal cost in renewable energy firms is obtained as follows:

$$mc_t^{re} = \frac{{w_t}^{1-\alpha_{yre}} {r_t^k}^{\alpha_{yre}}}{\alpha_{yre}^{\alpha_{yre}} (1-\alpha_{yre})^{1-\alpha_{yre}} A_t^{re}} \tag{20}$$

Where assume P_t^{re} is:

$$P_t^{re} = (mc_t^{re})^{\omega_{mcre}} (P_{t-1}^{re})^{(1-\omega_{mcre})} \tag{21}$$

Where mc_t^{re} is the marginal cost of renewable energy firms, and ω_{mcre} is the weight of mc_t^{re} in P_t^{re}. The marginal cost in non-renewable energy firms is calculated as follows:

$$mc_t^{ff} = \frac{{w_t}^{1-\alpha_{yff}} {r_t^k}^{\alpha_{yff}}}{\alpha_{yff}^{\alpha_{yff}} (1-\alpha_{yff})^{1-\alpha_{yff}} A_t^{ff}} \tag{22}$$

P_t^{ff} is:

$$P_t^{ff} = \left(mc_t^{ff}\right)^{\omega_{mcff}} (P_{t-1}^{re})^{(1-\omega_{mcff})} \tag{23}$$

Where mc_t^{ff} is the marginal cost of fossil fuel energy firms, ω_{mcff} weight of mc_t^{ff} in P_t^{ff}, and ω_{pff} is the weight of P_{t-1}^{ff} in P_t^{ff}. Firms maximize profit:

$$\pi_t^{fi} = P_t Y_t^i - mc_t^i Y_t^i - PAC_t^i \tag{24}$$

Then first-order conditions were obtained concerning, k_t^{non}, k_t^{re}, k_t^{ff} N_t^{non}, N_t^{re}, N_t^{ff} and P_t, P_t^{re}, P_t^{ff}.

Central Bank, Government, and Oil Sector

The Central Bank of Iran utilizes the determination of bond interest rates as a monetary policy instrument to limit the growth rate of money. In simulating the central bank's activity, it is assumed that the monetary authority follows Taylor's rule while establishing the bond interest rate: The bond's rate of interest is:

$$1 + r_t^b = \left(\frac{1 + r_{t-1}^b}{1 + \bar{r}_b}\right)^{\rho_{rr}} \left(\frac{1 + \pi_t}{1 + \bar{\pi}}\right)^{\rho_{\pi r}} \left(\frac{y_t}{\bar{y}}\right)^{\rho_{yr}} \left(\frac{1 + \dot{m}_t}{1 + \bar{m}}\right)^{\rho_{mr}} \varepsilon_{tr} \tag{25}$$

π_t is the inflation rate, ρ_{rr} is the weight of bond interest rate, $\rho_{\pi r}$ is the weight of inflation, ρ_{yr} is the weight of output in bond interest rate policy, ρ_{mr} is the weight of monetary growth rate, and ε_{tr} is the bond interest rate shock.

$\dot{m}_t$ is the monetary growth rate, which is obtained as follows:

$$\dot{m}_t = \frac{m_t}{m_{t-1}} \tag{26}$$

As Emma [12], it is assumed that the government is financed with tax t_t, oil revenue or_t, and other revenue x_t. Government expenditure is calculated as Eq. 27:

$$g_t = t_t^{\Phi_t^g} or_t^{\Phi_{or}^g} b_t^{\Phi_B^g} x_t^{\Phi_x^g} \tag{27}$$

Where Φ_t^g the weight of the tax is, Φ_{or}^g is the weight of oil revenue, Φ_B^g is the weight of the bond, and $\Phi_x^g$is weight of other revenue. $\Phi_t^g + \Phi_{or}^g + \Phi_B^g + \Phi_x^g = 1$.

$$b_t = \varphi_t^b y_t \tag{28}$$

Tax is:

$$t_t = \varphi_t^y y_t \tag{29}$$

Where φ_t^y is the weight of output. x_t is:

$$x_t = \varphi_x^y y_t \tag{30}$$

Which $\varphi_x^y$is the coefficient of Y_t. Oil revenue shock is:

$$OR_t = (OR_{t-1})^{\rho_{or}} (\overline{OR})^{1-\rho_{or}} \varepsilon_{t,or}$$
$$\varepsilon_{t,or} \sim N(0, \sigma_{t,or}) \tag{31}$$

That $\overline{OR}$ is oil revenue at a steady state.

Market Clearing

In equilibrium, the output must be clear.

$$y_t = c_t^{non} + i_t^{non} + g_t + AC_t \tag{32}$$

$$y_t^{re} = c_t^{re} + i_t^{re} \tag{33}$$

$$y_t^{ff} = c_t^{ff} + i_t^{ff} \tag{34}$$

$$N_t = \int_0^1 N_{tj}^i \, d_j \tag{35}$$

and

$$k_t = \int_0^1 k_{tj}^i \, d_j \tag{36}$$

Methodology and Stylized Facts

Using data from the central bank and the Statistical Center of Iran from 1981 to 2018, the Calibration and Bayesian approaches were used to estimate parameter values.

Calibration, Priors, and Posterior Estimates

This paper calibrates and estimates parameters such as those proposed by Tavakolian and Saram [31]. Table 1 depicts the parameters that were calibrated based on previous experimental studies or the researcher's calculations, whereas Table 2 depicts the parameters that were estimated using the Bayesian method.

Table 1. Calibrated parameters

Parameter	Value	Calibrated from	Description
Household			
$\boldsymbol{\beta}$	0.96	Solving model	Discount factor
$\boldsymbol{\sigma_c}$	0.93	[12]	The elasticity of intertemporal substitution
$\boldsymbol{\vartheta}$	0.58	[12]	Relative preference for money holdings
V1	0.22	[12]	Share parameter in the index of money holdings
Production			
$\boldsymbol{\theta}$	4.33	Mark-up 30%	The elasticity of demand, intermediate goods
$\boldsymbol{\varphi_f}$	4.26	Atta-Mensa & Dib (2010)	Adjusted cost parameter, prices
Central bank			
$\boldsymbol{\rho_{mr}}$	0.7	Author calculations	The weights assigned to the growth of money in the bond interest rate
$\boldsymbol{\rho_{rr}}$	0.80	Author calculations	The weights assigned to the bond interest rate of the previous period in the bond interest rate
$\boldsymbol{\rho_{\pi r}}$	0.89	Author calculations	The weight assigned to inflation in bond interest rate
$\boldsymbol{\rho_{yr}}$	0.36	Author calculations	The weight assigned to output in bond interest rate
Government			
$\boldsymbol{\Phi_B^g}$	0.1	[12]	The weight assigned to bonds in government expenditure
$\boldsymbol{\Phi_t^g}$	0.25	[12]	The weight assigned to tax in government expenditure
$\boldsymbol{\Phi_{or}^g}$	0.55	[12]	The weight assigned to oil revenue in government expenditure
$\boldsymbol{\Phi_x^g}$	0.1	[12]	The weight assigned to other revenue in government expenditure
$\boldsymbol{\Phi_y^t}$	2.08	[12]	The weight of output in tax
$\boldsymbol{\Phi_x^y}$	1.54	[12]	The weight of other revenue in other revenue
$\boldsymbol{\Phi_b^y}$	0.1	[12]	The weight of the bond in the bond
Shocks			
$\boldsymbol{\rho_{covidnon}, \sigma_{c}}$	0.30, 0.001	Appropriate structure of the model	Persistence/standard dev., COVID shock of non-energy labor
$\boldsymbol{\rho_{covidre}, \sigma_{co}}$	0.30, 0.001	Appropriate structure of the model	Persistence/standard dev., COVID shock on renewable labor

$\boldsymbol{\rho_{covidff}}, \boldsymbol{\sigma_{co}}$	0.30, 0.001	Appropriate structure of the model	Persistence/standard dev., COVID shock on fossil fuel labor
$\boldsymbol{\rho_{Anon}}, \boldsymbol{\sigma_{Anon}}$	0.40, 0.01	Author calculations	Persistence/standard dev., productivity shock in non-energy
$\boldsymbol{\rho_{Are}}, \boldsymbol{\sigma_{ren}}$	0.80, 0.010	[1]	Persistence/standard dev., productivity shock in renewable energy
$\boldsymbol{\rho_{Aff}}, \boldsymbol{\sigma_{rff}}$	0.80, 0.01	[1]	Persistence/standard dev., productivity shock in fossil fuel
$\boldsymbol{\rho_{or}}, \boldsymbol{\sigma_{or}}$	0.36, 0.001	Author calculations	Persistence/standard dev., oil revenue
$\boldsymbol{\rho_{ire}}, \boldsymbol{\sigma_{ire}}$	0.80	[1]	Persistence/standard dev., renewable investment
$\boldsymbol{\rho_{iff}}, \boldsymbol{\sigma_{iff}}$	0.80	[1]	Persistence/standard dev., fossil fuel investment

Table 2 indicates prior and posterior Distributions.

Table 2. Prior and posterior Distributions

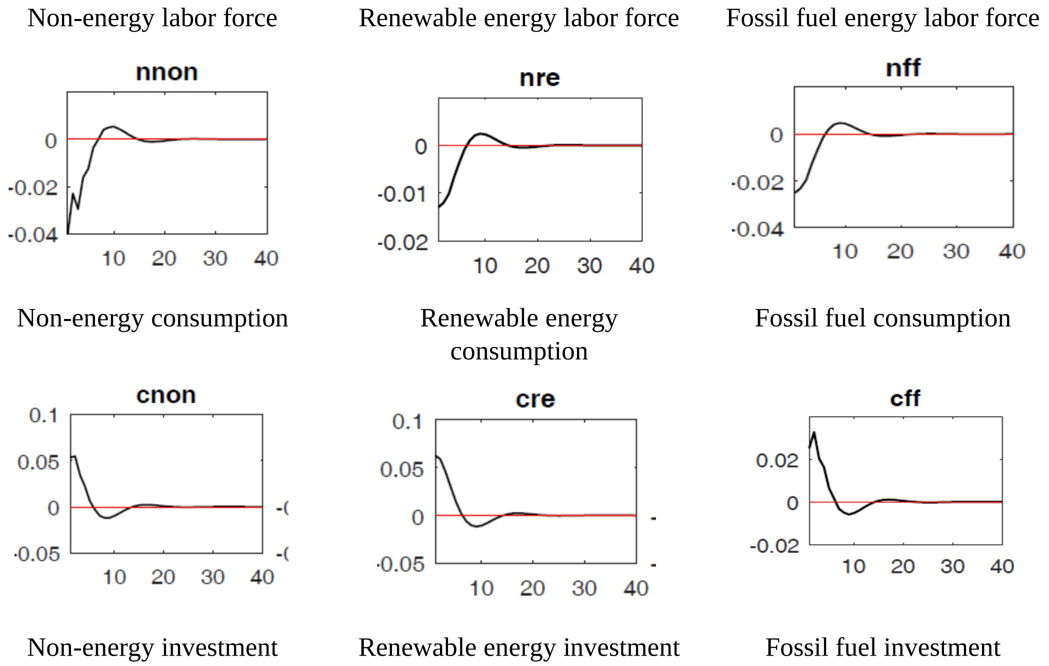
Parameter	**Description**	**Prior distribution**		**Calibrated from**	**Posterior distribution**		**Distribution**
		Mean	**Deviation**		**Mean**	**Deviation**	
Household							
σ_{nnon}	Share of non-energy labor	0.63	0.01	Author calculations	1.4684	0.1	Beta
σ_{nre}	Share of renewable energy labor	0.23	0.01	Author calculations	0.7156	0.01	Beta
wre	Share of renewable consumption	0.3	0.01	Author calculations	0.2407	0.01	Beta
wff	Share of fossil fuel consumption	0.3	0.01	Author calculations	0.2498	0.01	Beta
Production							
δ^{re}	The depreciation rate of physical capital in renewable	0.1205	0.01	[4]	0.1276	0.01	Beta
δ^{ff}	The depreciation rate of physical capital in fossil fuel	0.0838	0.01	[4]	0.1305	0.01	Beta
δ^{non}	The depreciation rate of physical capital in non-energy	0.10	0.01	[4]	0.1608	0.01	Beta
α_{yre}	Share of capital in output, renewable intermediate good	0.60	0.01	[4]	0.6524	0.01	Beta
α_{yff}	Share of capital in output, fossil fuel intermediate good	0.65	0.01	[4]	0.6750	0.01	Beta
α_{ynon}	Share of capital in output, non-energy intermediate good	0.63	0.01	[4]	0.6919	0.01	Beta
β_{ynon}	Share of capital in output, non-energy intermediate good	0.28	0.01	Author calculations	0.2433	0.01	Beta

γ_{ynon}	Share of fossil fuel intermediate good in output, non-energy intermediate good	0.83	0.01	Author calculations	0.8872	0.01	Beta
ω_{mcre}	Weight of mc in P_t^{re}	0.50	0.01	Appropriate structure of the model	0.5268	0.01	Beta
ω_{mcff}	Weight of mc in P_t^{ff}	0.50	0.01	Appropriate structure of the model	0.5634	0.01	Beta

Impulse Responses

According to the subject of this article, the effect of COVID-19 shock is explored in this article. The author has access to the findings of the study on the consequences of technology shocks, oil revenues, and monetary policy shocks. Fig. 1 depicts the impact of a shock on the residential sector. The impact of COVID-19 on employment, investment, and production is negative. As illustrated in Fig. 1, the non-energy sector will experience a bigger decline in the labor force than the energy sector. This conclusion is acceptable given that the non-energy sector has a larger labor force than the energy sector. In addition, the decrease in the labor force in the fossil fuel energy sector is greater than in the renewable energy sector.

Investment has fallen across all three sectors. Thus, the decline in investment in the non-energy sector is greater than the decline in investment in the energy sector, and the decline in investment in the renewable energy sector is more than the decline in investment in the fossil fuel energy sector. However, consumption has increased in all three sectors, which is consistent with the economic reality of Iran. Thus, the rise in non-energy consumption exceeds the increase in energy consumption, and the increase in consumption of renewable energy exceeds the increase in consumption of fossil fuel energy.



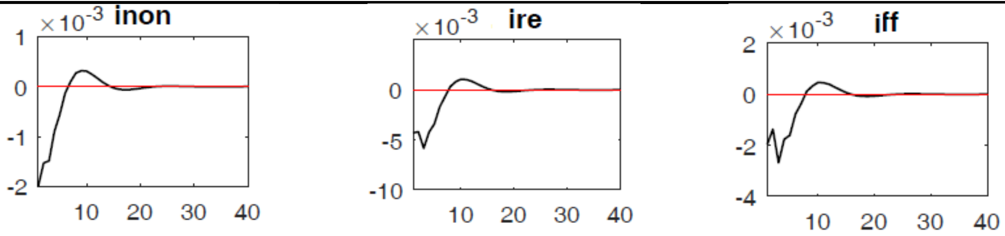


Fig. 1. Labor force COVID shock and household

The decline in production in the non-energy sector is greater than the decline in production in the other sectors, and the decline in production in the renewable energy sector is greater than the decline in production in the non-renewable energy sector. Also, production costs have increased due to COVID-19, so the increase in production costs in the non-energy sector is higher than in other sectors, and in the fossil fuel sector is higher than in the renewable energy sector.

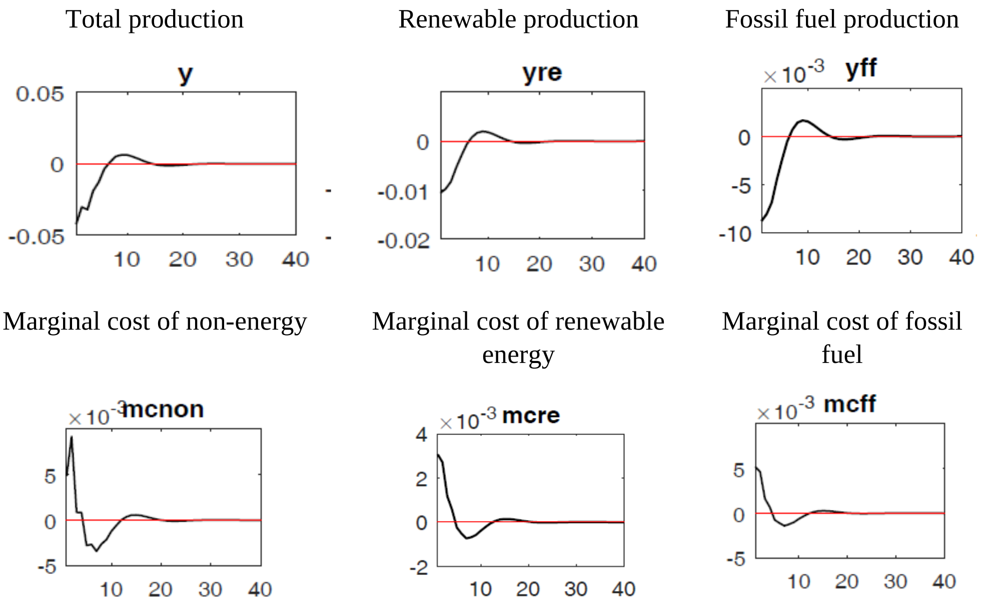
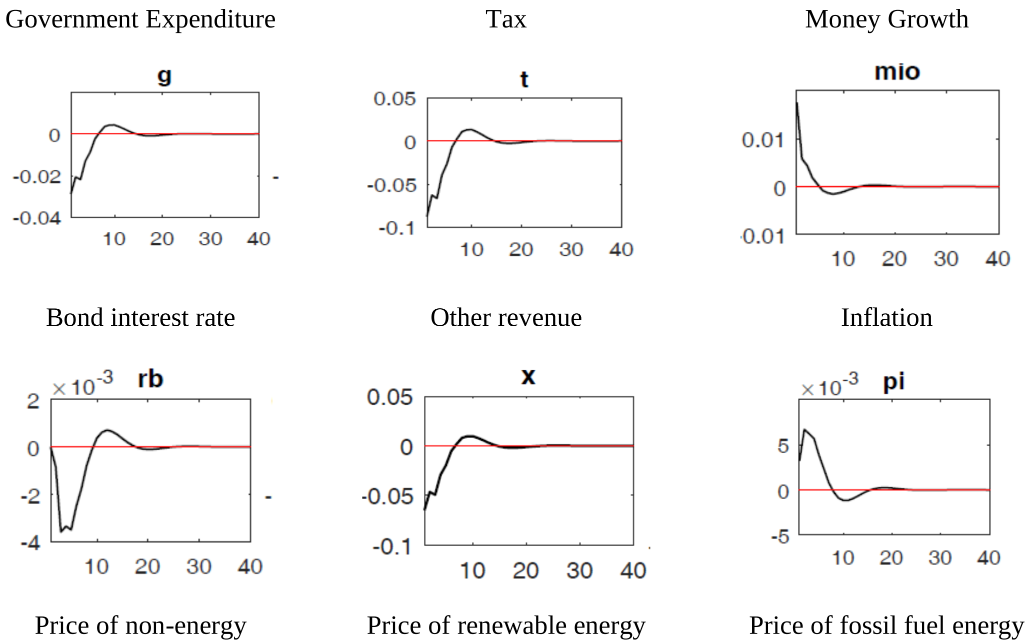


Fig. 2. Labor force COVID shock and production



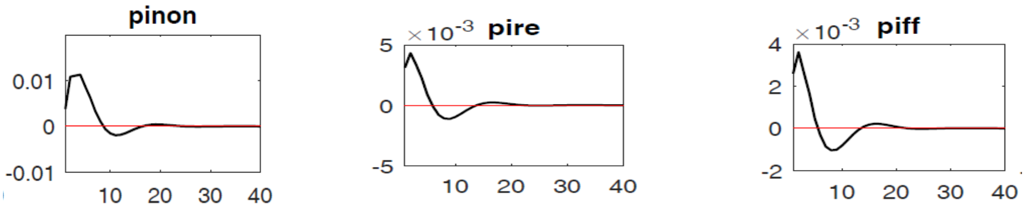


Fig. 3. Labor force COVID shock, government, central bank, and inflation

Due to a decline in production, tax revenue also falls. Moreover, government spending has dropped. During COVID-19, the government must subsidize and support various economic sectors. But as a result of decreased revenues, the government reduced its expenditure. Due to the economic slump, other government incomes are also falling. In contrast, the price index rises across all sectors and in general. So, the non-energy sector will experience price increases than other sectors. Also, the renewable energy sector is experiencing greater price growth than the fossil fuel energy sector. To promote output, the central bank policymaker will reduce bank interest rates but will have to infuse liquidity into society. For this reason, the growth of money accelerates. Money growth on the one hand and production decline, on the other hand, will lead to higher prices, which will boost prices in the non-energy sector more than in other sectors and in the renewable energy sector more than in the fossil energy sector.

Conclusion

Since 2019, the COVID-19 epidemic has spread over the globe. COVID–19 has a negative influence on numerous economic sectors. The energy sector is one of these sectors. Different countries have diverse policies to promote the energy sector, such as lowering prices and providing subsidies. However, Iran does not have a dedicated program to help this sector and has increased energy prices.

Due to the relevance of quantifying the influence of COVID-19 on the energy sector in this paper, the energy sector is modeled in the DSGE framework and COVID-19 has been added. The contribution made by this paper is:

- The renewable and fossil fuel energy sectors are modeled using DSGE models;
- In addition, the effect of COVID-19 on the energy sector via the labor force channel is modeled;
- The COVID-19 shock is in the utility function;
- Non-energy, renewable energy, and fossil fuel energy workforce are analyzed separately, as is the impact of COVID-19 on each;
- Consumption is classified into three categories: non-energy goods, renewable energy, and fossil fuels; the effect of COVID-19 has been evaluated independently for each category;
- The impact of COVID-19 on investment in each of the three sectors is explored.

According to the economic literature, the outbreak of COVID-19 creates supply and demand shocks, just like any other epidemic. On the supply side, the decline in this sector's investments and labor force has diminished the available resources. On the demand side, certain sectors have reduced their energy consumption while others have raised theirs. As demand for fossil fuels fell, renewable energy consumption soared. The results of this study support the theoretical literature. The study's findings indicate that COVID-19 has hurt production, investment, tax income, and other government revenues. COVID-19 also raises marginal production costs, prices, and consumption in all three sectors. The decline in production, the increase in the marginal cost of production, and the increase in prices in the non-energy sector are greater than in other sectors, as is the increase in non-energy sector consumption.

These findings are comparable to those of Zhong et al. [33], SeIa [29], and Eroğlu [13]. These three articles also studied the influence of COVID-19 emissions on the energy sector and found that the spread of the disease could lower energy production by harming energy sector investment and employment. And the demand for fossil fuels has fallen, while the demand for renewable energy has soared, particularly for electricity and water.

Finally, it is advised that Iranian economic policymakers examine pricing more closely. Since the government sets the price of energy, there exists a program to cut prices. As diminishing investment in the energy sector boosts future prices, the government should consider bolstering investment in this area and enhancing the energy sector's infrastructure.

References

[1] Alege P, Oye QE, Adu O. Renewable Energy, Shocks and the Growth Agenda: A Dynamic Stochastic General Equilibrium Approach. International Journal of Energy Economics and Policy. 2019;9(1):160.

[2] Akrofi MM, Antwi SH. COVID-19 energy sector responses in Africa: A review of preliminary government interventions. Energy Research & Social Science. 2020 Oct 1;68:101681.

[3] Amin S, Marsiliani L, Renström T. The impacts of fossil fuel subsidy removal on Bangladesh's economy. The Bangladesh Development Studies. 2018 Jun 1;41(2):65-81.

[4] Eroğlu H. Effects of Covid-19 outbreak on the environment and renewable energy sector. Environment, Development, and Sustainability. 2021 Apr;23(4):4782-90.

[5] Argentieri A, Bollino CA, Micheli S, Zopounidis C. Renewable energy sources policies in a Bayesian DSGE model. Renewable Energy. 2018 May 1;120:60-8.

[6] Atalla T, Blazquez J, Hunt LC, Manzano B. Prices versus policy: An analysis of the primary fossil fuel mix drivers. Energy Policy. 2017 Jul 1;106:536-46.

[7] Birol F. Put clean energy at the heart of stimulus plans to counter the coronavirus crisis. International Energy Agency. 2020 Mar 14;14:1-3.

[8] Blazquez J, Martin-Moreno JM, Perez R, Ruiz J. Fossil fuel price shocks and CO2 emissions: the case of Spain. The Energy Journal. 2017 Jun 1;38(6).

[9] David M. Coronavirus a crisis unlike anything the market has ever seen for the wind sector, Woodmac says—News for the oil and gas sector. Retrieved April. 2020;21:2020.

[10] Dixit AK, Stiglitz JE. Monopolistic competition and optimum product diversity. The American economic review. 1977 Jun 1;67(3):297-308.

[11] Duncan R. How Well Does a Monetary Dynamic Equilibrium Model Account for Chilean Data? Banco Central de Chile; 2005.

[12] Emma N. Coronavirus could weaken climate change action, and hit clean energy. Retrieved April 21, 2020.

[13] Eroğlu H. Effects of Covid-19 outbreak on the environment and renewable energy sector. Environment, Development, and Sustainability. 2021 Apr;23(4):4782-90.

[14] Figueroa J, Counts T, Graves F, Mudge B, Pant S. Impact of COVID-19 on the US energy industry. The Brattle Group Inc, Boston. 2020.

[15] Akrofi MM, Antwi SH. COVID-19 energy sector responses in Africa: A review of preliminary government interventions. Energy Research & Social Science. 2020 Oct 1;68:101681.

[16] Huynh BT. Monetary policy and energy price shocks. The BE Journal of Macroeconomics. 2017 Jun 1;17(2).

[17] International Energy Agency. Global energy review 2020. OECD Publishing; 2020.

[18] IRENA I. Renewable Energy and Jobs: Annual Review 2019. International Renewable Energy Agency (IRENA), United Arab Emirates. 2019 Jun 9.

[19] Ireland PN. Endogenous money or sticky prices? Journal of Monetary Economics. 2003 Nov 1;50(8):1623-48.

[20] Khoshnevis M, Ahmadyan A. Modeling Basel Regulatory in DSGE with Emphasis on Adequacy Regulatory. Journal of Money and Economy. 2017;12(4):389-418.

[21] Li-Xiang ZH, Chu-Xiao YA. Research on the impact of the new and renewable energy replacing fossil energy resources under the constraint of carbon emissions. China Petroleum Processing

& Petrochemical Technology. 2019 Dec 30;21(4):58.
[22] Lowder T, Lee N, Leisch JE. COVID-19 and the power sector in Southeast Asia: impacts and opportunities. National Renewable Energy Lab. (NREL), Golden, CO (United States); 2020 Jun 1.
[23] Manzoor D, Rajabi S, Ranjbaran R. Effects of COVID-19 Pandemic on Primary Energy Consumption in MENA Countries: Energy Input-Output Analysis. Journal of Economic Modeling Research. 2021 May 10;11(43):4-6.
[24] Martin C, Okolo M. Modelling the Differing Impacts of Covid-19 in the UK Labor Market. Oxford bulletin of economics and statistics. 2020 Jul 28.
[25] McPhee D. Moray east offshore wind project 'on track despite Covid-19 delays, director claims. Energy Voice. Retrieved 21 April 2020.
[26] Ahmadyan A, Nasr Esfahani M. COVID and energy sector in DSGE model. Petroleum Business Review. 2020 Oct 1;4(4):43-59.
[27] Qarnain SS, Muthuvel S, Bathrinath S. Review on a government action plan to reduce energy consumption in buildings amid COVID-19 pandemic outbreak. Materials Today: Proceedings. 2021 Jan 1;45:1264-8.
[28] Elavarasan RM, Shafiullah GM, Raju K, Mudgal V, Arif MT, Jamal T, Subramanian S, Balaguru VS, Reddy KS, Subramaniam U. COVID-19: Impact analysis and recommendations for power sector operation. Applied energy. 2020 Dec 1;279:115739.
[29] SeIA. 2020. Retrieved April 21, 2020, from https://www.seia.org/sites/default/files/2020-04/2020-April_SEIA-COVID-Factsheet.pdf.
[30] Geels FW, Sovacool BK, Schwanen T, Sorrell S. The socio-technical dynamics of low-carbon transitions. Joule. 2017 Nov 15;1(3):463-79.
[31] Tavakoliyan H, Sarem M. DSGE models in DYNARE software, modeling, solving and estimating based on the Iranian economy. 2017. Monetary and Banking Research Institute. Central Bank of the Islamic Republic of Iran. (In Persian).
[32] Dutta J, Choudhury M. COVID-19: The Pandemic and Way Forward. Voice of Environment Newsletter. 2020.
[33] Zhong H, Tan Z, He Y, Xie L, Kang C. Implications of COVID-19 for the electricity industry: A comprehensive review. CSEE Journal of Power and Energy Systems. 2020 Aug 6;6(3):489-95.

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