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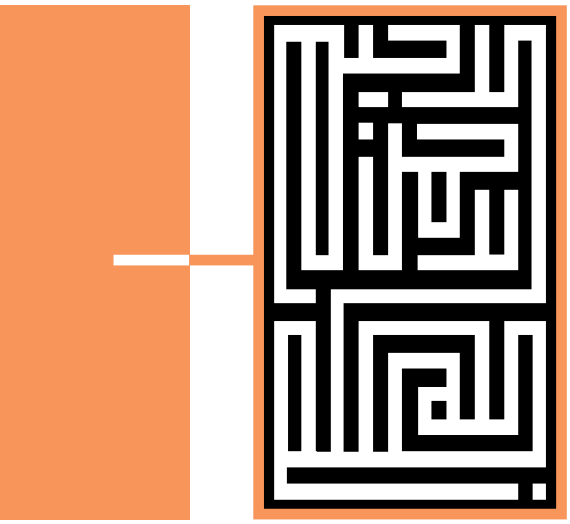

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Analyzing the Effect of International Sanctions on Selected Iranian Macroeconomic Variables Using the New Keynesian Dynamic Stochastic General Equilibrium Model

Zahra Zamani[1], Monireh Rafat[2], Rasoul Bakhshi Dastjerdi[3]

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Abstract

In this article, with the aim of investigating the impact of the international sanctions shock on the nominal exchange rate variable and other selected macroeconomic variables of Iran, and then the impact of the nominal exchange rate shock on selected macroeconomic variables, an appropriate model of the Iranian economy was designed within the framework of a dynamic stochastic general equilibrium model with a New Keynesian approach and solved using the calibration method. In order to ensure the reliability of the model results, the second-order moments of the main variables based on real data were compared with the second-order moments of the simulated values of those variables, and the instantaneous response functions of the variables to the model impulses were examined. The results of this study indicate that the increase in the intensity of international sanctions has significant effects on macroeconomic variables in the form of a decrease in foreign exchange earnings from oil exports, a decrease in the ratio of the central bank's foreign reserves to the monetary base, and an increase in the nominal exchange rate, leading to a decrease in the export of intermediate goods (non-oil exports). Also, an increase in the nominal exchange rate leads to an increase in the export of intermediate goods (non-oil exports), a decrease in the import of consumer goods, a decrease in the import of capital goods, a decrease in the import of intermediate inputs, and an increase in total production (GDP).

Keywords: Exchange Rate, Economic Sanctions, Dynamic Stochastic General Equilibrium Model, New Keynesian School.
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1. Introduction

Economic sanctions have a significant impact on the exchange rate, affecting the amount of foreign exchange inflows and outflows through a direct impact on exports and imports. By intensifying sanctions and creating obstacles in the path of exports, imports, and foreign exchange transfers, the amount of foreign exchange supply and demand is affected, leading to currency fluctuations (Vortabian Kashani, 2013). Oil sanctions reduce oil exports and reduce government revenues from oil exports (Rahmati *et al.*, 2016), which on the one hand, due to the dependence of the majority of government revenues on oil exports, including the sale of crude oil and petroleum products, causes a government budget deficit, and due to the stagnation of economic activities under sanctions and insufficient tax revenues, it leads the government to borrow from the banking network or withdraw from the reserves of the central bank, and can even cause the central bank's foreign exchange policies to deviate from maintaining the value of the national currency, towards a devaluation of the national currency or an increase in the exchange rate to compensate for the government budget deficit (Darakhshan, 2014). On the other hand, due to the reduction in the country's foreign exchange resources resulting from the reduction in oil exports and the reduction in the supply of foreign exchange in the market, the exchange rate increases International financial sanctions mainly focus on the banking network and the central bank to prevent international financial transactions and also to limit the use of international financial messengers to access services related to financial transactions (Taibi and Sadeghi, 2017). By increasing the risk of transactions between other countries and the banking and financial network of the target country, international financial sanctions have led to the expansion of financial activities in the informal sector, which in turn increases the risk of foreign exchange transfers due to the use of informal and insecure methods and increases the cost of trade transactions and international financing (Eyler, 2007). Due to the non-return of a significant percentage of foreign exchange resources from oil exports under central bank sanctions, there is a possibility of disruption in the central bank's foreign exchange policy because in these conditions, the central bank's ability to manage the foreign exchange market in a managed float from the foreign exchange supply side decreases, leading to an increase in the exchange rate (Darakhshan, 2014).

By imposing unfair sanctions as an external factor, the exchange rate increases significantly (Pourfathi and Kafaei, 2019). With an increase in the exchange rate, the price of the country's exported goods in foreign markets decreases, and as a result, the demand for these goods increases, leading to an increase in exports. Hence, domestic production is directed towards foreign markets and a smaller share is sold in the domestic market. As a result, domestic markets face a decrease in supply, and therefore, prices increase. In addition, with an increase in the exchange rate, the price of imported raw materials and intermediate inputs increases. This increases production costs and causes production to decrease, and in industries where production is largely dependent on imported intermediate inputs, with an increase in the price of imported intermediate inputs, there is an expectation of an increase in the cost price of goods, and this increase reduces the competitiveness of domestic production in foreign markets and reduces exports. On the one hand, an increase in the exchange rate increases the competitiveness of domestically produced goods in foreign markets, and on the other hand, an increase in the price of exported goods due to an increase in the price of imported intermediate inputs due to an increase in the exchange rate reduces the competitiveness of domestically produced goods in foreign markets. The

result of market forces in the general equilibrium model of the Iranian economy determines the increase or decrease in the country's exports (Davoodi and Sezavar, 2022).

This study attempts to examine the impact of the international sanctions shock on the macroeconomic variables of Iran by using a dynamic stochastic general equilibrium model with a new Keynesian approach.

The practical advantage of the method used in the present study over other studies, especially domestic studies, is that this study is one of the few studies that uses the New Keynesian dynamic stochastic general equilibrium model to analyze the effect of international sanctions shocks and exchange rate shocks on selected Iranian macroeconomic variables.

2. Theoretical foundations

2-1. How economic sanctions affect the exchange rate

International trade and international finance are interconnected through the balance of payments channel. Trade sanctions indirectly affect the financial markets of the target country. Financial sanctions also indirectly affect the commodity markets of the target country. When the sanctioning country restricts the target country's access to its financial resources, it actually reduces the supply of funds and increases the financing costs for the target country. Another form of financial sanctions involves reducing or cutting off income from assets of the target country held by the sanctioning countries, known as asset freezes. These types of sanctions can have a significant impact if the target country uses the financial markets of the sanctioning countries (Eyler, 2008).

The freezing of the assets of the Central Bank has been one of the first effects of the sanctions. As a result, the country's assets are frozen in all kinds of accounts in Iranian banks or with other banks, because any financial institution, since it ultimately belongs to the Central Bank, is affected by the sanctions. Another important consequence of the Central Bank sanctions is the disruption of monetary policies. Disruption of foreign exchange policy can be another result of the Central Bank sanctions, because in such circumstances, the Central Bank faces a shortage of foreign exchange reserves and loses the ability to effectively intervene in the market in order to maintain the value of the national currency. The freezing and freezing of revenues from oil exports is also one of the results of the Central Bank sanctions (Vesali and Torabi, 2010). The lack of full access to foreign exchange resources not only increases government costs, but also makes a significant part of government revenues practically unusable (Pahlavani *et al.*, 2014). In addition, banking sanctions, especially the Central Bank sanctions, pose problems for the country's monetary transactions and cause widespread disruptions to the country's commercial activities, thus seriously disrupting revenues from non-oil exports.

The transmission of negative oil shocks to the foreign exchange market, given the dominant share of foreign exchange earnings from oil exports in the country's foreign exchange reserves, has caused significant fluctuations in the exchange rate. Since the share of foreign exchange earnings from non-oil exports is very small and there are no alternative foreign exchange sources, the exchange rate is more susceptible to oil shocks. Given this, the Iranian economy is affected by events that affect oil exports, including economic sanctions (Taibi and Sadeghi, 2017).

Under the conditions of increasing sanctions pressure and the resulting uncertainty from the channel of limiting oil sales and foreign exchange earnings, the exchange rate is

affected upwards, which in turn increases production costs due to the increase in the price of imported raw materials and capital goods, and restricts non-oil production and exports. Even sanctions on the supply of certain goods, as well as sanctions in the interbank and financial transactions sector, and the like, restrict access to capital goods, which in turn puts pressure on the market for export products, and in the subsequent stages, its negative effects are transferred to different sectors of the economy.

Exports are considered one of the most important sources of foreign exchange supply in any country. If the export of goods and services is one of the areas of economic sanctions, then it is expected that foreign exchange resources, which are themselves import requirements, will be disrupted. Export sanctions can be extremely dangerous and damaging when export diversification in the target country is low (Gershasbi and Yousefi Dindarloo, 2016).

Financial and currency sanctions have significant effects on the country's monetary and foreign exchange system (Dreisner, 1999). Economic sanctions affect the country's foreign exchange market and foreign exchange reserves. They also directly affect other markets and speculative attacks, but economic sanctions indirectly affect the country's foreign exchange reserves, other markets, and speculative attacks through the foreign exchange market. Speculative attacks also affect the economy on the foreign exchange market, foreign exchange reserves, and other markets (Pourshahabi, 2014).

In fact, economic sanctions have three direct effects on the foreign exchange market, which are: an increase in the real exchange rate, an increase in the gap between the official exchange rate and the free market exchange rate, and an intensification of exchange rate fluctuations. Foreign exchange sanctions increase the gap between the nominal and real sectors, because if foreign exchange transactions are not carried out on time, these transactions must be carried out through mechanisms other than SWIFT or using other currencies. This can lead to corruption, delays in transactions, and increased costs associated with them. The exchange rate gap strengthens the rent-seeking process in the foreign exchange market, and this phenomenon can direct stray liquidity towards speculative transactions in the foreign exchange market and the use of multi-rate currency rents instead of being absorbed in productive activities. This phenomenon itself contributes to a sharp increase in the exchange rate and the formation of inflationary expectations in this market. Another mechanism by which sanctions affect the foreign exchange market is an increase in the exchange rate due to a decrease in foreign exchange resources and the supply of foreign exchange in the market.

2-2. How economic sanctions affect exports and imports

Depending on their type, sanctions can affect exports in different ways (Esmailpour *et al.*, 2023):

A) Direct trade sanctions, due to the existence of legal barriers in the sanctioning countries, cause these countries to cut off or reduce their imports from the target countries. On the other hand, increasing the risk of importers from the sanctioned exporting country prevents countries from exporting non-oil products, which can be due to the fear of punishment and sanctions from large economic countries (countries such as the United States, which have large economies, meaning their export and import volumes are very significant and are important for most economic enterprises).

B) Financial sanctions, commercial banks, and the central bank make it very difficult and even eliminate the possibility of trade for exporters from sanctioned countries and importers from destination countries, as a result of which the country's exports decrease.

C) Sanctions on knowledge and technology can reduce the possibility of exports by reducing the production capacity and competitiveness of exporting companies in competition with other exporting companies. However, given the ability to circumvent these types of sanctions, their effectiveness is low.

The high dependence of production on imports of various raw materials, intermediate inputs, and capital is one of the ways in which sanctions expose a country's economy to potential threats. Even if sanctions do not lead to a cut in imports, the cost of domestic production will increase due to increased import costs, which will increase domestic price levels and reduce the competitiveness of manufactured goods in international markets. On the one hand, imposing sanctions on imports can lead to a decrease in the amount of imports and, on the other hand, increase import costs per specific volume.

2-3. How exchange rate changes affect exports and imports

The current balance model in terms of the domestic currency is introduced as follows (Vaez, 2019):

$$CA = PX - RP^*M \quad (1)$$

So that P is the price of exported goods in terms of domestic currency, X amount of export, R of the exchange rate, ie the number of units required by the national currency to exchange with a foreign currency, P^* is the price of each unit of imported goods in terms of foreign currency and M is the amount of imports from abroad. The level of foreign and domestic prices can be written in a normal way (ie, divided by the price of each unit of domestic goods), so the first sentence will be x and the second sentence will be rm.

$$CA = x - rm \quad (2)$$

If a complete differential is taken from Equation (2) to express the complete change, then:

$$dCA = dx - rdm - mdr \quad (3)$$

By dividing the parties, we will have a relationship (3) to dr:

$$\frac{dCA}{dr} = \frac{dx}{dr} - \frac{rdm}{dr} - \frac{mdr}{dr} \quad (4)$$

This relationship can be shown in terms of export and import tensions. To do this, two tensions are introduced: export tension and import traction.

The price elasticity of the export demand:

$$\eta_x = \frac{\frac{dx}{x}}{\frac{dr}{r}} \rightarrow dx = \eta_x \frac{dr}{r} x \quad (5)$$

As it is clear, this elasticity indicates the percentage change in exports to the percentage change in the exchange rate. As a result of export changes in terms of export elasticity (price elasticity of demand for exports) is obtained in the form of (5).

The price elasticity of imports:

$$\eta_m = \frac{\frac{dm}{m}}{\frac{dr}{r}} \rightarrow dm = -\eta_m \frac{dr}{r} m \quad (6)$$

The price elasticity of demand for imports is equal to the percentage change in the amount of import to the percentage change in the exchange rate, which ultimately achieves the amount of import change in terms of import elasticity.

Now the relations (5) and (6) are placed in the relationship (4):

$$\frac{dCA}{dr} = \eta_x \frac{x}{r} + (\eta_m m) - m \quad (7)$$

If we multiply the sides by $\frac{1}{m}$, we will have:

$$\frac{dCA}{dr}\frac{1}{m} = \eta_x \frac{x}{r}\frac{1}{m} + \eta_m - 1 \quad (8)$$

If we assume that we are in a trade balance situation:

$$x = rm \quad (9)$$

In other words, the value of imports in terms of the foreign currency multiplied by the exchange rate is equal to the value of exports in terms of the national currency. According to the above assumption:

$$\frac{dCA}{dr} = m(\eta_x + \eta_m - 1) \quad (10)$$

Given that m is always positive in terms of trade, the phrase in parentheses will be positive when the sum of the export and import tensions is greater than one.

$$\eta_x + \eta_m > 1 \quad (11)$$

The final result is known as Marshall-Lerner. In other words, the Marshall-Lerner condition indicates that the increase in the exchange rate or the devaluation of the national currency improves the current balance when the total price elasticity of foreigners for our

export goods and the price elasticity of domestic demand for imported goods are greater than one. In other words, the condition for achieving the desired changes in the balance of payments by changing the exchange rate is to establish this condition.

In simple terms, if the current balance is in the deficit, if the Marshall-Lerner condition is met, the current balance deficit can be eliminated or reduced by increasing the exchange rate.

In short, following the increase in the exchange rate, events occur in three stages. The first stage is called the price effect, the second stage is called the value effect and the third stage is called the net effect.

Price effect: The price effect appears in such a way that when the exchange rate increases, this increase reduces the price of exported goods offered in foreign target markets and on the other hand increases the domestic price of imported goods and these two intensify the initial deficit in the current level. In other words, the effect of the policy of change in the exchange rate, in the event of a deficit in the current balance, intensifies it, because the monetary value of exports decreases and the monetary value of imports increases.

Quantitative effect: As a result of the increase in the exchange rate, the exchange rate of each unit of domestic export in foreign target markets decreases, and therefore the demand of foreigners for the import of domestic exports increases, the amount of exports increases from inside to outside. Likewise, as a result of the increase in the domestic price of imported goods, the amount of imports from abroad is reduced.

Net effect: The third net effect is two high effects. In fact, the net effect is expressed as the sum of the two tensions. In other words, if the sum of two elasticities is more than one, that is, the price elasticity of foreigners for our export goods and the price elasticity of domestic demand for imported goods, the effect of quantitative over the price effect prevails, and as a result, the increase in the exchange rate reduces or eliminates the initial deficit in the current level.

If we define the exchange rate as the value of a foreign currency compared to a country's domestic currency, then if the exchange rate increases, the price of imported goods in the country's domestic currency will increase. As a result, the demand for these goods will decrease. In addition, as the exchange rate increases, the price of the country's exported goods in foreign markets will become cheaper, and thus, the demand for these goods will increase. So, with a decrease in imports and an increase in exports, net exports and, consequently, GDP are expected to increase (Fouladi, 2012).

An increase in the exchange rate will increase the price level of imported goods in the domestic market, so it is expected that the demand for these goods will decrease and the demand for domestically produced goods will increase. In addition, with an increase in the exchange rate, the relative price of the country's exported goods in foreign markets will decrease, and as a result, the demand for these goods is expected to increase. As a result, domestic production may be directed to foreign markets and a smaller share will be sold in the domestic market. Due to the increase in the price of imported goods and the decrease in domestic supply, domestic markets will face a decrease in supply and therefore prices will increase.

Therefore, it is generally expected that domestic production will increase, imports will decrease, exports will increase, and the domestic price level will increase. In addition, with the increase in the exchange rate, the price of imported intermediate inputs will also

increase, and therefore, in sectors and industries where production is highly dependent on imported intermediate inputs, there is an expectation of an increase in the cost price of goods, and this increase may reduce the competitiveness of goods in foreign markets and intensify the increase in domestic prices.

3. Research background

Various domestic and foreign studies have been conducted on the impact of international sanctions on selected macroeconomic variables in Iran, of which only some of the most important are mentioned below:

Author	Title	Method and results
Ludati and Sons (2021)	Identifying the effects of sanctions on the Iranian economy using newspaper coverage	This study examines the impact of sanctions by using a new measure of sanctions severity based on newspaper coverage from 1979 to 2021, using the GVAR method. The findings of this study show that real household spending in most urban areas of Iran has decreased more than in rural areas. Sanctions have also had significant effects on exchange rates and inflation. In addition, sanctions have had significant negative consequences on employment, labor force participation, and secondary education in Iran.
Dizji and Farzanegan (2021)	Will sanctions limit Iran's military spending?	This study examines the role of sanctions on military spending in Iran using data from 1960 to 2017 and using the ARDL model. The results of this study show that increasing the severity of sanctions has had significant negative effects on Iran's military spending in both the short and long term.
Salehi Isfahani (2021)	Iran under sanctions, the impact of sanctions on household welfare and employment	This study examines the impact of sanctions imposed on Iran since 2010 on household consumption and employment. The findings of this study show that although household income and consumption have been hit hard, employment in Iran has shown greater resilience. The impact of sanctions on the Iranian economy has been twofold, both reducing government revenues from oil exports and reducing Iran's trade with the world.
Zarei *et al.* (2024)	The impact of international sanctions on the Iranian economy with emphasis on the role of the National Development Fund: Model Approach (DSGE)	The present study examines the simultaneous effects of various types of economic sanctions along with the role of the National Development Fund on Iranian economic variables. For this purpose, a dynamic stochastic general equilibrium model based on the New Keynesian approach has been used. The results show that the imposition of export sanctions on non-oil goods and imported intermediate goods has had the greatest impact on employment, wages, inflation, and total output. Also, the results indicate that the National Development Fund has not been able to play an effective role in reducing currency fluctuations caused by sanctions and has lost its effectiveness in the Iranian economy.

Various domestic and foreign studies have been conducted on the impact of exchange rate changes on selected Iranian macroeconomic variables, of which only some of the most important are mentioned below:

Author	Title	Method and results
Apollos *et al.* (2015)	Exchange rate fluctuations and economic growth in Nigeria	This study examines the relationship between GDP, exchange rate, exports, imports and inflation rate in Nigeria from 1986 to 2013. The results of the econometric model estimate show that there is a positive and significant relationship between GDP, exchange rate and exports. The results also show that exchange rate fluctuations have had an impact on Nigeria's economic growth.
Aziznejad and Komijani (2015)	Exchange rate changes and their effect on the fluctuations of selected macroeconomic variables in Iran	The present study has investigated the effects of exchange rate fluctuations on some macroeconomic variables using the vector autoregressive (VAR) method. The results of this study indicate that real exchange rate fluctuations in the Iranian economy have had the greatest impact on changes in short-term deposit interest rates. Also, after short-term deposit interest rates, the greatest changes in producer inflation rates have also been explained by changes in real exchange rates. Economic growth is positively affected by exchange rate changes in the short and long term and negatively affected by exchange rate changes in the medium term.
Habib *et al.* (2016)	Reexamining the relationship between real exchange rates and economic growth using external instruments	This study examines the impact of real exchange rate changes on economic growth using mixed data regression over the period 2010 to 2015 in 150 countries in the post-Bretton Woods monetary system. The results of this study show that an increase in real exchange rates significantly affects the annual economic growth of developing countries.
Aman, Ola, Khan and Khan (2017)	The relationship between exchange rate and economic growth in Pakistan (an econometric approach)	The present study examined the relationship between exchange rate and economic growth using the simultaneous equations method in Pakistan from 1976 to 2010. The findings of the present study show that an increase in the exchange rate has increased economic growth by strengthening export incentives, increasing investment volume, inflow of foreign direct investment, and strengthening import substitution.

4. Specifying the pattern

The research model consists of the following sections: household, labor market, intermediate goods producing firm, trade including exports of intermediate goods and imports of consumer goods, capital goods and intermediate inputs, oil, government and central bank, and the goods market settlement condition. Each section is explained in detail below, and the equations related to each section are presented.

4-1. Household

A point that is assumed in the context of modeling the household sector is the similarity of household preferences, which is called the assumption of household homogeneity or symmetry. This assumption is important because by analyzing the behavior of a typical

household, the results obtained can be generalized to other households. It is also assumed that the life of the household is unlimited. The household gains utility from consumption (C_t), holding real money balances $\left(\frac{M_t}{P_t}\right)$, and loses utility through labor supply (L_t). The household utility function is defined as follows (Tavakolian and Sarem, 2017):

$$U_t = E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t - H_t)^{1-\sigma_c}}{1-\sigma_c} + \frac{\chi_m}{1-\sigma_m} \left(\frac{M_t}{P_t}\right)^{1-\sigma_m} - \chi_l \frac{L_t^{1+\sigma_l}}{1+\sigma_l} \right] \quad (12)$$

Where, β is the subjective discount factor, C_t is the consumption index, M_t is the nominal money supply, P_t is the price index, and L_t is the household labor supply. σ_c is the inverse of the intertemporal substitution elasticity of consumption, σ_m is the interest elasticity of demand for real money balances, and σ_l is the inverse of the labor supply elasticity. H_t is the consumption habit variable and is defined as $H_t = hC_{t-1}$, where h is called the habit stability parameter.

The real household budget constraint is defined as follows:

$$C_t + I_t + m_t + b_t = w_t L_t + \frac{m_{t-1}}{\pi_t} + (1 + i_{t-1}) \frac{b_{t-1}}{\pi_t} + \left(r_t^k Z_t K_{t-1} - \Psi(Z_t) K_{t-1}\right) - ta_t \quad (13)$$

Where, $m_t = \frac{M_t}{P_t}$ is the real money balance, $b_t = \frac{B_t}{P_t}$ is the real amount of bonds, $w_t = \frac{W_t}{P_t}$ is the real wage rate, $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate, i_t is the nominal interest rate, r_t^k is the rate of return on capital, Z_t is the rate of capital utilization, K_{t-1} is the volume of capital, $\Psi(Z_t)$ is the cost of capital utilization, and ta_t is the tax paid by households.

The capital accumulation relationship is also defined as the second constraint of the household as follows:

$$K_t = (1-\delta) K_{t-1} + I_t \left[1 - S\left(\frac{\varepsilon_t^I I_t}{I_{t-1}}\right)\right] \quad (14)$$

Where, δ is the depreciation rate of private capital, ε_t^I is the investment impulse, and $S\left(\frac{I_t}{I_{t-1}}\right)$ is the investment adjustment cost function.

The household's goal is to find optimal paths for consumption, labor supply, real money balances, bonds, investment, capital utilization rate, and capital stock such that the household's utility function is maximized subject to the household's real budget constraints and the capital accumulation relationship. The Lagrange function of this problem is defined as:

$$\mathcal{L} = E_t \sum_{t=0}^{\infty} \beta^t \left\{ \left[\frac{(C_t - H_t)^{1-\sigma_c}}{1-\sigma_c} + \frac{\chi_m}{1-\sigma_m} \left(\frac{M_t}{P_t} \right)^{1-\sigma_m} - \chi_l \frac{{L_t}^{1+\sigma_l}}{1+\sigma_l} \right] + \lambda_t \left[w_t L_t + \frac{m_{t-1}}{\pi_t} + (1+i_{t-1}) \frac{b_{t-1}}{\pi_t} + \left(r_t^k Z_t K_{t-1} - \Psi(Z_t) K_{t-1} \right) - ta_t - C_t - I_t - m_t - b_t \right] + \mu_t \left[(1-\delta) K_{t-1} + I_t \left[1 - S\left(\frac{\varepsilon_t^I I_t}{I_{t-1}} \right) \right] - K_t \right] \right\} \quad (15)$$

Where, λ_t is the Lagrange coefficient associated with the real household budget constraint and μ_t is the Lagrange coefficient associated with the capital accumulation relationship.

The first-order optimal conditions for this problem are:

$$\frac{\partial \mathcal{L}}{\partial C_t} = 0 \rightarrow (C_t - H_t)^{-\sigma_c} - \lambda_t = 0 \quad (16)$$

$$\frac{\partial \mathcal{L}}{\partial L_t} = 0 \rightarrow -\chi_l {L_t}^{\sigma_l} + \lambda_t w_t = 0 \quad (17)$$

$$\frac{\partial \mathcal{L}}{\partial m_t} = 0 \rightarrow \chi_m (m_t)^{-\sigma_m} - \lambda_t + \beta E_t \frac{\lambda_{t+1}}{\pi_{t+1}} = 0 \quad (18)$$

$$\frac{\partial \mathcal{L}}{\partial b_t} = 0 \rightarrow -\lambda_t + \beta(1+i_t) E_t \frac{\lambda_{t+1}}{\pi_{t+1}} = 0 \quad (19)$$

$$\frac{\partial \mathcal{L}}{\partial I_t} = 0 \rightarrow -\lambda_t + \mu_t - \mu_t S\left(\frac{\varepsilon_t^I I_t}{I_{t-1}} \right) - \mu_t I_t \frac{\varepsilon_t^I}{I_{t-1}} S'\left(\frac{\varepsilon_t^I I_t}{I_{t-1}} \right) + \beta E_t \mu_{t+1} \varepsilon_{t+1}^I \left(\frac{I_{t+1}}{I_t} \right)^2 S'\left(\frac{\varepsilon_{t+1}^I I_{t+1}}{I_t} \right) = 0 \quad (20)$$

$$\frac{\partial \mathcal{L}}{\partial Z_t} = 0 \rightarrow r_t^k - \Psi'(Z_t) = 0 \quad (21)$$

$$\frac{\partial \mathcal{L}}{\partial K_t} = 0 \rightarrow E_t \beta^{t+1} \left[\lambda_{t+1} \left(r_{t+1}^k Z_{t+1} - \Psi(Z_{t+1}) \right) + \mu_{t+1}(1-\delta) \right] - \beta^t \mu_t = 0 \quad (22)$$

By placing Equation (16) in Equation (17), the labor supply equation is obtained as follows:

$$w_t = \frac{\chi_l {L_t}^{\sigma_l}}{(C_t - H_t)^{-\sigma_c}} \quad (23)$$

By placing the equation (19) in relation (18), the money demand equation is obtained as follows:

$$\frac{\chi_m (m_t)^{-\sigma_m}}{(C_t - H_t)^{-\sigma_c}} = \frac{i_t}{1+i_t} \quad (24)$$

By placing Equation (16) in Equation (19), the Euler equation of consumption is obtained as follows:

$$\beta(1+i_t)E_t \frac{(C_{t+1} - H_{t+1})^{-\sigma_c}}{\pi_{t+1}} = (C_t - H_t)^{-\sigma_c} \quad (25)$$

By placing Equation (19) in Equation (20), the investment equation is obtained as follows, in which, q_t is the final rate of Tobin and equal to the ratio of Lagrange coefficient of capital accumulation to Lagrange coefficient of budget constraint.

$$q_t - q_t S\left(\frac{\varepsilon_t^I I_t}{I_{t-1}}\right) - q_t I_t \frac{\varepsilon_t^I}{I_{t-1}} S'\left(\frac{\varepsilon_t^I I_t}{I_{t-1}}\right) + \frac{1}{R_t} E_t q_{t+1} \varepsilon_{t+1}^I \left(\frac{I_{t+1}}{I_t}\right)^2 S'\left(\frac{\varepsilon_{t+1}^I I_{t+1}}{I_t}\right) = 1 \quad (26)$$

By substituting equation (19) into equation (22), the equation for capital price dynamics is obtained as follows, where $\zeta_t = 1 + r_t^k + \Pi_t - \delta$ (which is actually the gross nominal interest rate of capital) and in this relation $\Pi_t = \pi_t - 1$, which is the net inflation rate.

$$E_t \frac{\pi_{t+1}}{\zeta_t}\left[r_{t+1}^k Z_{t+1} - \Psi(Z_{t+1}) + q_{t+1}(1-\delta)\right] = q_t \quad (27)$$

According to research (Nakhli *et al.*, 2020), household consumption is assumed to be a combination of domestic and imported goods, and accordingly, the household consumption index is expressed as follows:

$$C_t = \left[\alpha_c^{\frac{1}{\theta_c}} C_t^{d\,\frac{\theta_c - 1}{\theta_c}} + (1-\alpha_c)^{\frac{1}{\theta_c}} C_t^{m\,\frac{\theta_c - 1}{\theta_c}}\right]^{\frac{\theta_c}{\theta_c - 1}} \quad (28)$$

Where, C_t^d is the index of consumption of domestic goods, C_t^m is the index of consumption of imported goods, α_c is the share of domestic consumer goods in the household consumption index, and θ_c is the elasticity of substitution between domestic consumer goods and imported consumer goods. The household's goal is to find the optimal combination of consumption of domestic goods and imported goods, such that total expenditure is minimized. The mathematical form of this problem is as follows:

$$\min_{C_t^d, C_t^m} \quad P_t C_t - P_t^{cd} C_t^d - P_t^{cm} C_t^m \quad (29)$$

$$s.t. \quad C_t = \left[\alpha_c^{\frac{1}{\theta_c}} C_t^{d\,\frac{\theta_c - 1}{\theta_c}} + (1-\alpha_c)^{\frac{1}{\theta_c}} C_t^{m\,\frac{\theta_c - 1}{\theta_c}}\right]^{\frac{\theta_c}{\theta_c - 1}}$$

From solving this problem, the optimal demand functions for the consumption index of domestic and imported goods are obtained as follows:

$$C_t^d = \alpha_c \left(\frac{P_t^{cd}}{P_t}\right)^{-\theta_c} C_t \quad (30)$$

$$C_t^m = (1-\alpha_c)\left(\frac{P_t^{cm}}{P_t}\right)^{-\theta_c} C_t \quad (31)$$

Where, P_t^{cd} is the price index of domestic consumer goods, P_t^{cm} is the price index of imported consumer goods, and P_t is the price index of total consumer goods.

By substituting the optimal demand functions into equation (28), the total price index of consumer goods is obtained as follows:

$$P_t = \left[\alpha_c \left(P_t^{cd}\right)^{1-\theta_c} + (1-\alpha_c)(P_t^{cm})^{1-\theta_c}\right]^{\frac{1}{1-\theta_c}} \quad (32)$$

According to research (Nakhli *et al.*, 2020), household investment is assumed to be a combination of domestic and imported goods, and accordingly, the household investment index is expressed as follows:

$$I_t = \left[\alpha_I^{\frac{1}{\theta_I}} I_t^{d\,\frac{\theta_I-1}{\theta_I}} + (1-\alpha_I)^{\frac{1}{\theta_I}} I_t^{m\,\frac{\theta_I-1}{\theta_I}}\right]^{\frac{\theta_I}{\theta_I-1}} \quad (33)$$

Where, I_t^d is the domestic investment index, I_t^m is the imported investment index, α_I is the share of domestic capital goods in the household investment index, and θ_I is the elasticity of substitution between domestic capital goods and imported capital goods. The household's goal is to find the optimal combination of domestic and imported capital goods investment, such that total expenditure is minimized. The mathematical form of this problem is as follows:

$$\min_{I_t^d, I_t^m} \quad P_t I_t - P_t^{Id} I_t^d - P_t^{Im} I_t^m \quad (34)$$

$$s.t. \quad I_t = \left[\alpha_I^{\frac{1}{\theta_I}} I_t^{d\,\frac{\theta_I-1}{\theta_I}} + (1-\alpha_I)^{\frac{1}{\theta_I}} I_t^{m\,\frac{\theta_I-1}{\theta_I}}\right]^{\frac{\theta_I}{\theta_I-1}}$$

From solving this problem, the optimal demand functions for the domestic and imported goods investment index are obtained as follows:

$$I_t^d = \alpha_I \left(\frac{P_t^{Id}}{P_t}\right)^{-\theta_I} I_t \quad (35)$$

$$I_t^m = (1-\alpha_I)\left(\frac{P_t^{Im}}{P_t}\right)^{-\theta_I} I_t \quad (36)$$

Where, P_t^{Id} is the domestic capital goods price index, P_t^{Im} is the imported capital goods price index, and P_t is the total capital goods price index.

By substituting the optimal demand functions into equation (33), the total price index of capital goods is obtained as follows:

$$P_t = \left[\alpha_I \left(P_t^{Id}\right)^{1-\theta_I} + (1-\alpha_I)(P_t^{Im})^{1-\theta_I}\right]^{\frac{1}{1-\theta_I}} \quad (37)$$

4-2. Labor market

Inspired by the research (Erseg *et al.*, 2000), the labor market is a monopolistic competition market where households supply their differentiated labor to intermediary firms. Each household is a monopolistic supplier of labor who can determine its own wage and determine the amount of labor supplied in proportion to the determined wage. According to the method (Digit and Stiglitz, 1977), it is assumed that there is a labor aggregator who rents differentiated labor from households and transforms them into a homogeneous factor of production L_t using the following technology:

$$L_t = \left(\int_0^1 L_t(i)^{\frac{\theta_w-1}{\theta_w}} di\right)^{\frac{\theta_w}{\theta_w-1}} \quad (38)$$

where θ_w is the constant substitution elasticity between different labor forces. The goal of the labor aggregate is to choose the amount of labor force such that its profit is maximized.

The above problem is expressed as follows:

$$\max_{L_t(i)} \quad W_t L_t - \int_0^1 W_t(i) L_t(i)\, di \quad (39)$$

$$s.t. \quad L_t = \left(\int_0^1 L_t(i)^{\frac{\theta_w-1}{\theta_w}} di\right)^{\frac{\theta_w}{\theta_w-1}}$$

From solving this problem, the optimal aggregate demand function for labor from the labor force of the i house hold is obtained as follows:

$$L_t(i) = \left(\frac{W_t(i)}{W_t}\right)^{-\theta_w} L_t \quad (40)$$

By substituting the optimal demand function into equation (38), the total nominal wage index is obtained as follows:

$$W_t = \left(\int_0^1 W_t(i)^{1-\theta_w} di\right)^{\frac{1}{1-\theta_w}} \quad (41)$$

Households are assumed to be wage setters in the labor market because they supply their labor under monopolistic competition, but it is not possible for them to always adjust their wages optimally in each period. The probability that a representative household can adjust its wages optimally is $(1-\upsilon_w)$, but households that do not have such an opportunity to adjust their wages are assumed to set their wages for the next period according to a rule of thumb, adjusted for inflation:

$$W_{t+1}(i) = (\pi_t)^{\tau_w} W_t(i) \quad (42)$$

where τ_w is the degree of wage indexation. The percentage of households that do not have the opportunity to adjust their wages optimally will index their wages according to equation (42) until an opportunity for optimal adjustment arises in future periods. To determine their optimal wage, households behave in a way that maximizes their utility from work, assuming that they will not be able to adjust their wages for several future periods with probability υ_w. The mathematical form of this problem is as follows:

$$\max_{W_t(i)} \quad E_t \sum_{s=0}^{\infty} (\beta \upsilon_w)^s \Delta_{s,t+s} \left[-\frac{\chi_l}{1+\sigma_l} L_{t+s}(i)^{1+\sigma_l} + \lambda_{t+s} W_{t+s}(i) L_{t+s}(i) \right] \quad (43)$$

$$s.t. \quad L_{t+s}(i) = \left(\frac{W_{t+s}(i)}{W_{t+s}} \right)^{-\theta_w} L_{t+s}$$

Given that in each period, υ_w percent of households cannot adjust their wages and only $(1-\upsilon_w)$ percent of them will be able to adjust their wages, the total nominal wage index is defined as follows:

$$W_t = \left[(1-\upsilon_w)(W_t^*)^{1-\theta_w} + \upsilon_w ((\pi_{t-1})^{\tau_w} W_{t-1})^{1-\theta_w} \right]^{\frac{1}{1-\theta_w}} \quad (44)$$

Using the first-order optimal condition of problem (43) and equation (44), the wage Phillips curve is obtained as follows:

$$\hat{w}_t = \frac{\beta}{1+\beta} E_t \hat{w}_{t+1} + \frac{1}{1+\beta} \hat{w}_{t-1} + \frac{\beta}{1+\beta} E_t \hat{\pi}_{t+1} - \frac{1+\beta\tau_w}{1+\beta} \hat{\pi}_t + \frac{\tau_w}{1+\beta} \hat{\pi}_{t-1} - \frac{1}{1+\beta} \frac{(1-\beta\upsilon_w)(1-\upsilon_w)}{\upsilon_w} \left[\hat{w}_t - \sigma_l \hat{l}_t - \frac{\sigma_c}{1-h} (\hat{c}_t - h\hat{c}_{t-1}) \right] \quad (45)$$

4-3. Intermediate goods manufacturing firm

According to the research (Block and Brown, 2018), the intermediary firm produces the intermediate good $Y_t^{no}(j)$ using private capital input $K_{t-1}(j)$, labor input $L_t(j)$, government capital input KG_{t-1} and intermediate inputs $In_t(j)$. The production function of the intermediary firm is as follows:

$$Y_t^{no}(j) = A_t \left(Z_t K_{t-1}(j) \right)^{\varphi} L_t(j)^{\eta} {KG_{t-1}}^{\theta_g} In_t(j)^{1-\varphi-\eta} \quad (46)$$

Where, φ is the production elasticity of private capital input, η is the production elasticity of labor input, θ_g is the production elasticity of public capital input, $1-\varphi-\eta$ is the production elasticity of intermediate inputs, and $Z_t K_{t-1}(j)$ is the effective capital stock.

The goal of the intermediary firm is to find optimal demand functions for factors of production by minimizing the cost of production for a given level of output. The mathematical form of this problem is as follows:

$$\min_{K_{t-1}(j), L_t(j), In_t(j)} \quad r_t^k Z_t K_{t-1}(j) + W_t L_t(j) + P_t^{In} In_t(j)$$

(47)

$$s.t. \qquad Y_t^{no}(j) = A_t\left(Z_t K_{t-1}(j)\right)^{\varphi} L_t(j)^{\eta} {KG_{t-1}}^{\theta_g} In_t(j)^{1-\varphi-\eta}$$

From solving this problem, the optimal demand functions for the factors of production (private capital, labor, and intermediate inputs) are obtained as follows:

$$K_{t-1}(j) = \varphi mc_t \frac{Y_t^{no}(j)}{r_t^k Z_t} \tag{48}$$

$$L_t(j) = \eta mc_t \frac{Y_t^{no}(j)}{W_t} \tag{49}$$

$$In_t(j) = (1-\varphi-\eta) mc_t Y_t^{no}(j) \frac{P_t}{P_t^{In}} \tag{50}$$

By substituting relations (48), (49), and (50) into relation (46), the final cost is obtained as follows:

$$mc_t = \frac{1}{A_t}\left(\frac{1}{\varphi}\right)^{\varphi}\left(\frac{1}{\eta}\right)^{\eta}\left(\frac{1}{1-\varphi-\eta}\right)^{1-\varphi-\eta} {r_t^k}^{\varphi} {W_t}^{\eta} {KG_{t-1}}^{-\theta_g}\left(\frac{P_t^{In}}{P_t}\right)^{1-\varphi-\eta} \tag{51}$$

According to research (Nakhli *et al.*, 2020), it is assumed that a firm producing intermediate goods supplies its product to the domestic and foreign markets:

$$Y_t^{no} = \left[\alpha_y^{\frac{1}{\theta_y}} Y_t^{d\,\frac{\theta_y+1}{\theta_y}} + \left(1-\alpha_y\right)^{\frac{1}{\theta_y}} Y_t^{x\,\frac{\theta_y+1}{\theta_y}}\right]^{\frac{\theta_y}{\theta_y+1}} \tag{52}$$

Where, Y_t^d is the index of intermediate goods supplied to the domestic market, Y_t^x is the index of intermediate goods supplied to foreign markets, α_y is the share of intermediate goods supplied to the domestic market in the intermediate goods index of the intermediary firm, and θ_y is the elasticity of substitution between intermediate goods supplied to the domestic market and intermediate goods supplied to foreign markets. The objective of the intermediary firm is to find the optimal combination of supplies of intermediate goods to the domestic market and foreign markets, such that total costs are minimized. The mathematical form of this problem is as follows:

$$\min_{Y_t^d, Y_t^x} \quad P_t^y Y_t^{no} - P_t^d Y_t^d - P_t^x Y_t^x \tag{53}$$

$$s.t. \qquad Y_t^{no} = \left[\alpha_y^{\frac{1}{\theta_y}} Y_t^{d\,\frac{\theta_y+1}{\theta_y}} + \left(1-\alpha_y\right)^{\frac{1}{\theta_y}} Y_t^{x\,\frac{\theta_y+1}{\theta_y}}\right]^{\frac{\theta_y}{\theta_y+1}}$$

From solving this problem, the optimal supply functions for the index of intermediate goods supplied to the domestic market and supplied to foreign markets are obtained as follows:

$$Y_t^d = \alpha_y \left(\frac{P_t^d}{P_t^y}\right)^{\theta_y} Y_t^{no} \quad (54)$$

$$Y_t^x = (1-\alpha_y)\left(\frac{e_t P_t^x}{P_t^y}\right)^{\theta_y} Y_t^{no} \quad (55)$$

Where, P_t^d is the price index of intermediate goods supplied to the domestic market, P_t^x is the price index of intermediate goods supplied to foreign markets, and P_t^y is the price index of total intermediate goods.

By substituting the optimal supply functions into equation (52), the total price index of intermediate goods is obtained as follows:

$$P_t^y = \left[\alpha_y (P_t^d)^{1+\theta_y} + (1-\alpha_y)(e_t P_t^x)^{1+\theta_y}\right]^{\frac{1}{1+\theta_y}} \quad (56)$$

The market for the sale of products produced by intermediary firms in the domestic and foreign markets is of a monopolistic competition type, and these firms set the price of their products above the marginal cost. According to the method (Dixit and Stiglitz, 1977), it is assumed that there is an aggregator of intermediate goods supplied to the domestic market, which aggregates the supply of all intermediary firms to the domestic market according to the following technological relationship and supplies it to the market at a single price:

$$Y_t^d = \left(\int_0^1 Y_t^d(j)^{\frac{\theta_d-1}{\theta_d}} dj\right)^{\frac{\theta_d}{\theta_d-1}} \quad (57)$$

Where, θ_d is the elasticity of substitution of the products of intermediate firms supplying to the domestic market. The objective of the aggregator of intermediate goods supplied to the domestic market is to choose the quantity of intermediate goods supplied to the domestic market in such a way that its profit is maximized.

The above problem is expressed as follows:

$$\max_{Y_t^d(j)} \quad P_t^d Y_t^d - \int_0^1 P_t^d(j) Y_t^d(j) dj \quad (58)$$

$$s.t. \quad Y_t^d = \left(\int_0^1 Y_t^d(j)^{\frac{\theta_d-1}{\theta_d}} dj\right)^{\frac{\theta_d}{\theta_d-1}}$$

From solving this problem, the optimal demand function of the aggregate of intermediate goods supplied to the domestic market from the intermediate goods supplied to the domestic market of the j intermediary firm is obtained as follows:

$$Y_t^d(j) = \left(\frac{P_t^d(j)}{P_t^d}\right)^{-\theta_d} Y_t^d \quad (59)$$

By substituting the optimal demand function into equation (57), the price index of intermediate goods supplied to the domestic market is obtained as follows:

$$P_t^d = \left(\int_0^1 P_t^d(j)^{1-\theta_d}\, dj\right)^{\frac{1}{1-\theta_d}} \tag{60}$$

According to the method (Calvo, 1983) and due to the costs of price adjustment, intermediary firms supplying products to the domestic market cannot always set the price of their products optimally in a monopolistic competitive market. Intermediary firms supplying products to the domestic market are divided into two categories. The first category includes $(1-\upsilon_d)$ percent of firms that are able to set the optimal price in each period, which is also determined based on profit maximization in a time period. The second category includes υ_d percent of firms that are unable to set their optimal price and, therefore, their price is not obtained from maximizing the profit function. When an intermediary firm supplying products to the domestic market fails to set the price of its product at the optimal level, it sets the price of its products for the next period according to the rules of thumb and based on the adjusted inflation rate:

$$P_{t+1}^d(j) = \left(\pi_t^d\right)^{\tau_d} P_t^d(j) \tag{61}$$

Where, τ_d is the price indexation degree of the intermediary firm supplying the product to the domestic market. The intermediary firm supplying the product to the domestic market sets the price of its products in a monopolistic competition market, in accordance with the optimization behavior with the profit maximization approach, at a level higher than the marginal cost. This problem is expressed as follows:

$$\max_{P_t^d(j)} \quad E_t \sum_{s=0}^{\infty} (\beta\upsilon_d)^s \Delta_{s,t+s} \left[\frac{P_{t+s}^d(j)}{P_{t+s}^d} Y_{t+s}^d(j) - mc_{t+s} Y_{t+s}^d(j)\right] \tag{62}$$

$$s.t. \quad Y_{t+s}^d(j) = \left(\frac{P_{t+s}^d(j)}{P_{t+s}^d}\right)^{-\theta_d} Y_{t+s}^d$$

$$\begin{aligned}
&P_{t+1}^d(j) = \left(\pi_t^d\right)^{\tau_d} P_t^d(j)\\
&P_{t+2}^d(j) = \left(\pi_{t+1}^d\right)^{\tau_d} P_{t+1}^d(j) = \left(\pi_{t+1}^d\right)^{\tau_d}\left(\pi_t^d\right)^{\tau_d} P_t^d(j)\\
&P_{t+3}^d(j) = \left(\pi_{t+2}^d\right)^{\tau_d} P_{t+2}^d(j) = \left(\pi_{t+2}^d\right)^{\tau_d}\left(\pi_{t+1}^d\right)^{\tau_d}\left(\pi_t^d\right)^{\tau_d} P_t^d(j)\\
&\vdots\\
&P_{t+s}^d(j) = \left(\pi_{t+s-1}^d\right)^{\tau_d} P_{t+s-1}^d(j)\\
&\qquad = \left(\pi_{t+s-1}^d\right)^{\tau_d}\left(\pi_{t+s-2}^d\right)^{\tau_d} \times \ldots \times \left(\pi_{t+2}^d\right)^{\tau_d}\left(\pi_{t+1}^d\right)^{\tau_d}\left(\pi_t^d\right)^{\tau_d} P_t^d(j)
\end{aligned} \tag{63}$$

Given this trend, the relationship between the current price and the price in the next period s can be written as follows:

$$P_{t+s}^d(j) = \prod_{k=1}^{s}\left(\pi_{t+k-1}^d\right)^{\tau_d} P_t^d(j) \tag{64}$$

By substituting equation (64) into equation (62), the unconstrained form of this optimization problem will be as follows:

$$\max_{P_t^d(j)} \left\{ E_t \sum_{s=0}^{\infty} (\beta \upsilon_d)^s \Delta_{s,t+s} \left[\frac{\prod_{k=1}^{s} (\pi_{t+k-1}^d)^{\tau_d} P_t^d(j)}{P_{t+s}^d} \left(\frac{\prod_{k=1}^{s} (\pi_{t+k-1}^d)^{\tau_d} P_t^d(j)}{P_{t+s}^d} \right)^{-\theta_d} Y_{t+s}^d \right. \right.$$
$$\left. \left. - mc_{t+s} \left(\frac{\prod_{k=1}^{s} (\pi_{t+k-1}^d)^{\tau_d} P_t^d(j)}{P_{t+s}^d} \right)^{-\theta_d} Y_{t+s}^d \right] \right\} \quad (65)$$

By setting the optimal price as $P_t^d(j) = P_t^{d*}$, the first-order optimal condition of the above problem after simplification is as follows:

$$\frac{P_t^{d*}}{P_t^d} = \frac{\theta_d}{\theta_d - 1} \frac{E_t \sum_{s=0}^{\infty} (\beta \upsilon_d)^s \Delta_{s,t+s} mc_{t+s} \left(\frac{P_{t+s}^d}{P_t^d} \right)^{\theta_d} \left(\frac{P_{t-1}^d}{P_{t+s-1}^d} \right)^{\tau_d \theta_d} Y_{t+s}^d}{E_t \sum_{s=0}^{\infty} (\beta \upsilon_d)^s \Delta_{s,t+s} \left(\frac{P_{t+s}^d}{P_t^d} \right)^{\theta_d - 1} \left(\frac{P_{t-1}^d}{P_{t+s-1}^d} \right)^{\tau_d (\theta_d - 1)} Y_{t+s}^d} \quad (66)$$

Given that $(1 - \upsilon_d)$ percent of intermediary firms supplying products to the domestic market are able to determine the optimal price in each period and υ_d percent of intermediary firms supplying products to the domestic market are unable to determine their optimal price, the price index of intermediary goods supplied to the domestic market is defined as follows:

$$P_t^d = \left[(1 - \upsilon_d) \left(P_t^{d*} \right)^{1-\theta_d} + \upsilon_d \left((\pi_{t-1}^d)^{\tau_d} P_{t-1}^d \right)^{1-\theta_d} \right]^{\frac{1}{1-\theta_d}} \quad (67)$$

The linearization of equation (67) is as follows:

$$\hat{P}_t^d = (1 - \upsilon_d) \hat{P}_t^{d*} + \upsilon_d \tau_d \hat{\pi}_{t-1}^d + \upsilon_d \hat{P}_{t-1}^d \quad (68)$$

By subtracting the expression $\upsilon_d \hat{P}_t^d$ from both sides of equation (68), we have:

$$(1 - \upsilon_d) \hat{P}_t^d = (1 - \upsilon_d) \hat{P}_t^{d*} + \upsilon_d \tau_d \hat{\pi}_{t-1}^d - \upsilon_d \hat{\pi}_t^d \quad (69)$$

Therefore, from equation (69) we can conclude:

$$\hat{P}_t^{d*} - \hat{P}_t^d = \frac{\upsilon_d}{1 - \upsilon_d} \left(\hat{\pi}_t^d - \tau_d \hat{\pi}_{t-1}^d \right) \quad (70)$$

By defining $\mu = \frac{\theta_d}{\theta_d - 1}$ and $Q_t = \frac{P_t^{d*}}{P_t^d}$, the linearization of equation (66) can be written as follows:

$$\hat{P}_t^{d*} - \hat{P}_t^d = (1 - \beta \upsilon_d) E_t \sum_{s=0}^{\infty} (\beta \upsilon_d)^s \left[\widehat{mc}_{t+s} + \left(\hat{P}_{t+s}^d - \hat{P}_t^d \right) + \tau_d \left(\hat{P}_{t-1}^d - \hat{P}_{t+s-1}^d \right) \right] \quad (71)$$

If the expression on the right side of equation (71) is expanded to the first two terms, we will have:

$$\hat{P}_t^{d*} - \hat{P}_t^d = (1-\beta\upsilon_d)\widehat{mc}_t + (1-\beta\upsilon_d)(\beta\upsilon_d)E_t\left[\widehat{mc}_{t+1} + \left(\hat{P}_{t+1}^d - \hat{P}_t^d\right) + \tau_d\left(\hat{P}_{t-1}^d - \hat{P}_t^d\right)\right] \quad (72)$$

As a result:

$$\hat{P}_t^{d*} - \hat{P}_t^d = (1-\beta\upsilon_d)\widehat{mc}_t + \beta\upsilon_d E_t\left[\widehat{mc}_{t+1} + \left(\hat{P}_{t+1}^d - \hat{P}_t^d\right) + \tau_d\left(\hat{P}_{t-1}^d - \hat{P}_t^d\right)\right] - (\beta\upsilon_d)^2 E_t\left[\widehat{mc}_{t+1} + \left(\hat{P}_{t+1}^d - \hat{P}_t^d\right) + \tau_d\left(\hat{P}_{t-1}^d - \hat{P}_t^d\right)\right] \quad (73)$$

Assuming that $(\beta\upsilon_d)^2 \cong 0$, then equation (73) can be written as follows:

$$\hat{P}_t^{d*} - \hat{P}_t^d = (1-\beta\upsilon_d)\widehat{mc}_t + \beta\upsilon_d E_t\left[\widehat{mc}_{t+1} + \left(\hat{P}_{t+1}^d - \hat{P}_t^d\right) + \tau_d\left(\hat{P}_{t-1}^d - \hat{P}_t^d\right)\right] \quad (74)$$

On the other hand, given that $Q_t = \frac{P_t^{d*}}{P_t^d} = \mu mc_t$, therefore $\widehat{mc}_{t+1} = \hat{P}_{t+1}^{d*} - \hat{P}_{t+1}^d$ and we can write equation (74) as follows:

$$\hat{P}_t^{d*} - \hat{P}_t^d = (1-\beta\upsilon_d)\widehat{mc}_t + \beta\upsilon_d E_t\left[\hat{P}_{t+1}^{d*} - \hat{P}_{t+1}^d + \left(\hat{P}_{t+1}^d - \hat{P}_t^d\right) + \tau_d\left(\hat{P}_{t-1}^d - \hat{P}_t^d\right)\right] \quad (75)$$

On the other hand, by substituting equation (70) into equation (75), we can arrive at the following expression:

$$\frac{\upsilon_d}{1-\upsilon_d}\left(\hat{\pi}_t^d - \tau_d\hat{\pi}_{t-1}^d\right) = (1-\beta\upsilon_d)\widehat{mc}_t + \beta\upsilon_d\frac{\upsilon_d}{1-\upsilon_d}E_t\left[\hat{\pi}_{t+1}^d - \tau_d\hat{\pi}_t^d\right] + \beta\upsilon_d E_t\hat{\pi}_{t+1}^d - \beta\upsilon_d\tau_d\hat{\pi}_t^d \quad (76)$$

By simplifying equation (76), the new Phillips Keynesian curve of the inflation index of the price of intermediate goods supplied to the domestic market is obtained as follows:

$$\hat{\pi}_t^d = \frac{\tau_d}{1+\beta\tau_d}\hat{\pi}_{t-1}^d + \frac{\beta}{1+\beta\tau_d}E_t\hat{\pi}_{t+1}^d + \frac{(1-\beta\upsilon_d)(1-\upsilon_d)}{\upsilon_d(1+\beta\tau_d)}\widehat{mc}_t \quad (77)$$

According to research (Nakhli *et al.*, 2020), a firm producing intermediate goods demands its intermediate inputs from the domestic market and foreign markets:

$$In_t = \left[\alpha_{In}^{\frac{1}{\theta_{In}}}In_t^{d\,\frac{\theta_{In}-1}{\theta_{In}}} + (1-\alpha_{In})^{\frac{1}{\theta_{In}}}In_t^{m\,\frac{\theta_{In}-1}{\theta_{In}}}\right]^{\frac{\theta_{In}}{\theta_{In}-1}} \quad (78)$$

Where, In_t^d is the index of intermediate inputs demanded from the domestic market, In_t^m is the index of intermediate inputs demanded from foreign markets, α_{In} is the share of intermediate inputs demanded from the domestic market in the intermediate input index of the intermediary firm, and θ_{In} is the elasticity of substitution between intermediate inputs

demanded from the domestic market and intermediate inputs demanded from foreign markets. The objective of the intermediary firm is to find the optimal combination of demand for intermediate inputs from the domestic market and foreign markets, such that total expenditure is minimized. The mathematical form of this problem is as follows:

$$\min_{In_t^d, In_t^m} \quad P_t^{In} In_t - P_t^{Ind} In_t^d - P_t^{Inm} In_t^m \tag{79}$$

$$s.t. \qquad In_t = \left[\alpha_{In}^{\frac{1}{\theta_{In}}} In_t^{d\,\frac{\theta_{In}-1}{\theta_{In}}} + (1-\alpha_{In})^{\frac{1}{\theta_{In}}} In_t^{m\,\frac{\theta_{In}-1}{\theta_{In}}}\right]^{\frac{\theta_{In}}{\theta_{In}-1}}$$

From solving this problem, the optimal demand functions for the index of intermediate inputs demanded from the domestic market and demanded from foreign markets are obtained as follows:

$$In_t^d = \alpha_{In}\left(\frac{P_t^{Ind}}{P_t^{In}}\right)^{-\theta_{In}} In_t \tag{80}$$

$$In_t^m = (1-\alpha_{In})\left(\frac{P_t^{Inm}}{P_t^{In}}\right)^{-\theta_{In}} In_t \tag{81}$$

Where, P_t^{Ind} is the price index of intermediate inputs demanded from the domestic market, P_t^{Inm} is the price index of intermediate inputs demanded from foreign markets, and P_t^{In} is the price index of total intermediate inputs.

By substituting the optimal demand functions into equation (78), the total price index of intermediate inputs is obtained as follows:

$$P_t^{In} = \left[\alpha_{In}\left(P_t^{Ind}\right)^{1-\theta_{In}} + (1-\alpha_{In})(P_t^{Inm})^{1-\theta_{In}}\right]^{\frac{1}{1-\theta_{In}}} \tag{82}$$

4-4. Trade

4-4-1. Export

Firms producing intermediate goods, despite supplying part of their products to the domestic market, export part of their products to foreign markets and, since foreign markets are monopolistically competitive, they set a price for their products higher than the marginal cost. According to the method (Dixit and Stiglitz, 1977), it is assumed that there is an aggregator of intermediate goods supplied to foreign markets that aggregates the supply of all intermediate firms to foreign markets according to the following technological relationship and supplies the market with a single price:

$$Y_t^x = \left(\int_0^1 Y_t^x(j)^{\frac{\theta_x-1}{\theta_x}} dj\right)^{\frac{\theta_x}{\theta_x-1}} \tag{83}$$

Where, θ_x is the elasticity of substitution of the products of intermediate firms supplying to foreign markets. The objective of the aggregate of intermediate goods supplied to foreign

markets is to choose the quantity of intermediate goods supplied to foreign markets in such a way that its profit is maximized.

The above problem is expressed as follows:

$$\max_{Y_t^x(j)} \quad P_t^x Y_t^x - \int_0^1 P_t^x(j) Y_t^x(j) dj \tag{84}$$

$$s.t. \qquad Y_t^x = \left(\int_0^1 Y_t^x(j)^{\frac{\theta_x - 1}{\theta_x}} dj \right)^{\frac{\theta_x}{\theta_x - 1}}$$

From solving this problem, the optimal aggregate demand function for intermediate goods supplied to foreign markets from intermediate goods supplied to foreign markets of the j exporting firm is obtained as follows:

$$Y_t^x(j) = \left(\frac{P_t^x(j)}{P_t^x} \right)^{-\theta_x} Y_t^x \tag{85}$$

By substituting the optimal demand function into equation (83), the price index of intermediate goods supplied to foreign markets is obtained as follows:

$$P_t^x = \left(\int_0^1 P_t^x(j)^{1-\theta_x} dj \right)^{\frac{1}{1-\theta_x}} \tag{86}$$

According to the method (Calvo, 1983) and due to the costs of price adjustment, intermediary firms supplying products to foreign markets cannot always set the price of their products optimally in a foreign monopolistic competitive market. Intermediary firms supplying products to foreign markets are divided into two categories. The first category includes $(1 - \upsilon_x)$ percent of firms that are able to set the optimal price in each period, which is also determined based on profit maximization in a time period. The second category includes υ_x percent of firms that are unable to set their optimal price and, therefore, their price is not obtained from maximizing the profit function. When an intermediary firm supplying products to foreign markets fails to set the price of its product at the optimal level, it sets the price of its products for the next period according to the rules of thumb and based on the adjusted inflation rate:

$$P_{t+1}^x(j) = (\pi_t^x)^{\tau_x} P_t^x(j) \tag{87}$$

Where, τ_x is the price indexation degree of the intermediary firm supplying the product to foreign markets. The intermediary firm supplying the product to foreign markets sets the price of its products in the foreign monopolistic competition market, in accordance with the optimization behavior with the profit maximization approach, at a level higher than the marginal cost. This problem is expressed as follows:

$$\max_{P_t^x(j)} \quad E_t \sum_{s=0}^{\infty} (\beta \upsilon_x)^s \Delta_{s,t+s} \left[\frac{P_{t+s}^x(j)}{P_{t+s}^x} Y_{t+s}^x(j) - mc_{t+s}^x Y_{t+s}^x(j) \right] \tag{88}$$

$$s.t. \qquad Y_{t+s}^x(j) = \left(\frac{P_{t+s}^x(j)}{P_{t+s}^x} \right)^{-\theta_x} Y_{t+s}^x$$

By setting the optimal price as $P_t^x(j) = P_t^{x*}$, the first-order optimal condition of the above problem after simplification is as follows:

$$\frac{P_t^{x*}}{P_t^x} = \frac{\theta_x}{\theta_x - 1} \frac{E_t \sum_{s=0}^{\infty} (\beta \upsilon_x)^s \Delta_{s,t+s} mc_{t+s}^x \left(\frac{P_{t+s}^x}{P_t^x}\right)^{\theta_x} \left(\frac{P_{t-1}^x}{P_{t+s-1}^x}\right)^{\tau_x \theta_x} Y_{t+s}^x}{E_t \sum_{s=0}^{\infty} (\beta \upsilon_x)^s \Delta_{s,t+s} \left(\frac{P_{t+s}^x}{P_t^x}\right)^{\theta_x - 1} \left(\frac{P_{t-1}^x}{P_{t+s-1}^x}\right)^{\tau_x(\theta_x - 1)} Y_{t+s}^x} \quad (89)$$

Given that $(1 - \upsilon_x)$ percent of intermediary firms supplying products to foreign markets are able to determine the optimal price in each period and υ_x percent of intermediary firms supplying products to foreign markets are unable to determine their optimal price, the price index of intermediary goods supplied to foreign markets is defined as follows:

$$P_t^x = \left[(1 - \upsilon_x)(P_t^{x*})^{1-\theta_x} + \upsilon_x((\pi_{t-1}^x)^{\tau_x} P_{t-1}^x)^{1-\theta_x}\right]^{\frac{1}{1-\theta_x}} \quad (90)$$

Using relations (89) and (90), the new Keynesian Phillips curve of the inflation index of the price of intermediate goods supplied to foreign markets is obtained as follows:

$$\hat{\pi}_t^x = \frac{\tau_x}{1 + \beta\tau_x} \hat{\pi}_{t-1}^x + \frac{\beta}{1 + \beta\tau_x} E_t \hat{\pi}_{t+1}^x + \frac{(1 - \beta\upsilon_x)(1 - \upsilon_x)}{\upsilon_x(1 + \beta\tau_x)} \widehat{mc}_t^x \quad (91)$$

The aggregator of intermediate goods supplied to foreign markets purchases the intermediate goods needed for export from the aggregator of intermediate goods supplied to the domestic market at the price P_t^d and sells them in foreign markets at the price P_t^x. International sanctions in the export sector of intermediate goods increase transaction costs (receiving and transferring foreign exchange from exports, transportation, insurance, etc.) in the process of exporting intermediate goods. Therefore, the real final cost of the aggregator of intermediate goods supplied to foreign markets is as follows:

$$mc_t^x = \frac{P_t^d}{e_t P_t^x} S_t^x \quad (92)$$

Where, S_t^x is the additional transaction costs resulting from the imposition of international sanctions that increase the real marginal cost of intermediate goods supplied to foreign markets and is assumed to follow a first-order autoregressive process. International sanctions $(sanc_t)$ increase transaction costs in the intermediate goods export sector through the parameter SSX.

$$S_t^x = \rho_x S_{t-1}^x + (1 - \rho_x)\bar{S}^x + SSX sanc_t + \varepsilon_t^x \quad (93)$$

4-4-2. Import

Importing firms operate in three sectors: importing consumer goods, importing capital goods, and importing intermediate inputs.

Consumer goods importers purchase consumer goods needed for import into the country from world markets and sell them to domestic consumers. It is assumed that the market for imported consumer goods in the country is monopolistically competitive and that importing

firms set the price of consumer goods above marginal cost and sell them. According to the method (Dixit and Stiglitz, 1977), it is assumed that there is an aggregator of imported consumer goods that purchases consumer goods from all importing firms and aggregates them according to the following technological relationship and supplies them to the domestic consumer goods market at a single price:

$$C_t^m = \left(\int_0^1 C_t^m(j)^{\frac{\theta_{cm}-1}{\theta_{cm}}} dj \right)^{\frac{\theta_{cm}}{\theta_{cm}-1}} \quad (94)$$

Where, θ_{cm} is the elasticity of substitution of imported consumer goods of different importing firms. The objective of the imported consumer goods aggregator is to choose the quantity of imported consumer goods such that its profit is maximized.
The above problem is expressed as follows:

$$\max_{C_t^m(j)} \quad P_t^{cm} C_t^m - \int_0^1 P_t^{cm}(j) C_t^m(j) dj \quad (95)$$

$$s.t. \quad C_t^m = \left(\int_0^1 C_t^m(j)^{\frac{\theta_{cm}-1}{\theta_{cm}}} dj \right)^{\frac{\theta_{cm}}{\theta_{cm}-1}}$$

From solving this problem, the optimal aggregate demand function for imported consumer goods from the consumer goods of the j importing firm is obtained as follows:

$$C_t^m(j) = \left(\frac{P_t^{cm}(j)}{P_t^{cm}} \right)^{-\theta_{cm}} C_t^m \quad (96)$$

By substituting the optimal demand function into equation (94), the price index of imported consumer goods is obtained as follows:

$$P_t^{cm} = \left(\int_0^1 P_t^{cm}(j)^{1-\theta_{cm}} dj \right)^{\frac{1}{1-\theta_{cm}}} \quad (97)$$

According to the method (Calvo, 1983) and due to the costs of price adjustment, firms importing consumer goods cannot always set the price of their products optimally in a monopolistic competitive market. Firms importing consumer goods are divided into two categories. The first category includes $(1 - \upsilon_{cm})$ percent of firms that are able to set the optimal price, which is also determined based on profit maximization in a time period. The second category includes υ_{cm} percent of firms that are unable to set their optimal price and, therefore, their price is not obtained from maximizing the profit function. When a firm importing consumer goods fails to set the price of its product at the optimal level, it sets the price of its products for the future period according to the rules of thumb and based on the adjusted inflation rate:

$$P_{t+1}^{cm}(j) = (\pi_t^{cm})^{\tau_{cm}} P_t^{cm}(j) \quad (98)$$

Where, τ_{cm} is the price indexation degree of the consumer goods importing firm. The consumer goods importing firm sets the price of its products in a monopolistically competitive market, in accordance with the optimization behavior with the profit maximization approach, at a level above the marginal cost. This problem is expressed as follows:

$$\max_{P_t^{cm}(j)} \quad E_t \sum_{s=0}^{\infty} (\beta \upsilon_{cm})^s \Delta_{s,t+s} \left[\frac{P_{t+s}^{cm}(j)}{P_{t+s}^{cm}} C_{t+s}^{m}(j) - mc_{t+s}^{cm} C_{t+s}^{m}(j) \right] \tag{99}$$

$$s.t. \qquad C_{t+s}^{m}(j) = \left(\frac{P_{t+s}^{cm}(j)}{P_{t+s}^{cm}} \right)^{-\theta_{cm}} C_{t+s}^{m}$$

By setting the optimal price as $P_t^{cm}(j) = P_t^{cm*}$, the first-order optimal condition of the above problem after simplification is as follows:

$$\frac{P_t^{cm*}}{P_t^{cm}} = \frac{\theta_{cm}}{\theta_{cm}-1} \frac{E_t \sum_{s=0}^{\infty} (\beta \upsilon_{cm})^s \Delta_{s,t+s} mc_{t+s}^{cm} \left(\frac{P_{t+s}^{cm}}{P_t^{cm}} \right)^{\theta_{cm}} \left(\frac{P_{t-1}^{cm}}{P_{t+s-1}^{cm}} \right)^{\tau_{cm}\theta_{cm}} C_{t+s}^{m}}{E_t \sum_{s=0}^{\infty} (\beta \upsilon_{cm})^s \Delta_{s,t+s} \left(\frac{P_{t+s}^{cm}}{P_t^{cm}} \right)^{\theta_{cm}-1} \left(\frac{P_{t-1}^{cm}}{P_{t+s-1}^{cm}} \right)^{\tau_{cm}(\theta_{cm}-1)} C_{t+s}^{m}} \tag{100}$$

Given that $(1-\upsilon_{cm})$ percent of firms importing consumer goods in each period are able to determine the optimal price and υ_{cm} percent of firms importing consumer goods are unable to determine their optimal price, the price index of imported consumer goods is defined as follows:

$$P_t^{cm} = \left[(1-\upsilon_{cm}) (P_t^{cm*})^{1-\theta_{cm}} + \upsilon_{cm} ((\pi_{t-1}^{cm})^{\tau_{cm}} P_{t-1}^{cm})^{1-\theta_{cm}} \right]^{\frac{1}{1-\theta_{cm}}} \tag{101}$$

Using relations (100) and (101), the new Phillips Keynesian curve for the inflation index of imported consumer goods is obtained as follows:

$$\hat{\pi}_t^{cm} = \frac{\tau_{cm}}{1+\beta\tau_{cm}} \hat{\pi}_{t-1}^{cm} + \frac{\beta}{1+\beta\tau_{cm}} E_t \hat{\pi}_{t+1}^{cm} + \frac{(1-\beta\upsilon_{cm})(1-\upsilon_{cm})}{\upsilon_{cm}(1+\beta\tau_{cm})} \widehat{mc}_t^{cm} \tag{102}$$

The aggregator of imported consumer goods purchases the consumer goods needed for import from the world markets at the price P_t^f and sells them in the domestic market at the price P_t^{cm}. International sanctions on the import of consumer goods increase transaction costs (payment and transfer of foreign exchange for the purchase of imported consumer goods, transportation, insurance, etc.) in the process of importing consumer goods. Therefore, the true final cost of the aggregator of imported consumer goods is as follows:

$$mc_t^{cm} = \frac{e_t P_t^f}{P_t^{cm}} S_t^{cm} \tag{103}$$

Where, S_t^{cm} is the additional transaction costs resulting from the imposition of international sanctions that increase the real marginal cost of importing consumer goods and is assumed to follow a first-order autoregressive process. International sanctions $(sanc_t)$ increase transaction costs in the consumer goods import sector through the parameter $SSCm$.

$$S_t^{cm} = \rho_{cm} S_{t-1}^{cm} + (1-\rho_{cm}) \bar{S}^{cm} + SSCm sanc_t + \varepsilon_t^{cm} \tag{104}$$

Importing capital goods firms purchase capital goods needed for import into the country from world markets and sell them to domestic investors. It is assumed that the market for imported capital goods in the country is monopolistically competitive and that importing firms set the price of capital goods above marginal cost and sell them. According to the method (Dixit and Stiglitz, 1977), it is assumed that there is an aggregator of imported capital goods that purchases the capital goods of all importing firms and aggregates them according to the following technological relationship and supplies them to the domestic capital goods market at a single price:

$$I_t^m = \left(\int_0^1 I_t^m(j)^{\frac{\theta_{Im}-1}{\theta_{Im}}} dj \right)^{\frac{\theta_{Im}}{\theta_{Im}-1}} \quad (105)$$

Where, θ_{Im} is the elasticity of substitution of imported capital goods of different importing firms. The objective of the imported capital goods aggregator is to choose the quantity of imported capital goods such that its profit is maximized.
The above problem is expressed as follows:

$$\max_{I_t^m(j)} \quad P_t^{Im} I_t^m - \int_0^1 P_t^{Im}(j)\, I_t^m(j) dj \quad (106)$$

$$s.t. \qquad I_t^m = \left(\int_0^1 I_t^m(j)^{\frac{\theta_{Im}-1}{\theta_{Im}}} dj \right)^{\frac{\theta_{Im}}{\theta_{Im}-1}}$$

From solving this problem, the optimal aggregate demand function for imported capital goods from the capital goods of the j importing firm is obtained as follows:

$$I_t^m(j) = \left(\frac{P_t^{Im}(j)}{P_t^{Im}} \right)^{-\theta_{Im}} I_t^m \quad (107)$$

By substituting the optimal demand function into equation (105), the price index of imported capital goods is obtained as follows:

$$P_t^{Im} = \left(\int_0^1 P_t^{Im}(j)^{1-\theta_{Im}} dj \right)^{\frac{1}{1-\theta_{Im}}} \quad (108)$$

According to the method (Calvo, 1983) and due to the costs of price adjustment, firms importing capital goods cannot always set the price of their products optimally in a monopolistic competitive market. Firms importing capital goods are divided into two categories. The first category includes $(1-\upsilon_{Im})$ percent of firms that are able to set the optimal price in each period, which is also determined based on profit maximization in a time period. The second category includes υ_{Im} percent of firms that are unable to set their optimal price and, therefore, their price is not obtained from maximizing the profit function. When a firm importing capital goods fails to set the price of its product at the optimal level, it sets the price of its products for the next period according to the rules of thumb and based on the adjusted inflation rate:

$$P_{t+1}^{Im}(j) = (\pi_t^{Im})^{\tau_{Im}} P_t^{Im}(j) \quad (109)$$

Where, τ_{Im} is the degree of price indexation of the capital goods importing firm. The capital goods importing firm sets the price of its products in a monopolistically competitive

market, in accordance with the optimization behavior with the profit maximization approach, at a level above the marginal cost. This problem is expressed as follows:

$$\max_{P_t^{Im}(j)} \quad E_t \sum_{s=0}^{\infty} (\beta \upsilon_{Im})^s \Delta_{s,t+s} \left[\frac{P_{t+s}^{Im}(j)}{P_{t+s}^{Im}} I_{t+s}^{m}(j) - mc_{t+s}^{Im} I_{t+s}^{m}(j) \right] \tag{110}$$

$$s.t. \qquad I_{t+s}^{m}(j) = \left(\frac{P_{t+s}^{Im}(j)}{P_{t+s}^{Im}} \right)^{-\theta_{Im}} I_{t+s}^{m}$$

By setting the optimal price as $P_t^{Im}(j) = P_t^{Im*}$, the first-order optimal condition of the above problem after simplification is as follows:

$$\frac{P_t^{Im*}}{P_t^{Im}} = \frac{\theta_{Im}}{\theta_{Im}-1} \frac{E_t \sum_{s=0}^{\infty} (\beta \upsilon_{Im})^s \Delta_{s,t+s} mc_{t+s}^{Im} \left(\frac{P_{t+s}^{Im}}{P_t^{Im}} \right)^{\theta_{Im}} \left(\frac{P_{t-1}^{Im}}{P_{t+s-1}^{Im}} \right)^{\tau_{Im}\theta_{Im}} I_{t+s}^{m}}{E_t \sum_{s=0}^{\infty} (\beta \upsilon_{Im})^s \Delta_{s,t+s} \left(\frac{P_{t+s}^{Im}}{P_t^{Im}} \right)^{\theta_{Im}-1} \left(\frac{P_{t-1}^{Im}}{P_{t+s-1}^{Im}} \right)^{\tau_{Im}(\theta_{Im}-1)} I_{t+s}^{m}} \tag{111}$$

Given that $(1-\upsilon_{Im})$ percent of firms importing capital goods in each period are able to determine the optimal price and υ_{Im} percent of firms importing capital goods are unable to determine their optimal price, the price index of imported capital goods is defined as follows:

$$P_t^{Im} = \left[(1-\upsilon_{Im}) (P_t^{Im*})^{1-\theta_{Im}} + \upsilon_{Im} ((\pi_{t-1}^{Im})^{\tau_{Im}} P_{t-1}^{Im})^{1-\theta_{Im}} \right]^{\frac{1}{1-\theta_{Im}}} \tag{112}$$

Using relations (111) and (112), the new Keynesian Phillips curve of the inflation index of imported capital goods is obtained as follows:

$$\hat{\pi}_t^{Im} = \frac{\tau_{Im}}{1+\beta\tau_{Im}} \hat{\pi}_{t-1}^{Im} + \frac{\beta}{1+\beta\tau_{Im}} E_t \hat{\pi}_{t+1}^{Im} + \frac{(1-\beta\upsilon_{Im})(1-\upsilon_{Im})}{\upsilon_{Im}(1+\beta\tau_{Im})} \widehat{mc}_t^{Im} \tag{113}$$

The aggregator of imported capital goods purchases the capital goods needed for import from the world markets at the price P_t^f and sells them at the price P_t^{Im} in the domestic market. International sanctions on the import of capital goods increase transaction costs (payment and transfer of foreign exchange for the purchase of imported capital goods, transportation, insurance, etc.) in the process of importing capital goods. Hence, the real marginal cost of the aggregator of imported capital goods is as follows:

$$mc_t^{Im} = \frac{e_t P_t^f}{P_t^{Im}} S_t^{Im} \tag{114}$$

Where, S_t^{Im} is the additional transaction costs resulting from the imposition of international sanctions that increase the real marginal cost of importing capital goods and is assumed to follow a first-order autoregressive process. International sanctions $(sanc_t)$ increase transaction costs in the capital goods import sector through the parameter $SSIm$.

$$S_t^{Im} = \rho_{Im} S_{t-1}^{Im} + (1-\rho_{Im})\bar{S}^{Im} + SSImsanc_t + \varepsilon_t^{Im} \quad (115)$$

Importing firms purchase the intermediate inputs needed for domestic imports from world markets and sell them to producers of intermediate goods. It is assumed that the market for imported intermediate inputs in the country is monopolistically competitive and that importing firms set the price of intermediate inputs above marginal cost and sell them. According to the method (Dixit and Stiglitz, 1977), it is assumed that there is an aggregator of imported intermediate inputs that purchases the intermediate inputs of all importing firms and aggregates them according to the following technology relationship and supplies them to the domestic intermediate input market at a single price:

$$In_t^m = \left(\int_0^1 In_t^m(j)^{\frac{\theta_{Inm}-1}{\theta_{Inm}}} dj \right)^{\frac{\theta_{Inm}}{\theta_{Inm}-1}} \quad (116)$$

Where, θ_{Inm} is the elasticity of substitution of imported intermediate inputs of different importing firms. The objective of the imported intermediate input aggregator is to choose the amount of imported intermediate inputs such that its profit is maximized.
The above problem is expressed as follows:

$$\max_{In_t^m(j)} \quad P_t^{Inm} In_t^m - \int_0^1 P_t^{Inm}(j) In_t^m(j)\, dj \quad (117)$$

$$s.t. \quad In_t^m = \left(\int_0^1 In_t^m(j)^{\frac{\theta_{Inm}-1}{\theta_{Inm}}} dj \right)^{\frac{\theta_{Inm}}{\theta_{Inm}-1}}$$

From solving this problem, the optimal demand function aggregating imported intermediate inputs from the intermediate inputs of the j importing firm is obtained as follows:

$$In_t^m(j) = \left(\frac{P_t^{Inm}(j)}{P_t^{Inm}} \right)^{-\theta_{Inm}} In_t^m \quad (118)$$

By substituting the optimal demand function into equation (116), the price index of imported intermediate inputs is obtained as follows:

$$P_t^{Inm} = \left(\int_0^1 P_t^{Inm}(j)^{1-\theta_{Inm}} dj \right)^{\frac{1}{1-\theta_{Inm}}} \quad (119)$$

According to the method (Calvo, 1983) and due to the costs of price adjustment, firms importing intermediate inputs cannot always set the price of their products optimally in a monopolistic competitive market. Firms importing intermediate inputs are divided into two categories. The first category includes $(1-\upsilon_{Inm})$ the percentage of firms that are able to set the optimal price in each period, which is also determined based on profit maximization in a time period. The second category includes the percentage of firms that are unable to set their optimal price and, therefore, their price is not obtained from maximizing the profit function. When a firm importing intermediate inputs fails to set the price of its product at the optimal level, it sets the price of its products for the next period according to the rules of thumb and based on the adjusted inflation rate:

$$P_{t+1}^{Inm}(j) = (\pi_t^{Inm})^{\tau_{Inm}} P_t^{Inm}(j) \quad (120)$$

Where, τ_{Inm} is the price indexation degree of the intermediate input importing firm. The intermediate input importing firm sets the price of its products in a monopolistically competitive market, in accordance with the optimization behavior with the profit maximization approach, at a level higher than the marginal cost. This problem is expressed as follows:

$$\max_{P_t^{Inm}(j)} \quad E_t \sum_{s=0}^{\infty} (\beta \upsilon_{Inm})^s \Delta_{s,t+s} \left[\frac{P_{t+s}^{Inm}(j)}{P_{t+s}^{Inm}} In_{t+s}^m(j) - mc_{t+s}^{Inm} In_{t+s}^m(j) \right] \quad (121)$$

$$s.t. \qquad In_{t+s}^m(j) = \left(\frac{P_{t+s}^{Inm}(j)}{P_{t+s}^{Inm}} \right)^{-\theta_{Inm}} In_{t+s}^m$$

By setting the optimal price as $P_t^{Inm}(j) = P_t^{Inm*}$, the first-order optimal condition of the above problem after simplification is as follows:

$$\frac{P_t^{Inm*}}{P_t^{Inm}} = \frac{\theta_{Inm}}{\theta_{Inm}-1} \frac{E_t \sum_{s=0}^{\infty} (\beta \upsilon_{Inm})^s \Delta_{s,t+s} mc_{t+s}^{Inm} \left(\frac{P_{t+s}^{Inm}}{P_t^{Inm}} \right)^{\theta_{Inm}} \left(\frac{P_{t-1}^{Inm}}{P_{t+s-1}^{Inm}} \right)^{\tau_{Inm}\theta_{Inm}} In_{t+s}^m}{E_t \sum_{s=0}^{\infty} (\beta \upsilon_{Inm})^s \Delta_{s,t+s} \left(\frac{P_{t+s}^{Inm}}{P_t^{Inm}} \right)^{\theta_{Inm}-1} \left(\frac{P_{t-1}^{Inm}}{P_{t+s-1}^{Inm}} \right)^{\tau_{Inm}(\theta_{Inm}-1)} In_{t+s}^m} \quad (122)$$

Given that $(1-\upsilon_{Inm})$ percent of firms importing intermediate inputs in each period are able to determine the optimal price and υ_{Inm} percent of firms importing intermediate inputs are unable to determine their optimal price, the price index of imported intermediate inputs is defined as follows:

$$P_t^{Inm} = \left[(1-\upsilon_{Inm}) (P_t^{Inm*})^{1-\theta_{Inm}} + \upsilon_{Inm} ((\pi_{t-1}^{Inm})^{\tau_{Inm}} P_{t-1}^{Inm})^{1-\theta_{Inm}} \right]^{\frac{1}{1-\theta_{Inm}}} \quad (123)$$

Using relations (122) and (123), the new Keynesian Phillips curve of the price index inflation of imported intermediate inputs is obtained as follows:

$$\hat{\pi}_t^{Inm} = \frac{\tau_{Inm}}{1+\beta\tau_{Inm}} \hat{\pi}_{t-1}^{Inm} + \frac{\beta}{1+\beta\tau_{Inm}} E_t \hat{\pi}_{t+1}^{Inm} + \frac{(1-\beta\upsilon_{Inm})(1-\upsilon_{Inm})}{\upsilon_{Inm}(1+\beta\tau_{Inm})} \widehat{mc}_t^{Inm} \quad (124)$$

The aggregator of imported intermediate inputs purchases the intermediate inputs needed for import from the world markets at the price P_t^f and sells them in the domestic market at the price P_t^{Inm}. International sanctions on the import of intermediate inputs increase transaction costs (payment and transfer of foreign exchange for the purchase of imported intermediate inputs, transportation, insurance, etc.) in the process of importing intermediate inputs. Hence, the true marginal cost of the aggregator of imported intermediate inputs is as follows:

$$mc_t^{Inm} = \frac{e_t P_t^f}{P_t^{Inm}} S_t^{Inm} \quad (125)$$

Where, S_t^{Inm} is the additional transaction costs resulting from the imposition of international sanctions that increase the real marginal cost of the aggregate of imported intermediate inputs and is assumed to follow a first-order autoregressive process. International sanctions $(sanc_t)$ increase transaction costs in the import sector of intermediate inputs through the parameter $SSInm$.

$$S_t^{Inm} = \rho_{Inm} S_{t-1}^{Inm} + (1 - \rho_{Inm})\bar{S}^{Inm} + SSInmsanc_t + \varepsilon_t^{Inm} \quad (126)$$

4-5. Oil

There are various methods for including the oil sector in the model. Some studies consider the oil sector as similar to other firms, but others use an exogenous process to model the oil sector. In the present study, the oil shock is considered through the imposition of international sanctions on the country's oil exports. It is also assumed that all extracted crude oil is exported at world prices and the foreign exchange income is provided to the government. In the modeling performed, real revenues from oil exports follow a first-order autoregressive process. International sanctions $(sanc_t)$ reduce real revenues from oil exports through the $SSor$ parameter.

$$or_t = \rho_{or} or_{t-1} + (1 - \rho_{or})\overline{or} + SSorsanc_t + \varepsilon_t^{or} \quad (127)$$

4-6. Government and Central Bank

Due to the lack of independence of the Central Bank in Iran, the government and the Central Bank cannot be included as two separate parts in the model, but rather the government and the Central Bank should be considered as a single agency. The government's revenue sources include: creating new debt (issuing bonds), collecting a lump sum tax from households, and revenues from oil exports. If the government balances its expenses through the above revenue sources, money creation will not occur in the form of increasing government debts to the Central Bank. However, if the government faces a budget deficit despite the above revenue sources and finances this deficit by borrowing from the Central Bank or through its deposits with the Central Bank, money creation will occur.

In this regard, following (Ireland, 1997; Deeb, 2001; Peiris and Sakjard, 2007), and (Gali, 2008), the government budget and central bank balance sheet constraints will be as follows.

4-6-1. Government budget constraints

In the government budget constraint, dc_t^g is the government's net debt to the central bank and b_t is the bonds. Government revenues are: ta_t lump sum tax collection from households and or_t real revenues from oil exports (ω is the percentage of real revenues from oil exports that are spent by the government and the rest is deposited in the National Development Fund) and government expenditures are: G_t real government expenditures and $(1 + i_{t-1})b_{t-1}$ principal and interest payments on bonds.

$$\Delta dc_t^g + \Delta b_t = G_t + (1 + i_{t-1})b_{t-1} - ta_t - \omega re_t or_t \quad (128)$$

4-6-2. Central Bank Balance Sheet

The central bank's balance sheet in real terms can be considered as follows:

$$mb_t = re_t fr_t + dc_t^g \quad (129)$$

Where, mb_t is the real monetary base, re_t is the real exchange rate, and fr_t is the real net foreign assets of the central bank.

4-6-3. Government spending

Following (Leeper *et al.*, 2009), real government spending is considered as the sum of current spending (G_t^c) and development spending (G_t^I):

$$G_t = G_t^c + G_t^I \quad (130)$$

In this regard, it is assumed that government investment (G_t^I) gradually and over time turns into government capital accumulation (KG), which indicates the delay between the start of investment projects and their fruition. To specify this delay, that is, the time interval between the approval of a government development project and the time when this investment is put into operation in the form of capital, we denote the start time of the project and the amount of investment at the time of approval by t and A_t^{GI}. The years required to complete and operate the investment project are also specified by L. Therefore, the relationship of government capital accumulation will be as follows:

$$KG_t = (1-\delta^G)KG_{t-1} + A_{t-L+1}^{GI} \quad (131)$$

Where, KG is the accumulation of government capital, δ^G is the depreciation rate of government capital, and A_t^{GI} is the amount of government investment approved in the budget, which follows a first-order autoregressive process as follows:

$$A_t^{GI} = \rho_{GI} A_{t-1}^{GI} + (1-\rho_{GI})\bar{A}^{GI} + \varepsilon_t^{GI} \quad (132)$$

As we know, the expenditures allocated to investment projects are made gradually and over time. Let us assume that the share of expenditures allocated in each year of the total investment made is defined as the sequence $\{b_0, b_1, b_2, \dots, b_{L-1}\}$. In this sequence, year zero is the time of project approval and year $L-1$ is the year before the project is completed. The project implementation at time t will be as follows:

$$G_t^I = \sum_{n=0}^{L-1} b_n A_{t-n}^{GI} \quad (133)$$

In this relation, $\sum_{n=0}^{L-1} b_n = 1$. As mentioned, b represents the investment rate in each period. If the project has no delay or in other words, if the project approval and completion time is only one year, then $(b=1, L=1)$ and as a result we have: $G_t^I = A_t^{GI}$.

It is also assumed that current government spending follows a Cobb-Douglas function of the variables of current government spending in the previous period, lump sum tax, and revenues from oil exports.

$$G_t^c = (G_{t-1}^c)^{\rho_g}(ta_t)^{g_1}e^{\omega\varepsilon_t^{or}}e^{\varepsilon_t^g} \quad (134)$$

4-6-4. Government tax revenue

The real lump-sum tax is assumed to be a proportion of GDP and is defined as follows:

$$ta_t = t_t^r Y_t \quad (135)$$

Where, t_t^r is the tax rate and follows a first-order autoregressive process as follows:

$$t_t^r = \rho_r t_{t-1}^r + (1-\rho_r)\bar{t}^r + \varepsilon_t^r \quad (136)$$

4-6-5. National Development Fund

The National Development Fund was established under the Third Development Plan Law (1990) with the objectives of reducing the vulnerability of the economy, mitigating the damage caused by the decline in oil prices, and supporting private sector infrastructure projects. The resources of the National Development Fund are mainly derived from oil export revenues, such that $(1-\omega)$ percent of oil export revenues are deposited into the fund in each period. It is also assumed that the accumulation of the National Development Fund reserves in each period follows the following process:

$$DF_t = DF_{t-1} + (1-\omega)or_t \quad (137)$$

Where, DF_{t-1} is the balance of National Development Fund reserves from the previous period that is carried over to the current period.

4-6-6. Monetary policy

The Central Bank uses various tools for monetary policy, the choice of which depends on economic conditions and its goals. Among these tools, the interest rate and the monetary base growth rate are among the important tools in money market management and policymaking, which due to the inefficiency of the interest rate tool, the monetary base growth rate is considered as a monetary policy tool at the disposal of the Central Bank of Iran. Accordingly, the monetary policy response function is such that the Central Bank will determine the monetary base growth rate in a completely discretionary manner in such a way that its two desired goals, namely reducing the gap between current output and potential output and reducing the gap between the inflation rate and the target inflation, are achieved. The target inflation is an unobservable variable and is only available to the monetary authorities. Therefore, the monetary policy response function is defined as follows, following (Goli, 2008; Skode, 2013):

$$\frac{h_t}{\bar{h}} = \left(\frac{h_{t-1}}{\bar{h}}\right)^{\rho_h} \left(\frac{\pi_t}{\pi_t^T}\right)^{\lambda_\pi} \left(\frac{Y_t}{\bar{Y}}\right)^{\lambda_y} \varepsilon_t^{mb} \quad (138)$$

Where, h_t is the growth rate of the monetary base in period t, which is defined as follows:

$$h_t = \frac{mb_t}{mb_{t-1}} \pi_t \quad (139)$$

The target inflation (π_t^T) is assumed to follow a first-order autoregressive process as follows:

$$\pi_t^T = \rho_T \pi_{t-1}^T + (1-\rho_T)\bar{\pi}^T + \varepsilon_t^T \quad (140)$$

The change in the central bank's net foreign assets in real terms can be considered as follows:

$$re_t fr_t - re_t \frac{fr_{t-1}}{\pi_t^f} = \omega re_t or_t + \frac{P_t^x}{P_t^f} Y_t^x - \frac{P_t^{cm}}{P_t} C_t^m - \frac{P_t^{Im}}{P_t} I_t^m - \frac{P_t^{Inm}}{P_t} In_t^m \quad (141)$$

Where, π_t^f is the external inflation rate and follows a first-order autoregressive process as follows:

$$\pi_t^f = \rho_f \pi_{t-1}^f + (1-\rho_f)\bar{\pi}^f + \varepsilon_t^f \quad (142)$$

4-6-7. Exchange rate policymaking

There are three types of currency systems in the world: fixed exchange rate system, floating exchange rate system, and managed floating exchange rate system. The two fixed and floating exchange rate systems are less concerned by the monetary authorities of the countries, and the managed floating exchange rate system is used more to achieve the goals. Considering the managed floating exchange rate system for the exchange rate in Iran, the Central Bank uses the growth of the nominal exchange rate to set currency policy. In this regard, the Central Bank, on the one hand, reacts to the gap between the domestic inflation rate and the foreign inflation rate and, in proportion to the aforementioned gap, allows the exchange rate to increase in the foreign exchange market, and on the other hand, considers a precautionary limit for its foreign reserves and considers this precautionary limit as the share of foreign reserves in the monetary base to control the foreign exchange market. Therefore, in a situation where the share of the Central Bank's foreign reserves in the monetary base falls below the precautionary limit considered by the Central Bank, the Central Bank will allow the exchange rate to increase. Therefore, the reaction function of

exchange rate policy, following (Essonson and Woodford, 2003; Eskud, 2013), is defined as follows:

$$\frac{\gamma_t}{\bar{\gamma}} = \left(\frac{\gamma_{t-1}}{\bar{\gamma}}\right)^{\rho_\gamma} \left(\frac{\pi_t}{\pi_t^f}\right)^{e_1} \left(\frac{\frac{re_t fr_t}{mb_t}}{\frac{\bar{re}\,\bar{fr}}{\bar{mb}}}\right)^{e_2} \varepsilon_t^e \quad (143)$$

where γ_t is the nominal exchange rate growth. The nominal exchange rate impulse (ε_t^e) follows a first-order autoregressive process as follows:

$$\varepsilon_t^e = \rho_e \varepsilon_{t-1}^e + \varepsilon_t^{ue} \quad (144)$$

The real exchange rate (re_t) defined as follows:

$$re_t = \frac{e_t P_t^f}{P_t} \quad (145)$$

Where, e_t is the nominal exchange rate, P_t^f is the price index of foreign goods, and P_t is the price index of total consumer goods.

4-7. Commodity market settlement condition

One of the most important equations is the goods market settlement, where real GDP equals household consumption, household investment, government current expenditure, government development expenditure, and net exports (total exports minus total imports). Total exports equal the sum of revenues from oil exports and exports of intermediate goods (non-oil exports), and total imports equal the imports of consumer goods, imports of capital goods, and imports of intermediate inputs. Therefore, the goods market settlement condition is defined as follows:

$$Y_t = C_t + I_t + G_t^c + G_t^I + re_t or_t + \frac{P_t^x}{P_t^f} Y_t^x - \frac{P_t^{cm}}{P_t} C_t^m - \frac{P_t^{Im}}{P_t} I_t^m - \frac{P_t^{Inm}}{P_t} In_t^m \quad (146)$$

Real GDP (total output) is equal to the sum of non-oil production and revenues from oil exports, which is defined as follows:

$$Y_t = Y_t^{no} + re_t or_t \quad (147)$$

Given that all price variables in the research model need to be presented uniformly, the domestic consumer goods price index, imported consumer goods price index, domestic capital goods price index, imported capital goods price index, total intermediate input price index, price index of intermediate goods supplied to the domestic market, price index of intermediate inputs demanded from the domestic market, and price index of intermediate inputs demanded from foreign markets are considered in relation to the total consumer goods price index and the price index of intermediate goods supplied to foreign markets in relation to the price index of foreign goods.

Also, given that the domestic consumer goods price index, the imported consumer goods price index, the domestic capital goods price index, the imported capital goods price

index, the total intermediate input price index, the price index of intermediate goods supplied to the domestic market, the price index of intermediate goods supplied to foreign markets, the price index of intermediate inputs demanded from the domestic market, the price index of intermediate inputs demanded from foreign markets, the total consumer goods price index, and the price index of foreign goods are in the form of inflation rates, all of the aforementioned ratios are defined as follows:

Ratio of the domestic consumer price index to the total consumer price index:

$$\gamma_t^{cd} = \frac{P_t^{cd}}{P_t} \qquad \gamma_t^{cd} = \frac{\pi_t^{cd}}{\pi_t}\gamma_{t-1}^{cd} \tag{148}$$

Ratio of the price index of imported consumer goods to the price index of total consumer goods:

$$\gamma_t^{cm} = \frac{P_t^{cm}}{P_t} \qquad \gamma_t^{cm} = \frac{\pi_t^{cm}}{\pi_t}\gamma_{t-1}^{cm} \tag{149}$$

Ratio of the domestic capital goods price index to the total consumer goods price index:

$$\gamma_t^{Id} = \frac{P_t^{Id}}{P_t} \qquad \gamma_t^{Id} = \frac{\pi_t^{Id}}{\pi_t}\gamma_{t-1}^{Id} \tag{150}$$

Ratio of the price index of imported capital goods to the price index of total consumer goods:

$$\gamma_t^{Im} = \frac{P_t^{Im}}{P_t} \qquad \gamma_t^{Im} = \frac{\pi_t^{Im}}{\pi_t}\gamma_{t-1}^{Im} \tag{151}$$

Ratio of the total price index of intermediate inputs to the total price index of consumer goods:

$$\gamma_t^{In} = \frac{P_t^{In}}{P_t} \qquad \gamma_t^{In} = \frac{\pi_t^{In}}{\pi_t}\gamma_{t-1}^{In} \tag{152}$$

Ratio of the price index of intermediate goods supplied to the domestic market to the price index of total consumer goods:

$$\gamma_t^{d} = \frac{P_t^{d}}{P_t} \qquad \gamma_t^{d} = \frac{\pi_t^{d}}{\pi_t}\gamma_{t-1}^{d} \tag{153}$$

Ratio of the price index of intermediate goods supplied to foreign markets to the price index of foreign goods:

$$\gamma_t^x = \frac{P_t^x}{P_t^f} \qquad \gamma_t^x = \frac{\pi_t^x}{\pi_t^f}\gamma_{t-1}^x \tag{154}$$

Ratio of the price index of intermediate inputs demanded from the domestic market to the price index of total consumer goods:

$$\gamma_t^{Ind} = \frac{P_t^{Ind}}{P_t} \qquad \gamma_t^{Ind} = \frac{\pi_t^{Ind}}{\pi_t}\gamma_{t-1}^{Ind} \tag{155}$$

Ratio of the price index of intermediate inputs demanded from foreign markets to the price index of total consumer goods:

$$\gamma_t^{Inm} = \frac{P_t^{Inm}}{P_t} \qquad \gamma_t^{Inm} = \frac{\pi_t^{Inm}}{\pi_t}\gamma_{t-1}^{Inm} \tag{156}$$

5. Initializing template parameters

In this paper, due to the lack of access to high-quality data for a number of variables and also due to the complexity of simultaneous estimation, calibration is preferred over Bayesian estimation and the calibration method is used to estimate the model parameters.

Before simulating the model and obtaining the instantaneous response functions (IRF), it is necessary to estimate the model parameters, which is done in this study using the calibration method. In this study, a number of parameters are quantified using the estimation method and other parameters are quantified using the long-run ratio of macroeconomic variables. For this purpose, parameters such as the habit stability parameter, the elasticity of the investment adjustment cost function, the coefficient of the first-order autoregressive process of the investment impulse, the production elasticity of private capital input, the production elasticity of public capital input, the coefficient of the first-order autoregressive process of productivity, First-order autoregressive coefficient of transaction costs in the intermediate goods export sector, first-order autoregressive coefficient of transaction costs in the consumer goods import sector, first-order autoregressive coefficient of transaction costs in the capital goods import sector, first-order autoregressive coefficient of transaction costs in the intermediate inputs import sector, first-order autoregressive coefficient of oil export revenues, first-order autoregressive coefficient of government development expenditures, first-order autoregressive coefficient of government current expenditures, elasticity of government current expenditures relative to a lump sum tax, percentage of oil export revenues spent by the government, The coefficient of the first-order autoregressive process of the tax rate, the coefficient of the autoregressive process of the monetary policy response function, the coefficient of the importance of the gap between the inflation rate and the target inflation in the monetary policy response function, the coefficient of the importance of the gap between current output and potential output in the monetary policy response function, the coefficient of the first-order autoregressive process of the target inflation, the coefficient of the first-order autoregressive process of the inflation of the foreign goods price index, the coefficient of

the autoregressive process of the exchange rate response function, the coefficient of the importance of the gap between the domestic inflation rate and the foreign inflation rate in the exchange rate response function, The coefficient of the ratio of the central bank's foreign reserves to the monetary base in the exchange rate policy reaction function and the coefficient of the first-order autoregressive process of the nominal exchange rate shock were obtained using the estimation method from previous studies.

Other research parameters are estimated using the long-term ratio of macroeconomic variables. According to this method, in the first stage, the geometric mean of the ratio of non-price macro variables to GDP and the ratio of price macro variables, including the ratio of the domestic consumer goods price index, the ratio of the imported consumer goods price index, the ratio of the domestic capital goods price index, the ratio of the imported capital goods price index, the ratio of the total intermediate inputs price index, the ratio of the price index of intermediate goods supplied to the domestic market, the ratio of the price index of intermediate inputs demanded from the domestic market, and the ratio of the price index of intermediate inputs demanded from foreign markets to the total consumer goods price index And the ratio of the price index of intermediate goods supplied to foreign markets to the price index of foreign goods has been calculated using the time series of macroeconomic variables.

In the second stage, the equations of the research model were entered nonlinearly into the Maple computing software and the geometric mean of the ratio of non-price macro variables to GDP and the ratio of price macro variables, including the ratio of the domestic consumer goods price index, the ratio of the imported consumer goods price index, the ratio of the domestic capital goods price index, the ratio of the imported capital goods price index, the ratio of the total intermediate inputs price index, the ratio of the price index of intermediate goods supplied to the domestic market, the ratio of the price index of intermediate inputs demanded from the domestic market, and the ratio of the price index of intermediate inputs demanded from foreign markets to the total consumer goods price index, and The ratio of the price index of intermediate goods supplied to foreign markets to the price index of foreign goods is entered as the long-term ratio of macroeconomic variables in the nonlinear equations of the model, and the Maple software, by solving simultaneous equations, determines the model parameters using the long-term ratio of macroeconomic variables calculated from the geometric mean of the ratio of non-price macroeconomic variables to GDP and It calculates the ratio of macro-price variables, including the ratio of the domestic consumer goods price index, the ratio of the imported consumer goods price index, the ratio of the domestic capital goods price index, the ratio of the imported capital goods price index, the ratio of the total intermediate inputs price index, the ratio of the price index of intermediate goods supplied to the domestic market, the ratio of the price index of intermediate inputs demanded from the domestic market, and the ratio of the price index of intermediate inputs demanded from foreign markets to the total consumer goods price index, and the ratio of the price index of intermediate goods supplied to foreign markets to the price index of foreign goods.

The long-term ratio of non-price macro variables to GDP and the long-term ratio of price macro variables, including the ratio of the domestic consumer goods price index, the ratio of the imported consumer goods price index, the ratio of the domestic capital goods price index, the ratio of the imported capital goods price index, the ratio of the total intermediate inputs price index, the ratio of the price index of intermediate goods supplied

to the domestic market, the ratio of the price index of intermediate inputs demanded from the domestic market, and the ratio of the price index of intermediate inputs demanded from foreign markets to the total consumer goods price index, and the ratio of the price index of intermediate goods supplied to foreign markets to the price index of foreign goods, are as follows in Table 1:

Table 1: Long-run ratio of macroeconomic variables

Explanation	Proportion symbol	Amount
Gross Domestic Product	Y	1
household consumption	C	0.446
Household consumption of domestic consumer goods	C^d	0.422
Household consumption of imported consumer goods	C^m	0.026
Household investment	I	0.23
Household investment in domestic capital goods	I^d	0.0221
Household investment in imported capital goods	I^m	0.016
Intermediate goods, intermediary firm	Y^{no}	1.2
Intermediate goods An intermediary firm's supply of intermediate goods to the domestic market	Y^d	1.1089
Intermediate goods An intermediary firm of intermediate goods supplied to foreign markets	Y^x	0.0859
Intermediate inputs of the intermediary firm	In	0.367
Intermediate inputs of an intermediary firm from the intermediate inputs demanded from the domestic market	In^d	0.3065
Intermediate inputs of an intermediary firm from intermediate inputs demanded from foreign markets	In^m	0.0701
Bonds	b	0.026
Wage	w	0.2987
Rate of return on capital	r^k	0.0527
Monetary base	mb	0.12
Real exchange rate	re	1
Central Bank Net Foreign Assets	fr	0.084
Net government debt to the central bank	dc^g	0.036
Government current expenditure	G^c	0.116
Government development spending	G^I	0.09
Ratio of the domestic consumer price index to the total consumer price index	γ^{cd}	1.01057
Ratio of the price index of imported consumer goods to the price index of total consumer goods	γ^{cm}	0.76
Ratio of the domestic capital goods price index to the total consumer goods price index	γ^{Id}	1.0367
Ratio of the price index of imported capital goods to the price index of total consumer goods	γ^{Im}	1.94
Ratio of the total price index of intermediate inputs to the total price index of consumer goods	γ^{In}	1.159
Ratio of the price index of intermediate goods supplied to the domestic market to the price index of total consumer goods	γ^d	0.9991
Ratio of the price index of intermediate goods supplied to foreign markets to the price index of foreign goods	γ^x	1.25
Ratio of the price index of intermediate inputs demanded from the domestic market to the price index of total consumer goods	γ^{Ind}	1.022
The ratio of the price index of intermediate inputs demanded from foreign markets to the price index of total consumer goods	γ^{Inm}	1.6

Source: Nakhli *et al.* (2020)

Using the above methods, the model parameters are estimated according to Tables 2, 3, 4, and 5:

Table 2: Estimated parameters of the household sector and the labor market

Explanation	Parameter symbol	Amount	Source
Inverse elasticity of labor supply	σ_l	2.9	Nakhli *et al.* (2020)
Inverse elasticity of substitution between consumption periods	σ_c	1.2	Nakhli *et al.* (2020)
Habit stability parameter	h	0.3096	Taghipour (2014)
Inverse interest elasticity of demand for real money balances	σ_m	1.25	Nakhli *et al.* (2020)
Elasticity of the investment adjustment cost function	$\emptyset$	3.9374	Taghipour (2014)
Discount factor	β	0.965	Nakhli *et al.* (2020)
Private capital depreciation rate	δ	0.0103	Nakhli *et al.* (2020)
Coefficient of the first-order autoregressive process of investment impulse	ρ_I	0.446	Vali Beigi *et al.* (2018)
Elasticity of substitution between domestic consumer goods and imported consumer goods	θ_c	2.46	Nakhli *et al.* (2020)
Share of domestic consumer goods in the household consumption index	α_c	0.9	Nakhli *et al.* (2020)
Elasticity of substitution between domestic capital goods and imported capital goods	θ_I	1.54	Nakhli *et al.* (2020)
Share of domestic capital goods in the household investment index	α_I	0.84	Nakhli *et al.* (2020)
Wage indexation level	τ_w	0.6	Nakhli *et al.* (2020)
Percentage of households unable to determine their optimal wage	υ_w	0.68	Heydarian *et al.* (2024)

Table 3: Estimated parameters of the intermediate goods manufacturing firm sector

Explanation	Parameter symbol	Amount	Source
Production elasticity of private capital input	φ	0.423	Farzin Vash *et al.* (2014)
Labor input production elasticity	η	0.3	Nakhli *et al.* (2020)
Production elasticity of government capital input	θ_g	0.082	Taghipour (2014)
Coefficient of the first-order autoregressive process of productivity	ρ_a	0.8	Tavakolian and Qayai (2019)
The elasticity of substitution between intermediate goods supplied to the domestic market and intermediate goods supplied to foreign markets	θ_y	2.77	Nakhli *et al.* (2020)
The share of intermediate goods supplied to the domestic market in the intermediate goods index of the intermediary firm	α_y	0.9	Nakhli *et al.* (2020)
The degree of price indexation of the intermediary firm supplying the product to the domestic market	τ_d	0.4984	Tavakolian (2012)
Percentage of intermediary firms supplying products to the domestic market that are unable to determine their optimal price	υ_d	0.5	Nakhli *et al.* (2020)
Elasticity of substitution between intermediate inputs demanded from the	θ_{In}	1.39	Nakhli *et al.* (2020)

domestic market and intermediate inputs demanded from foreign markets			
The share of intermediate inputs demanded from the domestic market in the intermediate input index of the intermediary firm	α_{In}	0.7	Nakhli *et al.* (2020)

Table 4: Estimated parameters of the trade sector

Explanation	Parameter symbol	Amount	Source
The degree of price indexation of the intermediary firm supplying the product to foreign markets	τ_x	0.499	Vali Beigi *et al.* (2018)
Percentage of intermediary firms supplying products to foreign markets that are unable to determine their optimal price	υ_x	0.66	Heydarian *et al.* (2024)
Coefficient of the first-order autoregressive process of transaction costs in the intermediate goods export sector	ρ_x	0.4	Nakhli *et al.* (2020)
Elasticity of transaction costs in the intermediate goods export sector to the increasing severity of international sanctions	SSX	0.2	Nakhli *et al.* (2020)
The degree of price indexation of the consumer goods importing firm	τ_{cm}	0.499	Vali Beigi *et al.* (2018)
Percentage of firms importing consumer goods that are unable to determine their optimal price	υ_{cm}	0.42	Heydarian *et al.* (2024)
Coefficient of the first-order autoregressive process of transaction costs in the consumer goods import sector	ρ_{cm}	0.4	Nakhli *et al.* (2020)
Elasticity of transaction costs in the consumer goods import sector to the increasing severity of international sanctions	$SSCm$	0.2	Nakhli *et al.* (2020)
The degree of price indexation of the capital goods importing firm	τ_{Im}	0.499	Vali Beigi *et al.* (2018)
Percentage of firms importing capital goods that are unable to determine their optimal price	υ_{Im}	0.11	Heydarian *et al.* (2024)
Coefficient of the first-order autoregressive process of transaction costs in the capital goods import sector	ρ_{Im}	0.4	Nakhli *et al.* (2020)
Elasticity of transaction costs in the capital goods import sector to the increasing severity of international sanctions	$SSIm$	0.2	Nakhli *et al.* (2020)
The degree of price indexation of the firm importing intermediate inputs	τ_{Inm}	0.499	Vali Beigi *et al.* (2018)
Percentage of firms importing intermediate inputs that are unable to determine their optimal price	υ_{Inm}	0.11	Heydarian *et al.* (2024)
Coefficient of the first-order autoregressive process of transaction costs in the intermediate input import sector	ρ_{Inm}	0.4	Nakhli *et al.* (2020)
Elasticity of transaction costs of intermediate input imports to the increasing severity of international sanctions	$SSInm$	0.2	Nakhli *et al.* (2020)
Coefficient of the first-order autoregressive process of oil export revenues	ρ_{or}	0.33	Nakhli *et al.* (2020)

The elasticity of oil export revenues to the increasing severity of international sanctions	$SSor$	-0.5	Nakhli *et al.* (2020)

Table 5: Estimated parameters of the government sector and the central bank

Explanation	Parameter symbol	Amount	Source
Government capital depreciation rate	δ^G	0.0233	Nakhli *et al.* (2020)
Coefficient of the first-order autoregressive process of government development spending	ρ_{GI}	0.575	Vali Beigi *et al.* (2018)
Coefficient of the first-order autoregressive process of current government expenditure	ρ_g	0.4206	Vali Beigi *et al.* (2018)
Elasticity of current government spending relative to lump sum tax	g_1	0.3399	Taghipour (2014)
Percentage of oil export revenues spent by the government	ω	0.78	Tavakolian (2012)
Coefficient of the first-order autoregressive process of the tax rate	ρ_r	0.789	Vali Beigi *et al.* (2018)
The coefficient of the autoregressive process of the monetary policy response function	ρ_h	0.4	Tavakolian and Qayai (2019)
The importance coefficient of the gap between the inflation rate and the target inflation in the monetary policy reaction function	λ_π	-1.54	Taghipour and Manzoor (2014)
The importance coefficient of the gap between current output and potential output in the monetary policy response function	λ_y	-1.7	Taghipour and Manzoor (2014)
Coefficient of the first-order autoregressive process of target inflation	ρ_T	0.6	Permeh *et al.* (2016)
Coefficient of the first-order autoregressive process of inflation of the foreign goods price index	ρ_f	0.902	Vali Beigi *et al.* (2018)
Autoregressive process coefficient of the foreign exchange policy reaction function	ρ_γ	0.7	Tavakolian and Qayai (2019)
The importance coefficient of the gap between the domestic inflation rate and the external inflation rate in the exchange rate policy reaction function	e_1	-1.9	Tavakolian and Jalali (2017)
The coefficient of the ratio of central bank foreign reserves to the monetary base in the exchange rate policy reaction function	e_2	-1.55	Tavakolian and Jalali (2017)
Coefficient of the first-order autoregressive process of nominal exchange rate impulse	ρ_e	0.887	Vali Beigi *et al.* (2018)

6. Evaluating model fit and performance

To assess the fit and accuracy of the model simulation, the comparison of second-order moments in the form of variance and correlation of variables with the benchmark variable (here GDP) between real-world data and simulated values of variables is used. Since the basis of DSGE models is the changes in the random component of variables in a general equilibrium framework and the model of the present study is also linearly coded and the equations are linearized in logarithms and all variables are considered as logarithmic differences of their long-term values, it is necessary to extract the moments of the real data of the variables, first the time series of all selected variables are considered logarithmically and then using the Hodrick-Prescott filter, the long-term logarithm value of the variable is

separated as a trend component from the value of fluctuations. Then the value of the fluctuations of the variables is used as the basis for calculating the moments of the variables (variance or correlation). Considering the torque values obtained from the model simulation as well as the calculated torque values of the real data in Table 6, the model is acceptable for simulation.

A comparison of the second-order moments of the variables of GDP, household consumption, household investment, current government spending, and non-oil exports with the simulated moments of these variables is presented in Table 6. The closer the simulated moments are to the actual moments, the more appropriately the model has been able to explain the realities of the Iranian economy.

Table 6: Comparison of actual and simulated torques of selected variables

Variable	Variable symbol	Variance		Correlation with GDP	
		Real data	Simulation data	Real data	Simulation data
Gross Domestic Product	Y	0.0056	0.0021	1	1
Household consumption	C	0.0044	0.0032	0.924	0.911
Household investment	I	0.0136	0.0131	0.721	0.518
Current government spending	G^c	0.0042	0.0061	0.362	0.648
Non-oil exports	Y^x	0.0752	0.0516	0.432	0.583

Source: Research findings

As is clear from the above table, the second-order moments of the variables of GDP, household consumption, household investment, current government expenditure and non-oil exports of the model are almost consistent with the second-order moments of the actual data of these variables. This situation indicates that the designed model can be used for studying the Iranian economy.

7. Analysis of instantaneous response functions of macroeconomic variables

In this section, the impact of international sanctions shocks on macroeconomic variables and the impact of nominal exchange rate shocks on macroeconomic variables are analyzed using the instantaneous response functions of the variables.

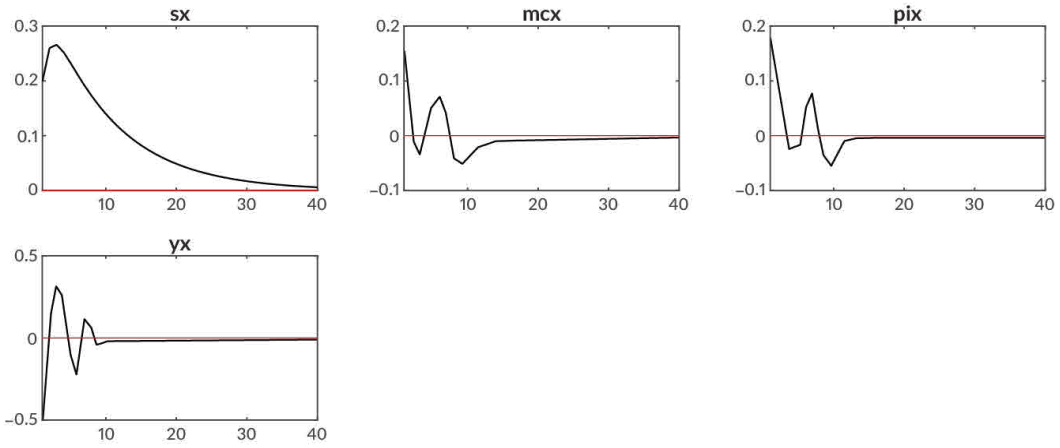

Fig. 1: The impact of the international sanctions shock on the variables of transaction costs of exports of intermediate goods, the marginal cost of intermediate goods supplied to foreign markets (exported intermediate goods), the inflation index of the price of intermediate goods supplied to foreign markets, and the amount of exports of intermediate goods (Source: Research findings).

According to Figure 1, as the intensity of international sanctions increases, the transaction costs of exporting intermediate goods increase. The increase in the transaction costs of exporting intermediate goods increases the final cost of intermediate goods supplied to foreign markets (exported intermediate goods), and the increase in the final cost of intermediate goods supplied to foreign markets leads to an increase in the inflation of the price index of intermediate goods supplied to foreign markets. The increase in the inflation of the price index of intermediate goods supplied to foreign markets causes the competitiveness of domestic products to decrease against foreign products, which reduces foreign demand for domestic products, and ultimately reduces the amount of exports of intermediate goods.

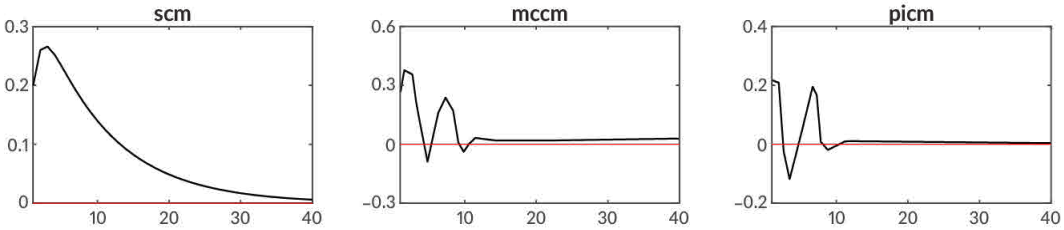

Fig. 2: The impact of the international sanctions shock on the variables of transaction costs of imported consumer goods, the marginal cost of imported consumer goods, and the inflation index of imported consumer goods (Source: Research findings).

According to Figure 2, as the intensity of international sanctions increases, the transaction costs of importing consumer goods increase. The increase in the transaction costs of importing consumer goods increases the final cost of imported consumer goods, and the increase in the final cost of imported consumer goods leads to an increase in the inflation of the price index of imported consumer goods.

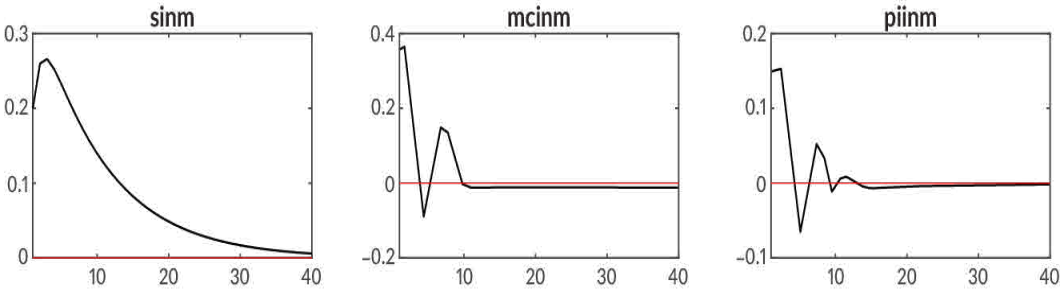

Fig3: The impact of the international sanctions shock on the variables of transaction costs of imported intermediate inputs, the final cost of imported intermediate inputs, and the inflation of the price index of imported intermediate inputs (Source: Research findings).

According to Figure 3, as the intensity of international sanctions increases, the transaction costs of importing intermediate inputs increase. An increase in the transaction costs of importing intermediate inputs increases the final cost of imported intermediate inputs, and an increase in the final cost of imported intermediate inputs leads to an increase in the inflation of the price index of imported intermediate inputs.

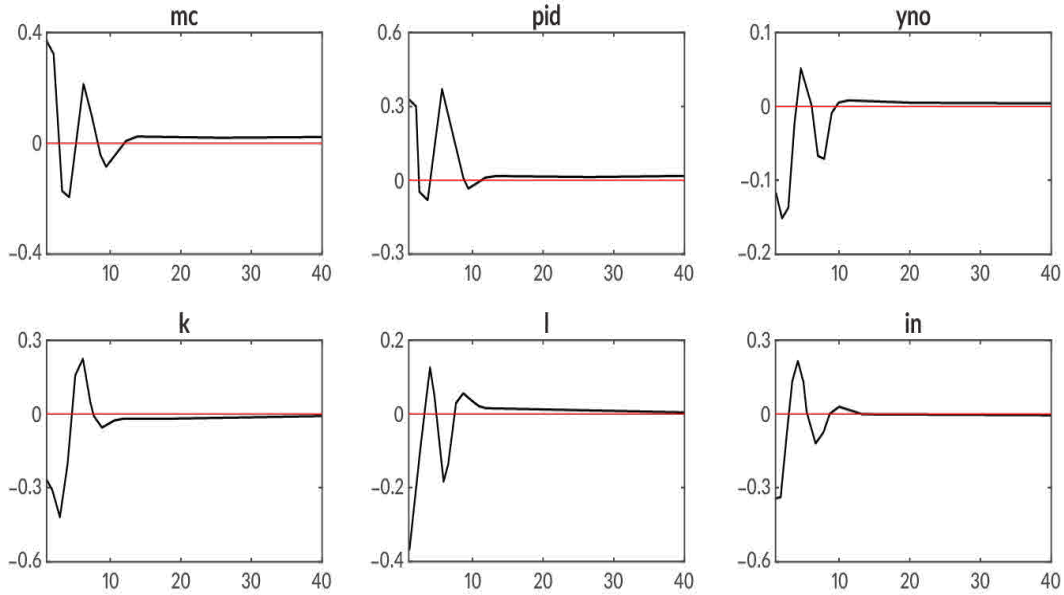

Figure 4 - The impact of the shock of international sanctions on the variables of the final cost of products produced by intermediary firms, the inflation index of the price of intermediate goods supplied to the domestic market, the production volume of intermediary firms, and the demand of producers of intermediate goods for private capital inputs, labor, and intermediate inputs (Source: Research findings).

According to Figure 4, intermediate goods manufacturing firms that supply part of their products to the domestic market, due to the fact that they use imported intermediate inputs in the process of producing intermediate goods, face cost pressure with an increase in the inflation index of the price of imported intermediate inputs, which is manifested in the form of an increase in the final cost of the products produced by intermediate firms. With an increase in the final cost of the products produced by intermediate firms, the inflation index of the price of intermediate goods supplied to the domestic market increases. With an

increase in the final cost of the products produced by intermediate firms, the production of intermediate firms decreases and subsequently the demand of intermediate goods manufacturers for private capital inputs, labor, and intermediate inputs decreases.

8. Sensitivity analysis of model parameters

In this section, we examine the sensitivity analysis of the impact of international sanctions shocks on the inflation variable of the price index of intermediate goods supplied to the domestic market with respect to changes in the parameter of the degree of stickiness of the price of the intermediary firm supplying the product to the domestic market (τ_d) and the sensitivity analysis of the impact of the nominal exchange rate shock on the inflation variable of the price index of intermediate goods supplied to foreign markets with respect to changes in the parameter of the degree of stickiness of the price of the intermediary firm supplying the product to foreign markets (τ_x).

The parameter of the degree of price stickiness of the intermediary firm supplying the product to the domestic market (τ_d) and the parameter of the degree of price stickiness of the intermediary firm supplying the product to foreign markets (τ_x) can range between zero (perfect price flexibility) and one (perfect price stickiness).

The results of the sensitivity analysis of the impact of the international sanctions shock on the inflation variable of the price index of intermediate goods supplied to the domestic market to changes in the price stickiness parameter of the intermediary firm supplying the product to the domestic market (τ_d) are given in Table 7. As explained in Figure 6, the impact of the international sanctions shock on the inflation variable of the price index of intermediate goods supplied to the domestic market is positive.

Table 7: Sensitivity analysis of the impact of international sanctions on the inflation variable of the price index of intermediate goods supplied to the domestic market with respect to changes in the parameter of the degree of stickiness of the price of the intermediate firm supplying the product to the domestic market (τ_d)

The parameter of the degree of price stickiness of the intermediary firm supplying the product to the domestic market (τ_d)	0	0.1	0.2	0.3	0.4
Average ($\times 10^{-6}$)	6.032	6.008	5.982	5.946	5.824
The parameter of the degree of price stickiness of the intermediary firm supplying the product to the domestic market (τ_d)	0.5	0.6	0.7	0.8	0.9
Average ($\times 10^{-6}$)	5.653	5.378	4.759	3.127	3.068

Source: Research findings

In Table 7, the average refers to the average impact of the international sanctions shock on the inflation variable of the price index of intermediate goods supplied to the domestic market over the 40 periods under study. As can be seen in Table 7, the average impact of the international sanctions shock on the inflation variable of the price index of intermediate goods supplied to the domestic market is close to each other at different values of the parameter of the degree of stickiness of the price of the intermediary firm supplying the product to the domestic market (τ_d), and the closeness of the average impact of the international sanctions shock on the inflation variable of the price index of intermediate goods supplied to the domestic market at different values of the parameter of the degree of

stickiness of the price of the intermediary firm supplying the product to the domestic market (τ_d) shows that the results are not dependent on the calibrated values.

The results of the sensitivity analysis of the effect of the nominal exchange rate shock on the inflation variable of the price index of intermediate goods supplied to foreign markets with respect to changes in the parameter of the degree of stickiness of the price of the intermediary firm supplying the product to foreign markets (τ_x) are given in Table 8. As explained in Figure 7, the effect of the nominal exchange rate shock on the inflation variable of the price index of intermediate goods supplied to foreign markets is negative.

Table 8: Sensitivity analysis of the effect of a nominal exchange rate shock on the inflation variable of the price index of intermediate goods supplied to foreign markets with respect to changes in the parameter of the degree of stickiness of the price of the intermediate firm supplying the product to foreign markets (τ_x)

The parameter of the price stickiness of the intermediary firm supplying the product to foreign markets (τ_x)	0	0.1	0.2	0.3	0.4
Average ($\times 10^{-4}$)	-8.9304	-8.9257	-8.9241	-8.9185	-8.9062
The parameter of the price stickiness of the intermediary firm supplying the product to foreign markets (τ_x)	0.5	0.6	0.7	0.8	0.9
Average ($\times 10^{-4}$)	-8.8529	-8.8244	-8.7635	-8.4169	-8.2873

Source: Research findings

In Table 8, the mean means the average effect of the nominal exchange rate shock on the inflation variable of the price index of intermediate goods supplied to foreign markets over the 40 periods under study. As can be seen in Table 8, the average effect of the nominal exchange rate shock on the inflation variable of the price index of intermediate goods supplied to foreign markets is close to each other at different values of the parameter of the degree of stickiness of the price of the intermediary firm supplying the product to foreign markets (τ_x), and the closeness of the average effect of the nominal exchange rate shock on the inflation variable of the price index of intermediate goods supplied to foreign markets at different values of the parameter of the degree of stickiness of the price of the intermediary firm supplying the product to foreign markets (τ_x) shows that the results are not dependent on the calibrated values.

9. Conclusion

1- Sanctioning countries do not impose sanctions on the strengths of the target country. The issue of reducing the value of the national currency (increasing the exchange rate) is one of the main weaknesses of the country. Surgery, reforms and structural changes, eliminating structural problems and strengthening the country's economic infrastructure (such as problems with the business environment, problems with the tax system, problems with the money, currency, capital markets, etc.) must be carried out in such a way that the Iranian economy can resist sanctions and neutralize their effects. This is the same as turning sanctions into a favorable opportunity to strengthen economic structures. The Iranian economy needs a resilient and resilient monetary and exchange system. It is obvious that by strengthening each area, the sanctions in that area will be lifted or rendered ineffective.

2- In the context of economic sanctions, where the amount of income from oil exports has been severely limited and the amount of non-oil exports of the country and the foreign exchange earned from it have also decreased, and the country's import needs, mainly consumer goods, capital goods, and essential intermediate inputs, remain strong, the country's foreign exchange resources are limited. Therefore, in the first step, it is necessary for the government and the Central Bank to prevent the negative and destructive impact of economic sanctions on the country's trade, firstly, to prevent the wastage of the country's foreign exchange resources and refrain from allocating foreign exchange to unnecessary imported goods, and secondly, to make the foreign exchange available in the country available to meet the country's essential imported needs and goods that do not have domestic equivalents. Announcing a list of essential imported items and goods that do not have domestic equivalents and establishing supervisory systems in the country's customs are among the prerequisites for this policy proposal.

3- Since Iran is forced to import a number of raw materials, goods and services, and under economic sanctions, the import of these goods that are in the process of production is reduced, therefore, through necessary policies such as incentive policies, maximum use of domestic tricks, foreign joint investments, etc., measures should be devised so that a part of the capital goods and intermediate inputs required are produced domestically, considering the existing capabilities, so that the country's production capacity does not face problems. Therefore, the first step is long-term planning in the field of self-sufficiency in the production of those goods and cutting off imports. Entering this path requires prerequisites such as a calculated roadmap, estimating the ability and capacity to achieve the required technical knowledge, using all available capacities (even foreign capacity), and finally, real support for those working in that field. The second step is to continue on the path of self-sufficiency, and even if sanctions are lifted or it is possible to import those goods cheaper than the domestic cost, the prepared roadmap should still proceed without interruption. Even if it is not economically viable for those products to be produced in the country, the potential possibility of producing them in the country should be institutionalized and, with the advancement of science, the quality and technology of their production should also be updated.

4- The results show that the policy of devaluation of the national currency (policy of increasing the exchange rate) cannot create serious momentum in non-oil exports. If policymakers are seeking to stimulate non-oil exports, non-price policies should also be considered in addition to this policy. These policies include: improving the country's business environment, improving trade infrastructure, developing credit lines with target export markets, granting facilities at preferential and targeted rates, strong economic and trade diplomacy in export markets, and ... .

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Conflict of Interest

In adherence to ethical publication standards, the authors affirm that there are no conflicts of interest, either personal or financial, that could have influenced the content or conclusions presented in this research.

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تحلیل اثر تحریم‌های بین‌المللی بر متغیرهای منتخب کلان اقتصادی ایران با استفاده از مدل تعادل عمومی پویای تصادفی کینزی جدید

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چکیده

در این پژوهش، با هدف بررسی تأثیر شوک تحریم‌های بین‌المللی بر متغیرهای منتخب کلان اقتصادی ایران مدلی متناسب با اقتصاد ایران در چارچوب مدل تعادل عمومی پویای تصادفی با رویکرد کینزی جدید طراحی و با استفاده از روش کالیبراسیون حل شده است. به‌منظور اطمینان از اعتبار نتایج مدل، گشتاورهای مرتبهٔ دوم متغیرهای اصلی براساس داده‌های واقعی با گشتاورهای مرتبهٔ دوم مقادیر شبیه‌سازی‌شدهٔ همان متغیرها مقایسه‌شده و توابع واکنش آنی متغیرها به تکانه‌های واردشده به مدل مورد بررسی قرار گرفته‌اند. نتایج این مطالعه نشان می‌دهد که افزایش شدت تحریم‌های بین‌المللی ازطریق کاهش درآمدهای ارزی حاصل از صادرات نفت، کاهش نسبت ذخایر ارزی بانک مرکزی به پایهٔ پولی و افزایش نرخ ارز اسمی، آثار قابل‌توجهی بر متغیرهای کلان اقتصادی دارد و درنهایت به کاهش صادرات کالاهای واسطه‌ای (صادرات غیرنفتی) منجر می‌شود. همچنین، افزایش نرخ ارز اسمی موجب افزایش صادرات کالاهای واسطه‌ای (صادرات غیرنفتی)، کاهش واردات کالاهای مصرفی، کاهش واردات کالاهای سرمایه‌ای، کاهش واردات نهاده‌های واسطه‌ای و افزایش تولید کل (تولید ناخالص داخلی) می‌شود.

کلیدواژگان: نرخ ارز، تحریم‌های اقتصادی، مدل تعادل عمومی پویای تصادفی، مکتب کینزی جدید.
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Did Market Closure Stabilize or Delay the Market? Price Discovery and Volatility Resilience in the Tehran Stock Exchange under Geopolitical Shock

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Abstract

This paper documents nominal price adjustment and daily return variability in the Tehran Stock Exchange around the equity-market suspension from 28 February to 18 May 2026 and reopening on 19 May. It uses a TGJU broad-market proxy and the TSETMC equal-weight index, with 68 valid post-reopening observations. The analysis combines a reproducible suspension audit, historical reference windows, dependence-preserving resampling, pre-event forecast validation, interrupted time-series regressions and volatility-normalization sensitivity tests. The twenty-session cumulative nominal returns are 37.33% and 41.90%, respectively. Both exceed simple forecast benchmarks, but historical tail probabilities lose significance after adjustment across outcomes and horizons, and resampling conclusions depend on block length. Equal-weight absolute-return variability rises more relative to its own baseline; the broad-market conclusion changes when centered standard deviation replaces absolute returns. Normalization estimates of five and twenty-seven sessions arise only under a permissive retrospective rule. Under a rolling-distribution threshold with five consecutive compliant observations, the broad-market confirmation occurs at session 32 and the equal-weight series does not confirm within 68 sessions. A restricted forecasting exercise selects models using pre-event validation and finds no uniform post-event superiority. These findings describe adjustment under a combined geopolitical shock, closure and controlled reopening. They do not identify the causal effect of suspension or establish real recovery, informational efficiency or liquidity resilience.

Keywords: Geopolitical Risk, Market Closure, Price Discovery, Volatility Resilience, Tehran Stock Exchange.
JEL Classification: G01, G10, G14, G15, C22, C53.

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1. Introduction

Geopolitical shocks pose a special challenge for financial markets because they simultaneously affect information flows, investor sentiment, liquidity, inflation expectations, exchange-rate risk, and the credibility of market institutions. In normal conditions, equity markets process news through continuous trading. Under extreme stress, however, authorities may suspend trading in an attempt to protect investors and prevent disorderly price formation. The central question is whether such a closure stabilizes the market or simply transfers the adjustment to the reopening date.

This paper examines the 2026 suspension and controlled reopening of the Tehran Stock Exchange (TSE). The exchange announcement circulated by the Federation of Euro-Asian Stock Exchanges (FEAS, 2026) confirms that equities resumed trading on 19 May 2026 after an 80-day interruption. Reuters (2026) had reported the planned 19 May reopening on 16 May and described the suspension as a measure intended to protect investors, limit panic-driven trading, and improve information for pricing. Iran International (2026) described the actual reopening under tight controls, with several major firms still suspended. The episode provides a case study of post-interruption price adjustment in a sanctioned, inflationary market with limited international integration.

The study makes three contributions. It documents nominal price adjustment after a prolonged exchange-level suspension during a geopolitical shock; compares a TGJU broad-market proxy with the TSETMC equal-weight index; and evaluates the sensitivity of return and variability measures to historical benchmarks, forecast specifications and normalization criteria. Both indices were exposed to the event, so neither serves as an untreated comparison. The analysis describes the combined episode rather than identifying the separate effects of conflict, suspension and reopening restrictions.

The first twenty observed sessions produced nominal cumulative returns of 37.33 percent for the broad-market proxy and 41.90 percent for the equal-weight index. The sixty-session mean absolute-return ratios relative to the pre-event baseline were 1.13 and 1.64. Centered standard-deviation ratios were 0.85 and 1.28, showing that return magnitude and dispersion need not move together. Historical-window tail probabilities do not remain significant after adjustment across eighteen comparisons. Normalization dates vary with the definition, and five- and twenty-seven-session estimates arise only under a permissive retrospective rule.

The rebound is consistent with substantial repricing after reopening, including possible incorporation of accumulated information. However, inflation expectations, changing exchange rates and risk premia, subsequent news and managed trading provide alternative

explanations. A positive nominal index change does not establish real recovery or successful price discovery. The central policy question in the title therefore remains a motivation rather than an identified causal conclusion.

The rest of the paper is organized as follows. Section 2 describes the institutional background and event design. Section 3 reviews the literature. Section 4 describes the data and variables. Section 5 presents the empirical methodology. Section 6 reports the empirical results and discussion. Section 7 discusses policy and risk-management implications. Section 8 summarizes limitations and robustness considerations, and Section 9 concludes.

2. Institutional Background and Event Context

The episode combines a prolonged interruption, a controlled reopening and a challenging macroeconomic setting. Unlike brief trading halts or intraday circuit breakers, the suspension prevented domestic equity trading for an extended period. The reopening involved continued suspensions of some firms and restrictions intended to contain selling pressure (Iran International, 2026). Sanctions, inflation and exchange-rate pressure further limit direct comparisons with deep, internationally integrated markets.

The equity-market suspension ran from 28 February through 18 May 2026 inclusive (80 calendar days), and trading resumed on Tuesday, 19 May 2026. The analysis uses the verified 18 May endpoint throughout. The 80-calendar-day closure is distinct from the 68 valid observed post-reopening returns. The FEAS (2026) exchange statement separately reports 51 foregone trading sessions, a count not reconstructed from a generic weekday calendar.

The primary contemporaneous source is the Tehran Securities Exchange reopening announcement circulated by the Federation of Euro-Asian Stock Exchanges (FEAS, 2026) on 19 May. It confirms that equity-market trading resumed on that date following an 80-day closure; the opening-bell statement by the chairperson of Iran's Securities and Exchange Organization also reports 51 foregone trading days and refers to wartime uncertainty and the need for company disclosures. Mondo Visione (2026) republished the exchange announcement on 20 May, while explicitly dating the ceremony Tuesday, 19 May. Reuters (2026) independently reported on 16 May that equity trading was scheduled to resume on Tuesday, 19 May. The verified institutional dates determine the exclusion interval used throughout the analysis.

The last valid pre-event observation is 25 February 2026. The first reopened return on 19 May bridges this last pre-event price and the first valid reopened level. It is retained

because the adjustment across the interruption is relevant, but it is a long-gap holding-period return rather than a conventional one-day innovation. The 68 valid post-reopening observations end on 1 September 2026.

The episode permits three related descriptive exercises: measuring the direction and timing of observed repricing, comparing return variability across the two affected indices, and testing pre-event forecast relationships during the reopening period. The intervention is not isolated from the geopolitical shock or administrative controls. No untreated market or other identifying variation establishes the counterfactual path under continued trading.

3. Literature Review and Contribution

3-1. Geopolitical risk and financial-market responses

Caldara and Iacoviello (2022) provide a news-based framework for measuring geopolitical risk (GPR) and relate geopolitical threats and adverse events to macroeconomic and financial risks. Subsequent research examines equity returns, volatility and liquidity. Emerging markets are particularly relevant because exchange-rate exposure, commodity dependence and limited financial buffers can shape their responses to geopolitical shocks. A first strand studies the aggregate volatility effect of geopolitical risk. Bouras *et al*. (2019), Yang *et al*. (2021), Salisu *et al*. (2022), and Zhang *et al*. (2023) show that GPR is associated with higher stock-market volatility and has forecasting content in GARCH-MIDAS and related frameworks. Ndako *et al*. (2021) reach similar conclusions in Islamic equity markets. Jaffar *et al*. (2026) extend the evidence to South African industries and show that the volatility effect of geopolitical risk is heterogeneous across sectors. Chatziantoniou *et al*. (2025) document that U.S. sectoral volatility responds differently to distinct categories of geopolitical risk. These studies establish that geopolitical risk matters for volatility, but they generally study markets that remain continuously open.

A second strand focuses on returns and cross-sectional heterogeneity. Zaremba *et al*. (2022) show that geopolitical news can have non-uniform effects across emerging-market equities. Fiorillo *et al*. (2023) and Liu *et al*. (2024) emphasize liquidity and stock-liquidity channels. Yilmazkuday (2024) examines stock-price responses to geopolitical risk, while Ginn and Saadaoui (2025) use local projections to examine equity-return responses across economies. SenGupta and Debnath (2026) provide detailed evidence for India and highlight heterogeneous resilience across sectors and factor-style indices. Huynh and Khoa (2026) provide another emerging-market perspective by studying Vietnam. This literature motivates our distinction between the broad market and the equal-weight index.

A third strand examines military conflicts. Studies of the Russia–Ukraine war document heterogeneous return and volatility responses across countries and markets (Ahmed *et al*., 2023; Assaf *et al*., 2023; Kamal *et al*., 2023; Oyadeyi *et al*., 2024). Altemur *et al*. (2024) examine stock-market responses to the Hamas–Israel conflict. Lakkol and Rao (2026) study resilience to geopolitical shocks and emphasize variation across episodes. The present paper extends this discussion to a market in which trading was suspended during the shock itself.

3-2. Market closures, trading halts, and price discovery

The second relevant literature examines how no-trading intervals affect price formation. Hong and Wang (2000) provide a theoretical foundation by showing that periodic market closures alter return and trading patterns. Corwin and Lipson (2000) show that order flow during trading halts is informative for reopening prices. Christie *et al*. (2002) demonstrate that halt and reopening mechanisms affect prices, trading activity, and execution costs. Hautsch and Horvath (2019) show that trading pauses can assist price discovery but may also create adverse effects for liquidity and post-pause volatility.

These studies make the institutional design of a trading interruption central to its interpretation. Reopening prices and order flow can reveal information accumulated during a halt, while changes in trading mechanisms can affect liquidity and execution costs (Corwin and Lipson, 2000; Christie *et al*., 2002). Evidence from shorter trading pauses also cautions against treating price adjustment and market quality as interchangeable outcomes (Hautsch and Horvath, 2019). A prolonged exchange-level suspension requires an additional distinction between observed post-reopening changes and the unobserved path under uninterrupted trading.

3-3. Volatility resilience and model-based counterfactuals

Resilience has several distinct dimensions: the persistence of return disturbances, the time required for variability to return to a specified baseline, and the restoration of trading conditions. Evidence on heterogeneous market responses to geopolitical shocks motivates examining these dimensions separately (Zaremba *et al*., 2022; Lakkol & Rao, 2026). With daily aggregate index data, this study measures return variability and operational normalization times. It does not directly measure liquidity recovery or a return to fundamental value.

Forecasting models can supply conditional benchmarks for observed post-event paths. GARCH models impose a structured variance recursion, while flexible methods can

capture additional patterns. In a short crisis sample, however, searching many specifications on the evaluation period can create optimistic rankings. This study therefore separates pre-event validation from post-event evaluation and restricts its principal forecasting comparison to transparent candidates. It does not claim that the forecast-implied path is an identified no-closure path.

3-4. Positioning relative to recent studies

Table 1. Positioning of the study within the recent and foundational literature. The study documents a prolonged exchange-level interruption and distinguishes observed repricing, historical rarity and definition-dependent return variability from causal price-discovery identification.

Representative studies	Literature strand and method	Relevance for the present paper
Caldara and Iacoviello (2022)	News-based geopolitical risk measurement	Geopolitical risk raises downside macro-financial risk and provides the conceptual basis for treating war-related events as priced uncertainty.
Salisu *et al*. (2022)	GARCH-MIDAS; emerging markets	Geopolitical risk improves stock-volatility forecasting in emerging markets, motivating volatility-based event assessment.
Zaremba *et al*. (2022)	Cross-section of emerging-market returns	Equity responses to geopolitical news are heterogeneous rather than uniformly negative.
Zhang *et al*. (2023)	Global GPR and stock volatility	Geopolitical volatility effects vary across countries and market states.
Kamal *et al*. (2023); Ahmed *et al*. (2023); Assaf *et al*. (2023)	Russia-Ukraine war event studies	Recent military conflicts generated heterogeneous return and volatility responses across global and regional markets.
Fiorillo *et al*. (2023); Liu *et al*. (2024)	Geopolitical risk and liquidity	Geopolitical uncertainty affects the liquidity channel, not only returns and volatility.
Yilmazkuday (2024); Ginn and Saadaoui (2025)	Global and local-projection evidence	Geopolitical risk can depress stock prices, but dynamic responses differ across economies.
Chatziantoniou *et al*. (2025); Jaffar *et al*. (2026)	Sectoral GPR and industry volatility	Risk transmission is strongly sector-specific; defensive segments may display resilience.
SenGupta and Debnath (2026); Huynh and Khoa (2026)	Emerging-market stock responses	Single-country emerging markets show rich heterogeneity in sensitivity to global and country-specific geopolitical risk.
Lakkol and Rao (2026)	Multi-event resilience event study	Recent markets show selective resilience and longer assimilation of geopolitical events after the pandemic period.
Hong and Wang (2000); Christie *et al*. (2002); Corwin and Lipson (2000)	Market closures and trading halts	No-trading intervals shift the timing of price discovery and affect reopening volatility and order flow.
Hautsch and Horvath (2019)	Trading pauses and market quality	Trading interruptions can stabilize information processing but may also intensify post-reopening volatility.

3-5. Research gap and innovations

Despite the rapid growth of research on geopolitical risk and financial markets, three gaps remain. First, most studies analyze continuously traded markets. They therefore estimate how prices react to geopolitical risk when trading is available, not how prices react after a long no-trading interval. Second, most market-closure studies examine short trading halts, circuit breakers, trading-floor closures, or regular overnight closures. They rarely study a prolonged national stock-market suspension during war. Third, the resilience literature often focuses on aggregate market recovery, while less attention is paid to differences between headline and equal-weight market behavior.

The paper addresses these gaps by documenting the suspension chronology, applying a common cleaning rule to two differently weighted market measures, and comparing event outcomes with historical and model-based benchmarks. Sensitivity analysis distinguishes return magnitude from centered dispersion and tests alternative normalization definitions. Model selection uses pre-event validation data. The contribution is a reproducible case study; the design does not estimate a structural information share, an optimal suspension duration or the causal effect of closure.

4. Data and Variables

4-1. Data sources and sample construction

The analysis draws on daily records from TSETMC, TGJU and Yahoo Finance for the extraction period from 1 January 2010 to 2 September 2026. Raw observations, including missing values, are aligned to a complete calendar; filled observations are not used to construct target returns. Because direct retrieval of TEDPIX was unsuccessful, tgju_bourse is treated as a TGJU broad-market proxy rather than an independently verified official total-return index.

Target returns are calculated from observed index levels without forward filling, after excluding all nonmissing target records dated from 28 February through 18 May 2026 inclusive, regardless of whether the reported index level changes. No target records dated 19 May or later are removed merely because their value repeats an earlier value. The underlying series are sourced from TSETMC, TGJU and Yahoo Finance. The four external predictors are log changes in USD/IRR, international gold and the S&P 500, together with the log VIX level. Domestic 18k gold provides an alternative valuation numeraire. Other source variables appear only in the descriptive inventory.

The available data contain date labels rather than intraday publication timestamps, vendor revision histories, target trade counts or index constituent histories. Provider labels

and field names are documented in the variable definitions below. Units and transformations of variables actually used are documented below. Unused fields, including the unusually scaled us10y series and WTI observations that can be nonpositive, are excluded from the predictors; no economic interpretation is based on transformations of these unused fields.

Target returns use successive observed target dates, with no target interpolation, backfill or synthetic closure zeros. The two target calendars coincide after reopening, but neither is forced onto a U.S. trading calendar. External transformations are first calculated between successive actually recorded source observations. Their most recent known transformation is carried forward for at most seven calendar days and delayed by two calendar days before being matched to a target observation. This conservative delay excludes same-date U.S. closing information from Iranian-session forecasts and handles different weekends without assuming synchronized closes.

Calendar dates are treated as provider-local session labels. Iran uses Asia/Tehran and U.S. sessions use America/New-York, with different intraday closing times. The two-day rule avoids relying on an undocumented same-day time-zone conversion. Missing predictor values are imputed using medians estimated only in each training window; regression medians use the pre-event baseline only. Scaling and Ridge estimation are also fitted within each training window. There is no backward fill or full-sample normalization. The source-date alignment requires predictor observations to precede target dates by at least two calendar days.

The date-based delay reduces look-ahead from same-day observations but does not establish historical vintage availability. Intraday release timestamps and subsequent vendor revisions are unavailable. Target-only benchmarks therefore provide comparisons that do not depend on external-data timing, while results using external predictors are interpreted as conditional sensitivity checks.

Table 2. Variable definitions and transformations. Source fields are retained by name; the four predictors use a two-calendar-day availability delay and training-only preprocessing. Unused source variables are explicitly identified.

Variable	Definition	Role	Transformation
equal_weight_index	TSETMC equal-weight index in points	Outcome	Observed-session log return × 100
tgju_bourse	TGJU broad-market proxy in index points	Outcome	Observed-session log return × 100
usd_irr	TGJU quotation in IRR per USD	Predictor	Log change × 100; 2-calendar-day delay
coin_emami	TGJU raw level field; inventory only	Inventory only	Excluded from predictors

Variable	Definition	Role	Transformation
domestic_gold_18k	TGJU 18k gold quotation in IRR per provider unit	Alternative numeraire	Matched-date price ratio
domestic_gold_24k	TGJU raw level field; inventory only	Inventory only	Excluded from predictors
mesghal	TGJU raw level field; inventory only	Inventory only	Excluded from predictors
global_gold_tgju	TGJU raw level field; inventory only	Inventory only	Excluded from predictors
oil_opec_tgju	TGJU raw level field; inventory only	Inventory only	Excluded from predictors
gold_global	Yahoo international gold price field in provider units	Predictor	Log change × 100; 2-calendar-day delay
silver_global	Yahoo Finance raw level field; inventory only	Inventory only	Excluded from predictors
oil_wti	Yahoo Finance raw level field; inventory only	Inventory only	Excluded from predictors
oil_brent	Yahoo Finance raw level field; inventory only	Inventory only	Excluded from predictors
sp500	Yahoo S&P 500 index in points	Predictor	Log change × 100; 2-calendar-day delay
vix	Yahoo volatility index in points	Predictor	Log level; 2-calendar-day delay
dxy	Yahoo Finance raw level field; inventory only	Inventory only	Excluded from predictors
us10y	Yahoo Finance raw level field; inventory only	Inventory only	Excluded from predictors
Closure interval	28 February–18 May 2026 inclusive	Date exclusion	80 calendar days
Return magnitude	$\lvert r_t \rvert$ in percentage points	Outcome proxy	Mean and baseline percentile shares
Squared return	r^2_t in squared percentage points	Second-moment proxy	RMS and QLIKE evaluation

4-2. Descriptive statistics of level variables

Table 3 summarizes the raw level-variable inventory on a complete calendar from 1 January 2010 to 2 September 2026. Missing rates include weekends, holidays and periods before a series begins. They are not conditional trading-day data-quality rates. The U.S. yield field retains its provider scale in the inventory but is excluded from estimation; nonpositive WTI values also preclude an automatic log transformation.

Table 3. Descriptive statistics of raw level variables. N counts nonmissing raw entries, while missing rates use the complete calendar. Provider units are retained; the U.S. yield field is not interpreted or used as a predictor.

Variable	N	Mean	SD	Median	Min.	Max.	Missing
equal_weight_index	2996	344776.83	364885.77	322999.50	9099.30	1.83e+06	0.508
tgju_bourse	2752	1.05e+06	1.19e+06	376331.00	61163.70	6.58e+06	0.548
usd_irr	3940	314277.37	418083.35	131905.00	13350.00	2.14e+06	0.353
coin_emami	3473	2.61e+08	4.52e+08	9.70e+07	8.40e+06	2.18e+09	0.430
domestic_gold_18k	3492	2.53e+07	4.53e+07	9.34e+06	860000.00	2.22e+08	0.427
domestic_gold_24k	3351	3.52e+07	6.12e+07	1.39e+07	1.19e+06	2.96e+08	0.450
mesghal	3494	1.10e+08	1.96e+08	4.05e+07	3.73e+06	9.62e+08	0.426
global_gold_tgju	4362	1795.38	835.33	1562.14	1051.74	5400.25	0.284
oil_opec_tgju	2572	67.62	20.66	67.58	12.22	145.24	0.578
gold_global	4191	1780.55	811.51	1556.70	1050.80	5318.40	0.312
silver_global	4191	25.19	12.84	21.85	11.73	115.08	0.312
oil_wti	4192	71.98	20.68	71.94	-37.63	123.70	0.312
oil_brent	4161	77.87	23.27	75.68	19.33	127.98	0.317
sp500	4191	3114.21	1682.28	2672.63	1022.58	7798.99	0.312
vix	4193	18.42	6.77	16.73	9.14	82.69	0.311
dxy	4193	92.99	9.27	95.54	72.93	114.11	0.311
us10y	4189	0.27	0.10	0.25	0.05	0.50	0.312

5. Empirical Strategy

5-1. Event definition and target cleaning

All observed index levels dated within the documented suspension, 28 February–18 May 2026 inclusive, are excluded before target returns are calculated. The equal-weight source contains 50 such records: 42 dated 28 February–6 May and eight dated 9–13 May (five) and 16–18 May (three). Thus, 42 + 8 = 50 excluded equal-weight observations. All 50 repeat the last pre-event level of 952,681.5 within a tolerance of 10^{-8} index points. The additional eight records predate the actual reopening on 19 May; none is an excluded post-reopening observation. The broad-market proxy contains two closure-dated records, one equal to its last pre-event level and one different. Both are excluded by their dates, regardless of their values.

The target-cleaning procedure is institutional and date-based. Observed levels dated before 28 February 2026 or on or after 19 May 2026 are eligible; levels dated from 28 February through 18 May are excluded. The final observed pre-event level is dated 25 February for both indices. No separate filter removes flat-valued observations after reopening. Constant prices outside the documented suspension cannot, on their own, demonstrate an absence of trading. Matched intraday transactions and vendor revision histories are unavailable, so the executability of each quoted level cannot be independently verified.

The date audit yields 2,996 raw equal-weight levels minus 50 closure-dated records, leaving 2,946 retained levels (2,878 pre-event levels and 68 reopened levels). The broad-market proxy contains 2,752 raw levels minus two closure-dated records, leaving 2,750

retained levels (2,682 pre-event and 68 reopened). The two samples therefore yield 2,877 and 2,681 pre-event adjacent-session returns, respectively, and 68 reopened returns for each index, including the first return spanning the no-trading interval. The exclusion counts by index and period are summarized in Table 4. No synthetic closure zero returns, interpolated target prices or post-reopening stale-value deletions are introduced.

5-2. Return, volatility, and event-window measures

For each target index, daily log returns are calculated as:

$$r_t = 100[ln\, P_t - ln\, P_{t-1}]$$

Here P_t is the raw index level on the current observed target session and P_{t-1} is the preceding valid target level. Absolute return is a daily return-magnitude proxy:

$$RV_t = |r_t|$$

The squared return supplies a second-moment proxy:

$$RV_t^{(2)} = r_t^2$$

For a post-reopening horizon H, cumulative nominal return is:

$$\mathrm{CR(H)} = 100\{\exp[\frac{1}{100}\sum_{h=1}^{H} r_h] - 1\}$$

The cumulative abnormal log return is defined as the sum of deviations from the selected forecast benchmark:

$$CAR_{log}(\mathrm{H}) = \sum_{h=1}^{H}(r_h - \hat{r}_h)$$

Return-magnitude resilience compares the average absolute return over H reopened sessions with its mean over the final 252 pre-event sessions. In the following expression, h = 1 denotes the first reopened return, and s = 0 denotes the last pre-event return:

$$VR_H = \frac{\frac{1}{H}\sum_{h=1}^{H}|r_h|}{\frac{1}{252}\sum_{s=-251}^{0}|r_s|}$$

Absolute-return ratios compare the event mean of |r| with its mean over the final 252 pre-event sessions. Root-mean-square (RMS) ratios use √mean(r^2) for both periods, whereas centered standard deviations remove each window's sample mean. High- and extreme-magnitude shares use the 75th and 90th percentiles of baseline daily absolute returns. Absolute returns and RMS can increase during a sustained positive drift even if centered dispersion falls. These measures are observable proxies rather than direct observations of latent volatility.

The primary normalization criterion compares the post-event 10-session rolling mean of |r| with the 75th percentile of the corresponding pre-event rolling-mean distribution. Only complete windows are used. Normalization is confirmed after five consecutive rolling observations are at or below the threshold. The onset is the first observation in that run, and confirmation occurs four sessions later. If no qualifying run occurs, normalization is right-censored at session 68. This operational definition describes return-magnitude normalization rather than recovery of fundamental value.

Sensitivity grids vary the pre-event baseline over 126, 252 and 504 sessions, rolling length over 5, 10 and 20 sessions, percentile over 75 and 90, and the metric over absolute-return means, mean squared returns and centered rolling variance. The last two have the same crossing dates as RMS and rolling standard deviation under their corresponding transformed thresholds. A permissive sensitivity criterion is also evaluated: a 10-session absolute-return average with as few as five observations is compared with the percentile of individual daily absolute returns, and at least 70% of the next up-to-ten rolling values must comply. That rule uses future observations and an unmatched reference distribution.

5-3. Placebo windows

Historical pseudo-starts begin after 252 pre-event return observations. Each has a complete subsequent 60-session window ending before the actual event, and horizons 5, 20 and 60 share the same start dates. A dense design advances starts by five sessions, producing 474 broad-market and 514 equal-weight reference windows. Event windows overlap in that design. A second design advances by sixty sessions, producing 40 and 43 nonoverlapping event windows; their baseline windows can still overlap. Starts are deterministic, not selected for favorable outcomes.

For each horizon, the outcomes are cumulative return, the absolute-return ratio and the high-magnitude share. The upper-tail reference probability is (1 + number of reference statistics at least as large as the event statistic)/(1 + number of reference windows). This finite-sample convention prevents zero probabilities. The Holm (1979) adjustment covers 18 comparisons: two indices × three horizons × three statistics, separately for each reference design. The resulting probabilities describe historical rarity; they are not exact randomization-test p-values because the event date was not randomly assigned and market conditions may change over time.

A separate circular moving-block exercise draws 1,999 histories of length 312 from each complete pre-event return sequence using contiguous blocks of 5, 10 or 20 sessions. The first 252 simulated observations form a local baseline and the last 60 an event path.

Each horizon and statistic is recalculated within the simulated history, and the same finite-sample and Holm conventions are applied. Blocks retain short-run temporal dependence; they do not reproduce an 80-day closure or guarantee stationarity. Contrasts across block lengths are reported rather than selecting a preferred significance result. Seed 20261017 fixes all simulations.

5-4. Counterfactual forecasting

The forecast exercise uses six fixed candidates: the final-252-session historical mean, the expanding historical mean, a recursive AR(1), and standardized Ridge regressions with penalty 1, 10 or 100 using the four delayed external predictors. Three consecutive 63-session validation blocks end before the shock. Each model is fitted only on observations preceding its validation block. The selected candidate minimizes pooled validation squared error across the 189 validation observations. It is then refitted through 25 February 2026. All candidates, including those not selected, remain visible in the sensitivity results.

Target-only forecasts are fixed-origin sequences indexed by observed post-reopening sessions. No daily target returns are imputed for the closure, and these forecasts do not construct a traded price path inside it. The reopening bridge return is compared with a session-return benchmark, so its horizon mismatch is explicitly acknowledged; exclusion of that first observation is checked. Ridge paths condition on delayed external realizations arriving after the shock. Their coefficients are estimated pre-event, but their predictor paths are not wholly known at the pre-event origin. They are conditional benchmark paths, not unconditional no-war or no-closure counterfactuals.

The cumulative benchmark deviation is $\Sigma(r - \hat{r})$, in log percentage points. The associated relative-price gap is $100\{\exp[\Sigma(r - \hat{r})/100] - 1\}$. This ratio measure is distinguished from the arithmetic difference between two cumulative percentages. Forecast prediction bands add cumulative, mean-centered, out-of-sample validation residuals resampled in circular blocks of 5, 10 and 20 sessions to the forecast sum. The 2.5th and 97.5th percentiles give 95% conditional predictive bands. They capture validation-error dependence, but not full parameter-selection uncertainty, changing regimes or a causal policy counterfactual; 189 validation errors limit their precision.

5-5. Interrupted time-series regressions

The interrupted time-series model uses 252 pre-event sessions and 60 observed sessions after reopening. Three mutually exclusive indicators identify reopening sessions 1–5, 6–20

and 21–60. The pre-event period serves as the comparison baseline, with all three reopening indicators equal to zero. The specification is:

$$y_t = \alpha + \rho r_{t-1} + \gamma|r_{t-1}| + \tau t + \beta_1 D_{1-5,t} + \beta_2 D_{6-20,t} + \beta_3 D_{21-60,t} + \delta' X_t + u_t$$

The dependent variable y_t is the daily log return or its absolute value. X_t contains the four delayed external predictors, and t is an observed-session trend scaled by 252. Lags refer to successive observed target returns, so the first reopened return remains in the regression sample. Missing controls are imputed using pre-event medians. Ordinary least squares estimates use heteroskedasticity- and autocorrelation-consistent (HAC) standard errors following Newey and West (1987), with a Bartlett kernel, maximum lag 5 and finite-sample correction n/(n − k).

Sensitivity specifications use HAC maximum lags 1, 10 and 20; an unadjusted mean-shift model; a trend without external controls; a calendar-day trend; an additional post-event slope; exclusion of the first reopening return; and squared return as the outcome. The post-slope variant can weaken significance. All estimates describe conditional associations under the combined event, not a separately identified effect of closure.

5-6. Volatility model comparison

To avoid reselecting among numerous models on 68 event observations, the comparison restricts candidates to a constant pre-event variance, EWMA with decay 0.94 or 0.97, and Gaussian quasi-maximum-likelihood GARCH(1,1). Candidate selection uses pooled QLIKE over the same three pre-event validation blocks. GARCH parameters and the return mean are refitted using all pre-event returns and then frozen. One-step filters update only with preceding observed post-event returns. The first reopening forecast uses the pre-event state; no zero returns are inserted during suspension. This is a session-clock approximation, whose first forecast does not model 80 calendar days of latent risk accumulation.

$$\text{QLIKE} = \frac{1}{T}\sum_{t=1}^{T}[\ln(h_t) + \frac{r_t^2}{h_t}]$$

The evaluation loss is QLIKE = mean[$\ln(h_t) + r^2_t/h_t$], where h_t is the one-step conditional variance forecast. The return-squared proxy is noisy and has a mean component; it is not high-frequency realized variance (Patton, 2011). GARCH dynamics are:

$$h_t = \omega + a\varepsilon_{t-1}^2 + bh_{t-1}$$

The GARCH parameters obey $\omega > 0$, $a \geq 0$, $b \geq 0$ and $a + b \leq 0.999$. Innovations are demeaned using the pre-event mean. EWMA candidates have fixed decay 0.94 or 0.97. All parameters are frozen after pre-event estimation; states update using only preceding

observed returns. Paired moving-block intervals for loss differences versus constant variance use 1,999 draws with block lengths 5, 10 and 20. They remain exploratory in a 68-observation event sample.

The forecasting exercise is retrospective in its research design: the restricted candidate set was defined after the episode. Keeping estimation and validation entirely within pre-event data reduces evaluation-sample leakage but does not make the study prospectively registered. Model rankings are interpreted as exploratory forecast comparisons.

6. Empirical Analysis and Discussion

The results follow the empirical sequence in Section 5: sample construction, return diagnostics, event windows, historical comparisons, normalization, forecast benchmarks, interrupted time-series estimates, volatility-model comparisons and predictor availability. The analysis distinguishes the 80-calendar-day suspension from counts of observed trading sessions.

The analysis asks whether observed nominal returns are large relative to pre-event conditions, whether historical reference windows and dependence-preserving resampling agree, how variability differs across the two affected indices, and how normalization changes with its definition. None of these questions identifies the separate effect of suspension. Forecast comparisons supplement the event evidence rather than establish a no-closure counterfactual.

The daily return of each target index is computed as:

$$r_t = 100[ln\, P_t - ln\, P_{t-1}]$$

P_t denotes a valid observed target level. The absolute return is a return-magnitude proxy:

$$RV_t = |r_t|$$

For an H-session reopening window, cumulative nominal return is:

$$\mathrm{CR(H)} = 100\{\exp[\frac{1}{100}\sum_{h=1}^{H} r_h] - 1\}$$

The abnormal log-return sum is measured relative to a forecast-implied benchmark:

$$CAR_{log}(\mathrm{H}) = \sum_{h=1}^{H}(r_h - \hat{r}_h)$$

The event absolute-return ratio compares matching event and baseline statistics, using the event-time indexing defined in Section 5.2:

$$VR_H = \frac{\frac{1}{H}\sum_{h=1}^{H}|r_h|}{\frac{1}{252}\sum_{s=-251}^{0}|r_s|}$$

6-1. Event Definition, Data Cleaning, and Data Sufficiency

Table 4 reports the institutional chronology and reconciles the complete raw and retained index-level counts. For the equal-weight index, 42 closure-dated records occur through 6 May and another eight occur on 9–13 and 16–18 May. All 50 are within the documented 28 February–18 May suspension, before the 19 May reopening, and are excluded once. The broad-market proxy has two suspension-dated records, both excluded under the same date rule.

Table 4. Institutional suspension dates and transparent reconciliation of raw and retained index levels. The 42 + 8 decomposition concerns closure-dated equal-weight records, not post-reopening deletions.

Item	Broad market index	Equal-weight index
Documented suspension	28 February–18 May 2026	28 February–18 May 2026
Last pre-event level	25 February 2026	25 February 2026
First reopened session	19 May 2026	19 May 2026
Calendar closure duration	80 days	80 days
Valid target levels	2750	2946
Pre-event returns	2681	2877
Post-event returns	68	68
Raw target-level entries	2,752	2,996
Excluded 28 February–6 May	2	42
Excluded 9–13 and 16–18 May	0	8
Excluded on or after reopening (19 May)	0	0
Excluded suspension entries	2	50
External predictors	4	4

The arithmetic is consistent across the two indices. The equal-weight sample contains $2{,}996 - 42 - 8 = 2{,}946$ retained levels; the broad-market sample contains $2{,}752 - 2 = 2{,}750$ retained levels. Their valid pre-event return counts are 2,877 and 2,681, respectively, with 68 post-reopening returns for each index. The first reopening return bridges the trading suspension. The unchanged equal-weight readings during closure corroborate their status as carried-forward values, but exclusion is determined by the institutional dates rather than the absence of a level change.

6-2. Return and Tail-Risk Diagnostics

Tables 5a and 5b summarize the distributions and time-series properties of the retained observed-session returns. Both targets exhibit non-normality and serial dependence. These features motivate inference that allows for temporal clustering and sensitivity to resampling block length. The diagnostics characterize the series; they do not establish causal identification or validate a fundamental-recovery interpretation.

Table 5a. Distributional diagnostics. Returns and absolute returns are measured in percent. Jarque-Bera p-values reject normality for both targets and volatility proxies.

Target	Series	N	Mean	SD	Skewness	Excess kurtosis	JB p
Broad market index	Return	2749	0.161	1.250	0.279	5.395	<0.001
Broad market index	Absolute return	2749	0.818	0.959	2.256	9.369	<0.001
Equal-weight index	Return	2945	0.177	1.062	0.126	1.706	<0.001
Equal-weight index	Absolute return	2945	0.760	0.761	1.573	2.467	<0.001

Table 5b. Time-series diagnostics for the retained return series. ADF, Ljung–Box and ARCH-LM results refer to the same valid observed-session sample. Ljung–Box and ARCH-LM use lag 10; very small probabilities are shown as p < 0.001. These diagnostics do not identify a closure effect.

Target	Series	ADF p	Ljung–Box p	ARCH LM	ARCH p	Result
Broad market index	Return	<0.001	<0.001	200.25	<0.001	Serial dependence and ARCH
Broad market index	Absolute return	<0.001	<0.001	200.25	<0.001	Serial dependence and ARCH
Equal-weight index	Return	<0.001	<0.001	664.30	<0.001	Serial dependence and ARCH
Equal-weight index	Absolute return	<0.001	<0.001	664.30	<0.001	Serial dependence and ARCH

Figures 1 and 2 display the observed return and absolute-return paths around the suspension. The closure is a blank no-trading interval, not a synthetic string of zero returns. Positive return magnitude can reflect the reopening drift as well as centered dispersion.

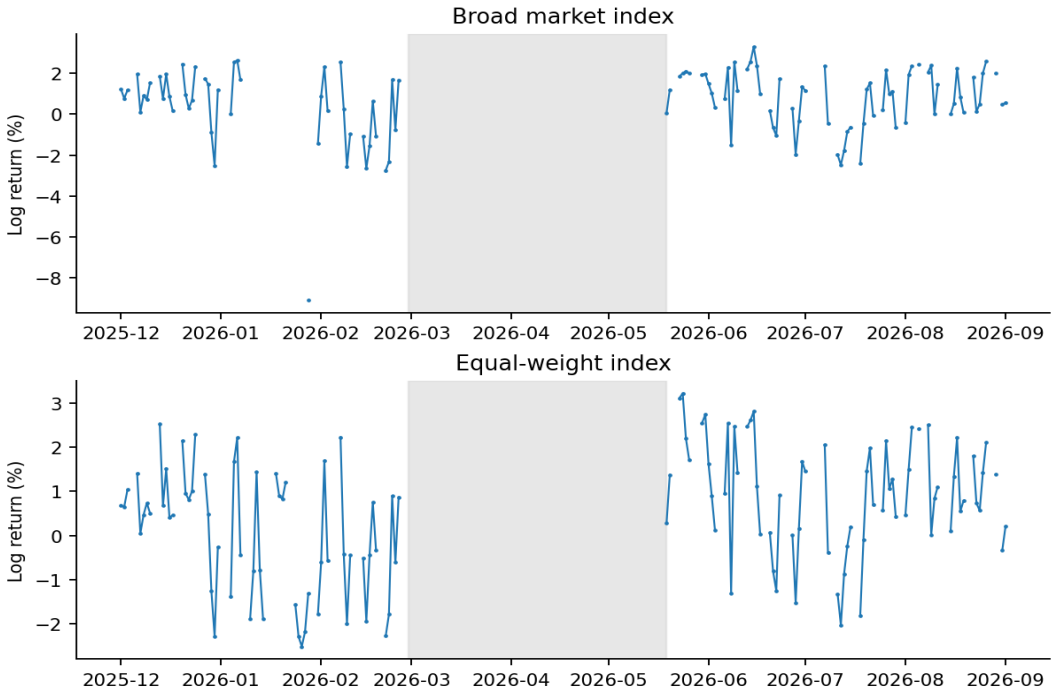

Fig. 1: Observed-session log returns around the documented suspension. Shading covers 28 February–18 May 2026; the return at 19 May bridges the preceding valid level.

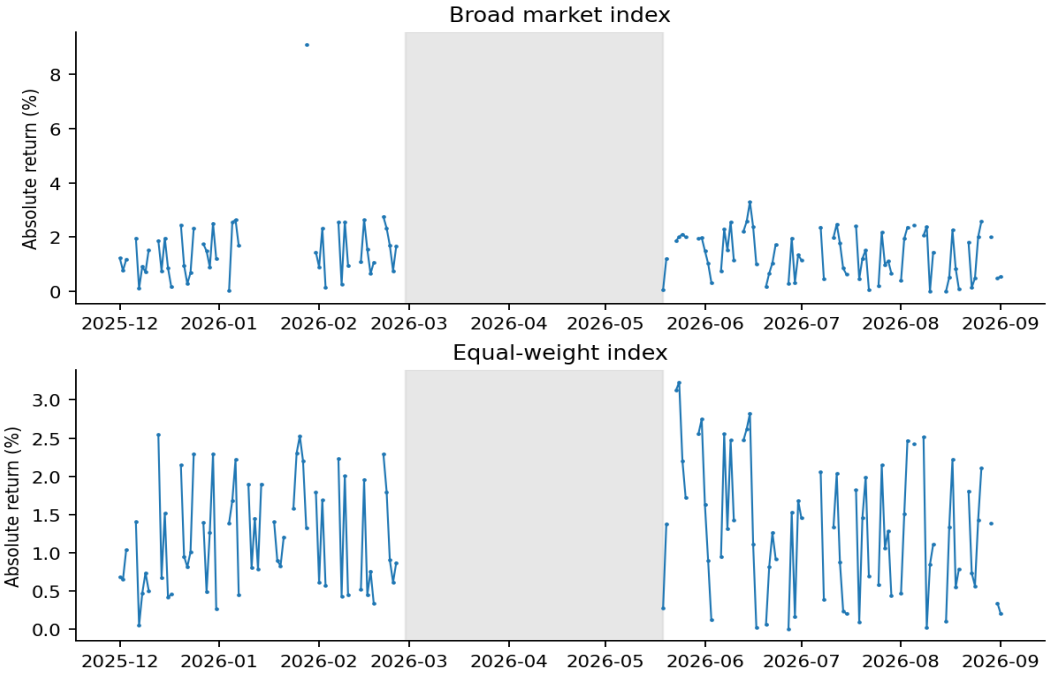

Fig. 2: Absolute log returns around the documented suspension. This daily magnitude proxy is distinct from centered volatility and high-frequency realized variance.

Figure 3 compares pre-event and reopened absolute-return distributions. Both are right-skewed, but the comparison is descriptive and affected by the short event sample. A different mean return can shift absolute magnitudes without an equivalent rise in centered dispersion.

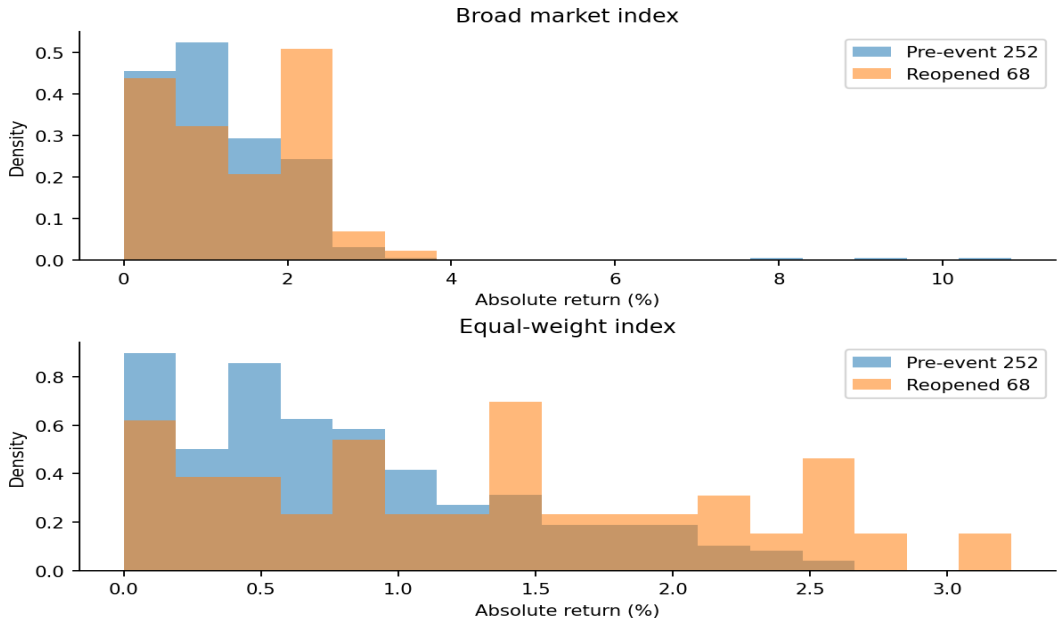

Fig. 3: Distribution of absolute returns in the final 252 pre-event sessions and the 68 observed reopening sessions, using identical bins for each index.

6-3. Event-Window Evidence: Post-Reopening Price Adjustment

Table 6. Event-window cumulative nominal returns, abnormal log-return sums and variability. CAR is Σ(r − r̂), in log percentage points, using the pre-event-validation-selected benchmark. High and extreme shares use daily baseline |r| percentiles 75 and 90.

Target	Window	CR %	CAR log pp	Mean |r|	Abs ratio	High %	Extreme %	Drawdown %
Broad market index	Pre 252	77.63	—	1.218	1.00	25.0	10.3	-26.34
Broad market index	Post 5	7.52	5.73	1.450	1.19	60.0	0.0	0.00
Broad market index	Post 20	37.33	28.03	1.738	1.43	60.0	30.0	-1.50
Broad market index	Post 60	60.28	37.71	1.377	1.13	43.3	21.7	-10.47
Equal-weight index	Pre 252	8.70	—	0.817	1.00	25.0	10.3	-22.88

Target	Window	CR %	CAR log pp	Mean |r|	Abs ratio	High %	Extreme %	Drawdown %
Equal-weight index	Post 5	10.76	10.05	2.043	2.50	80.0	60.0	0.00
Equal-weight index	Post 20	41.90	34.34	1.881	2.30	75.0	50.0	-1.30
Equal-weight index	Post 60	77.07	55.15	1.342	1.64	55.0	31.7	-6.38

Table 6 reports horizons of 5, 20 and 60 observed sessions and the 252-session local baseline. Cumulative nominal returns use exact exponential compounding of log returns. CAR denotes the sum of abnormal log returns in log percentage points, rather than an arithmetic simple-return product or an identified closure effect.

The broad-market cumulative nominal returns are 7.52%, 37.33% and 60.28% at 5, 20 and 60 sessions. Equal-weight returns are 10.76%, 41.90% and 77.07%. The twenty-session abnormal log-return sums against the validation-selected benchmarks are 28.03 and 34.34 log percentage points. These correspond to relative-price gaps of 32.35% and 40.97%, respectively. A relative-price gap, an abnormal log-return sum and an arithmetic difference of cumulative percentages are different quantities.

Inflation expectations, nominal asset demand, evolving risk premia, firm composition, disclosure news and managed order flow remain plausible explanations. A matched CPI series is not included in the analysis, so CPI-deflated investor recovery is not estimated. Higher index levels do not establish restored purchasing power, the ability to sell at quoted prices, or welfare improvement. Continued firm suspensions can affect both index representativeness and the set of investors able to trade.

Excluding the first reopened return while retaining the same twenty-session end date gives cumulative nominal returns of 37.23% and 41.51%. The rebound therefore extends across subsequent sessions rather than arising entirely from the return spanning the suspension. These are changes in domestic nominal index levels, without an independently verified dividend-reinvestment adjustment.

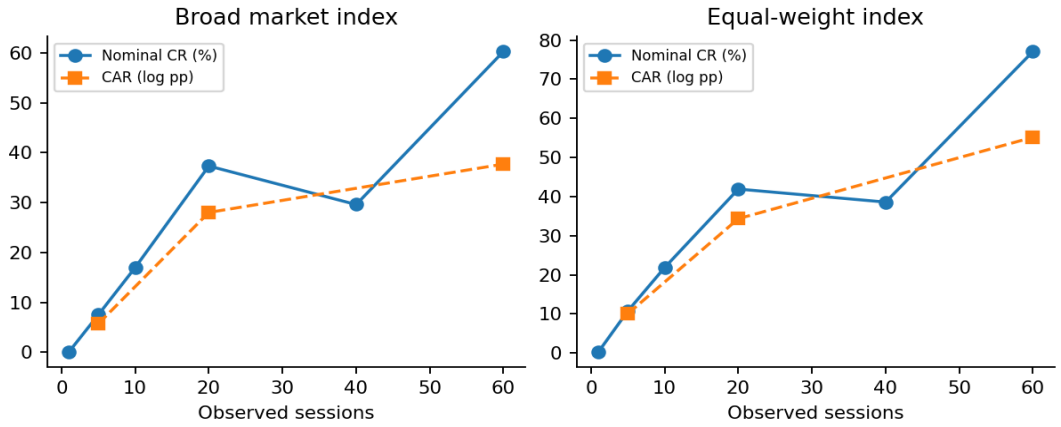

Fig. 4: Cumulative nominal returns and cumulative abnormal log-return sums over 1, 5, 10, 20, 40 and 60 observed sessions. The benchmark parameters are estimated before the shock.

6-4. Placebo Evidence

The historical comparison uses complete pre-event windows selected by a deterministic rule. Five-session spacing yields 474 broad-market and 514 equal-weight starting dates; sixty-session spacing yields 40 and 43 nonoverlapping event windows, although their baselines can still overlap. Table 7 reports cumulative returns, and Table 8 reports variability measures. The tail probabilities describe the reference distributions rather than randomized treatment effects.

Table 7. Historical reference comparison for cumulative nominal returns. Tail p = (exceedances + 1)/(windows + 1). Holm adjustment covers eighteen comparisons per design: two indices × three horizons × three outcomes.

Target	H	Actual %	Median %	p95 %	N windows	Tail p	Holm 18
Broad market index	5	7.52	0.37	7.38	474	0.0505	0.5558
Broad market index	20	37.33	1.88	21.54	474	0.0253	0.3789
Broad market index	60	60.28	4.37	60.29	474	0.0526	0.5558
Equal-weight index	5	10.76	0.51	7.72	514	0.0214	0.3631
Equal-weight index	20	41.90	1.49	26.15	514	0.0117	0.2097
Equal-weight index	60	77.07	5.25	69.18	514	0.0427	0.5301

The broad-market twenty-session gain exceeds 463 of 474 historical reference windows and the equal-weight gain exceeds 509 of 514. Their upper-tail probabilities are 0.0253 and 0.0117, but Holm-adjusted values are 0.3789 and 0.2097. Thus, the reference-window design does not establish family-wise significance at 5%. The nonoverlapping-event design

is even less precise, with only 40 and 43 windows. Its twenty-session probabilities are 0.0244 and 0.0455 before adjustment and 0.4390 and 0.7727 after it.

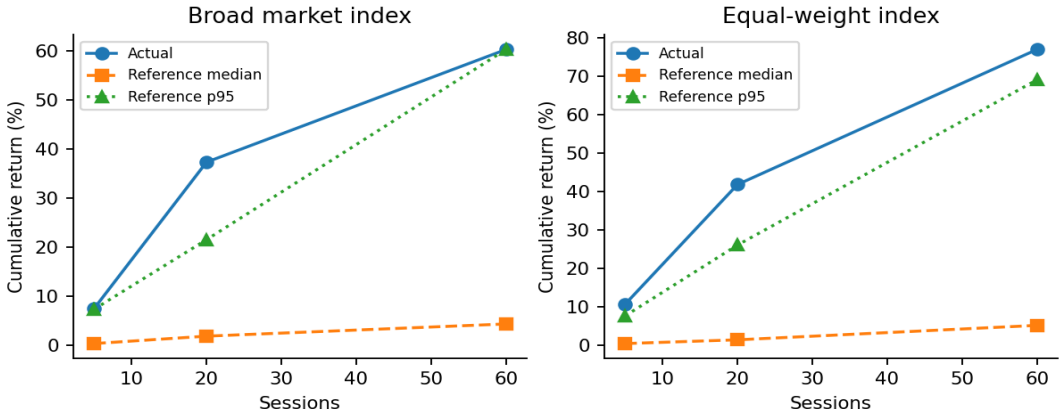

Fig. 5: Actual cumulative nominal returns and historical-reference medians and 95th percentiles. Visual extremity is distinguished from family-wise significance.

Table 8 reports the same reference calculations for absolute-return ratios and high-magnitude shares. The equal-weight magnitude response is larger relative to its baseline, but unadjusted tail probabilities must be read together with their multiplicity correction and dependence sensitivity.

Table 8: Historical reference probabilities for variability. Each cell reports unadjusted upper-tail p followed by Holm-adjusted p in parentheses; ratios use mean absolute returns and high shares use the daily baseline p75.

Target	H	Abs ratio	Ref median	p (Holm)	High %	Ref median %	p (Holm)
Broad market index	5	1.19	0.91	0.3179 (1.0000)	60.0	20.0	0.2000 (1.0000)
Broad market index	20	1.43	0.90	0.2168 (1.0000)	60.0	20.0	0.0905 (0.7242)
Broad market index	60	1.13	0.95	0.3747 (1.0000)	43.3	21.7	0.2232 (1.0000)
Equal-weight index	5	2.50	0.88	0.0408 (0.5301)	80.0	20.0	0.0932 (0.7242)
Equal-weight index	20	2.30	0.93	0.0311 (0.4350)	75.0	25.0	0.0233 (0.3728)
Equal-weight index	60	1.64	0.95	0.1107 (0.7242)	55.0	23.3	0.0602 (0.5558)

The block-resampling exercise gives smaller probabilities than the actual historical-window comparison. With blocks of ten sessions, adjusted twenty-session probabilities are 0.0425 and 0.0360. With blocks of twenty, they rise to 0.0540 and 0.0595. The historical-window design preserves realized long market episodes, whereas shorter resampled blocks can break sustained runs. The inference is therefore sensitive to the reference distribution.

The defensible conclusion is a large nominal rebound and substantial benchmark deviation, with uncertainty about the strength of historical-rarity inference after multiplicity and dependence adjustments.

6-5. Volatility Resilience

Table 9 summarizes return magnitude over sixty sessions and normalization over all 68 available sessions. Mean absolute returns are 1.377% for the broad-market proxy and 1.342% for the equal-weight index, compared with baseline medians of 1.007% and 0.704%. The ratios to baseline means are 1.13 and 1.64; the ratios to baseline medians are 1.37 and 1.91. Under the primary rolling-distribution criterion, broad-market normalization is confirmed at session 32, while equal-weight normalization is not confirmed within 68 sessions.

Table 9. Return magnitude and normalization. Magnitude summaries use sixty sessions; normalization uses all 68 sessions and complete rolling windows. Confirmation requires five consecutive 10-session rolling means at or below the 75th percentile of the pre-event rolling-mean distribution.

Target	H	Pre median	Post mean	Mean ratio	Median ratio	High %	p90 %	Confirm
Broad market index	60	1.007	1.377	1.13	1.37	43.3	21.7	32
Equal-weight index	60	0.704	1.342	1.64	1.91	55.0	31.7	Censored 68

The permissive sensitivity criterion yields five and twenty-seven sessions. Under the primary matched rolling criterion, broad-market compliance starts at session 28 and is confirmed at session 32. Equal-weight absolute-return normalization is not confirmed within 68 sessions. Under the rolling squared-return criterion at p75, confirmation occurs at sessions 33 and 32. Centered rolling variance gives 14 and 52. The ordering is therefore not invariant to the volatility definition.

Across the full sensitivity grid, some normalization definitions are right-censored and the remaining confirmation dates vary substantially. For example, centered-variance confirmation spans sessions 9–24 for the broad market and 9–62 for equal weight. A single recovery duration is not a structural market property. The evidence supports persistent equal-weight return-magnitude elevation under several definitions, while precise normalization times and cross-index rankings require qualification.

At sixty sessions, mean absolute-return ratios are 1.13 for the broad market and 1.64 for equal weight. Centered standard-deviation ratios are 0.85 and 1.28, respectively. The broad-market return magnitude therefore rises slightly while its centered dispersion falls relative to the local baseline. For equal weight, both magnitude and centered dispersion rise. This distinction weakens any general claim that volatility increased uniformly across market measures.

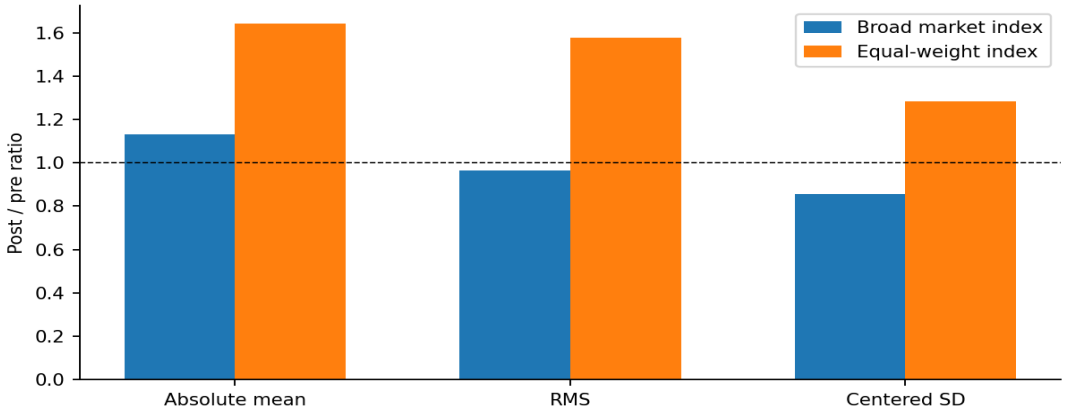

Fig. 6: Absolute-return, RMS and centered-standard-deviation ratios after sixty observed sessions. The three metrics need not imply the same volatility response.

6-6. Counterfactual Return and Volatility Paths

Pre-event validation selects AR(1) for the broad-market return and the 252-session historical mean for equal weight. Their twenty-session forecast returns are 3.76% and 0.66%; corresponding relative-price gaps are 32.35% and 40.97%. All six benchmarks predict much smaller nominal gains than observed. The twenty-session observations lie above their block-10 predictive bands. This is evidence of predictive instability around the combined event, not an estimated benefit or cost of market closure.

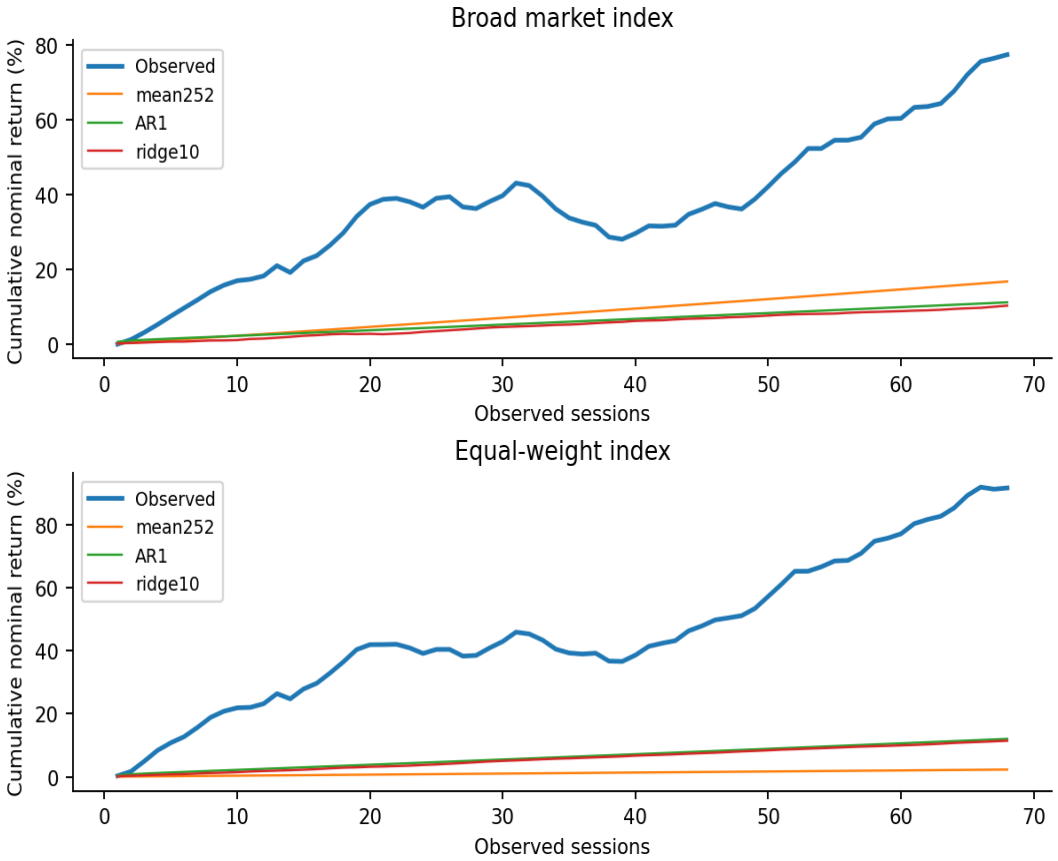

Fig. 7: Actual cumulative nominal return and alternative forecast benchmarks. Target-only paths are fixed-origin forecasts; Ridge uses post-event external realizations delayed by two calendar days.

Figure 8 compares absolute observed returns with square-root variance forecasts from the restricted pre-event-selected models. These are one-step session-clock forecasts, not a reconstruction of latent risk during the suspension. No closure zeros are inserted. A forecast mismatch indicates a challenge for predictive stability under the combined event; it does not identify why the closure occurred or how uninterrupted trading would have behaved.

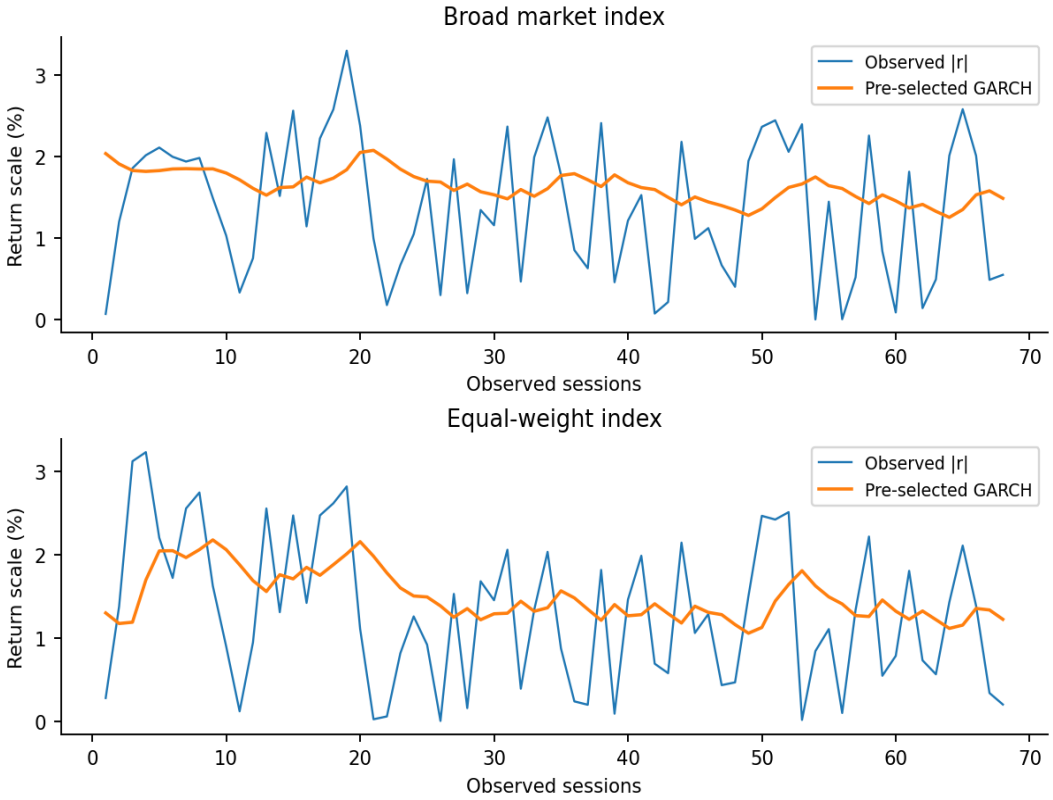

Fig. 8: Observed absolute returns and one-step pre-event-selected volatility forecasts. The first forecast uses the last pre-event state; subsequent forecasts use only previous observed returns.

6-7. Interrupted Time-Series Evidence

The interrupted time-series estimates use the specification in Section 5.5. Three indicators distinguish the reopening intervals, with lagged returns, a time trend and four delayed external predictors included as controls:

$$y_t = \alpha + \rho r_{t-1} + \gamma|r_{t-1}| + \tau t + \beta_1 D_{1-5,t} + \beta_2 D_{6-20,t} + \beta_3 D_{21-60,t} + \delta' X_t + u_t$$

The dependent variable y_t is r_t or $|r_t|$. The pre-event period serves as the comparison baseline. Each primary regression uses the same 312 observations, with lags defined over observed sessions and a HAC maximum lag of 5. The reopening coefficients measure conditional differences relative to the pre-event baseline; they do not isolate the causal effect of suspension. Sensitivity specifications vary controls, trends, HAC lags and inclusion of the first reopened return.

Table 10a. Interrupted time-series estimates for daily log returns. All regressions use 312 observations, lagged returns, a trend and four delayed controls. The pre-event period is the comparison baseline. Standard errors use a Bartlett HAC estimator with maximum lag 5. Coefficients are percentage points per observed session.

Target	Sessions	Coefficient	HAC SE	p	N	R^2
Broad market index	1–5	0.942	0.373	0.011	312	0.149
Broad market index	6–20	1.078	0.405	0.008	312	0.149
Broad market index	21–60	0.212	0.348	0.542	312	0.149
Equal-weight index	1–5	1.245	0.328	<0.001	312	0.316
Equal-weight index	6–20	0.851	0.266	0.001	312	0.316
Equal-weight index	21–60	0.179	0.256	0.485	312	0.316

Table 10b. Interrupted time-series estimates for absolute log returns, using the specification in Table 10a. Reported p-values are unadjusted and do not test a separately identified causal effect of closure.

Target	Sessions	Coefficient	HAC SE	p	N	R^2
Broad market index	1–5	0.214	0.349	0.540	312	0.037
Broad market index	6–20	0.524	0.345	0.129	312	0.037
Broad market index	21–60	-0.073	0.249	0.770	312	0.037
Equal-weight index	1–5	0.925	0.332	0.005	312	0.214
Equal-weight index	6–20	0.643	0.206	0.002	312	0.214
Equal-weight index	21–60	-0.031	0.139	0.821	312	0.214

In the primary controlled specification, the return coefficients for sessions 6–20 are 1.078 for the broad market and 0.851 for equal weight. The sessions 21–60 coefficients are small and not statistically distinguishable from zero. The primary absolute-return coefficients are not significant for the broad market; they are positive and significant for equal weight in the first two bins. The results indicate that the variability response differs between the two indices.

For sessions 6–20, changing HAC lag between 1 and 20 keeps the primary return p-values below 0.008 for the broad market and below 0.005 for equal weight. Adding a post-event slope reduces the coefficients to 0.715 and 0.550, and their maximum p-values across HAC lags rise to 0.083 and 0.101. Thus, the timing of the average rebound is visible, but its division into level and slope changes depends on specification. The sensitivity checks also consider unadjusted means, calendar-day trends, exclusion of the first reopening return and squared-return outcomes; these are not treated as independent confirmation of a preferred specification.

6-8. Post-Reopening Volatility Model Comparison

The restricted volatility comparison uses a constant pre-event variance, EWMA decays 0.94 and 0.97, and Gaussian GARCH(1,1). Three pre-event validation blocks select a

candidate; post-event performance is then reported once for all 68 observed sessions. The common loss is:

$$\text{QLIKE} = \frac{1}{T}\sum_{t=1}^{T}[\ln(h_t) + \frac{r_t^2}{h_t}]$$

Here h_t is the one-step forecast variance and r^2_t is the daily squared-return proxy. GARCH follows:

$$h_t = \omega + a\varepsilon_{t-1}^2 + bh_{t-1}$$

Parameters are estimated on pre-event demeaned returns and then held fixed. Filter states update only using preceding observed returns. Paired circular-block loss intervals versus constant variance allow dependence within blocks of 5, 10 and 20 sessions. The short evaluation sample and the retrospectively chosen candidate set limit any superiority claim.

GARCH is selected using pre-event validation data for both indices, but EWMA achieves slightly lower post-event QLIKE in both. For the broad market, GARCH minus constant-variance mean QLIKE is −0.122, with a paired block-10 interval from −0.299 to 0.028. For equal weight, the difference is −0.406, with interval −0.853 to −0.032. These exploratory differences do not establish dominance among all dynamic candidates, and 68 observations offer limited precision. The GARCH persistence constraints approach their upper boundary for both targets, reinforcing caution about regime stability. These comparisons do not support a general model-superiority claim or an operational trading recommendation.

Table 11: Volatility-model comparison with model selection based only on pre-event validation. Validation QLIKE and post-event QLIKE are separate quantities. Lower post-event QLIKE or RMSE alone is not a new model-selection rule.

Target	Candidate	Validation QLIKE	Post QLIKE	Post RMSE	Selection
Broad market index	constant	1.934	2.104	0.857	Fixed comparator
Broad market index	EWMA0.94	1.836	1.969	0.924	Fixed comparator
Broad market index	EWMA0.97	1.864	1.962	0.931	Fixed comparator
Broad market index	GARCH	1.798	1.983	0.916	Selected pre-event
Equal-weight index	constant	1.073	2.359	0.918	Fixed comparator
Equal-weight index	EWMA0.94	1.030	1.919	0.908	Fixed comparator
Equal-weight index	EWMA0.97	1.038	1.937	0.907	Fixed comparator
Equal-weight index	GARCH	1.025	1.953	0.913	Selected pre-event

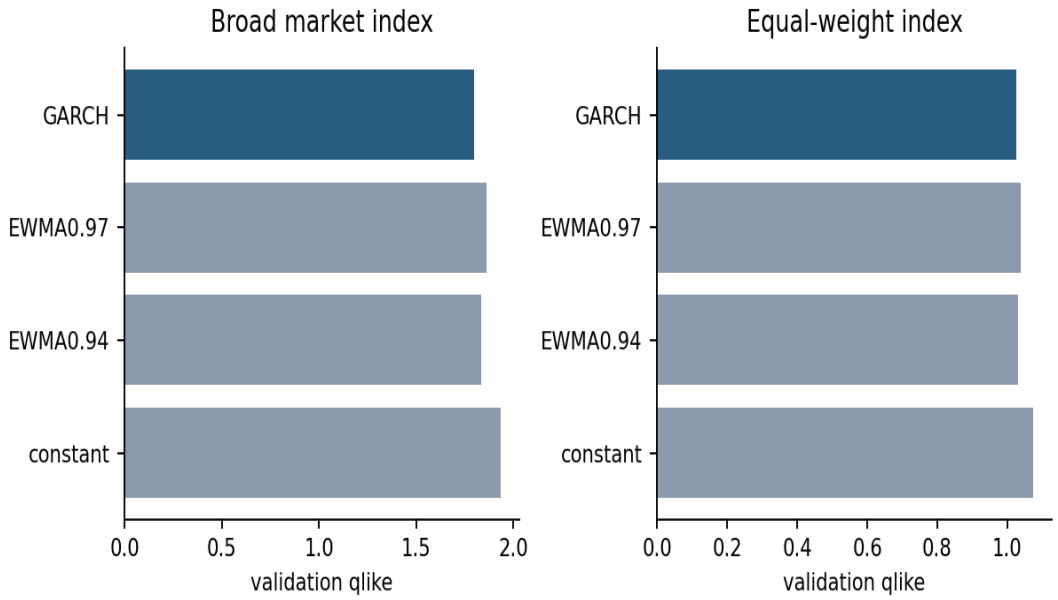

Fig. 9: Pre-event validation QLIKE for the fixed candidate set. Candidate selection uses validation loss; post-event QLIKE is reported separately in Figure 10.

Figures 9–11 distinguish validation QLIKE, post-event QLIKE and post-event RMSE. The criteria need not produce identical rankings. Selection is based exclusively on pre-event validation QLIKE, while the other criteria describe performance during the evaluation period.

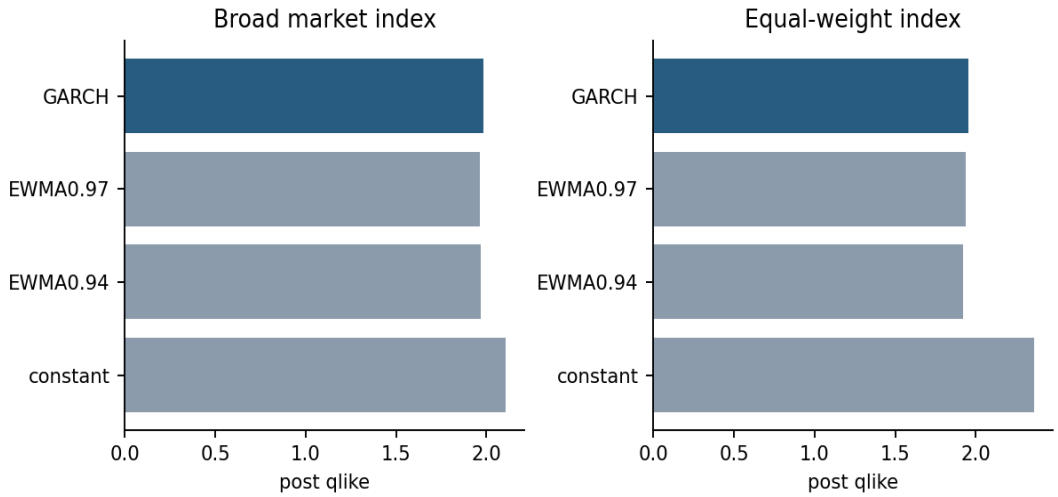

Fig. 10: Post-event QLIKE for the four fixed candidates. These evaluation-period rankings do not determine model selection, which uses pre-event validation data.

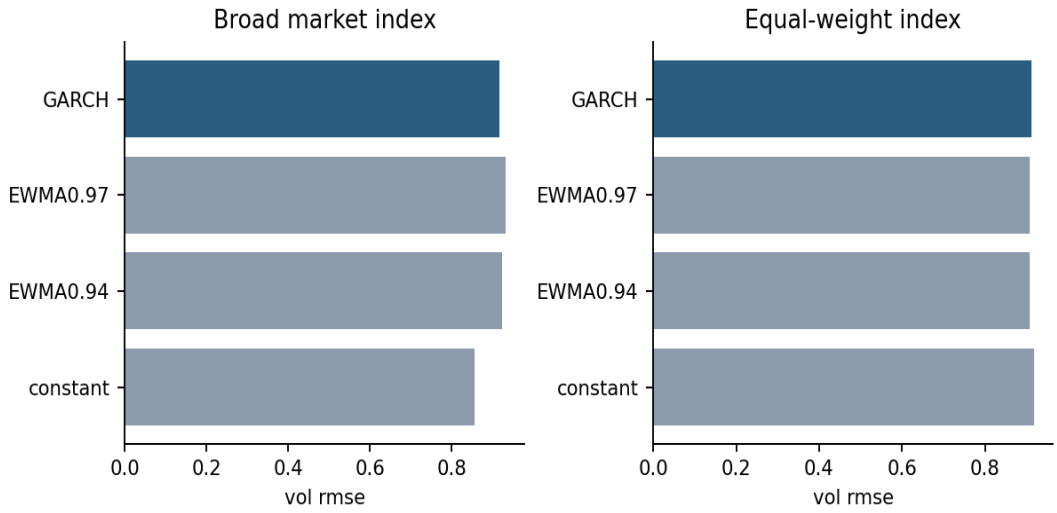

Fig. 11: Post-event RMSE between absolute returns and square-root variance forecasts for the same fixed candidates.

Table 12 summarizes selection by pooled pre-event validation QLIKE and reports paired post-event loss differences relative to constant variance. GARCH is selected for both indices. The loss intervals are exploratory comparisons rather than a basis for selecting another model on the event sample.

Table 12. Pre-event model selection and exploratory paired post-event loss comparison against constant variance. Confidence intervals use 1,999 paired circular-block draws of length 10.

Target	Criterion	Selected	Post QLIKE	Loss difference	95% paired interval
Broad market index	Validation QLIKE	GARCH	1.983	-0.122	-0.299 to 0.028
Equal-weight index	Validation QLIKE	GARCH	1.953	-0.406	-0.853 to -0.032

6-9. Feature Timing and Availability Evidence

The predictor audit assesses the timing of the four external series. A global market's closing observation is not assigned to an Iranian session that ends before that observation becomes available. Transformations are delayed by two calendar days, carried forward for a limited period and imputed using training data only.

Table 13 and Figure 12 report predictor availability on evaluation dates before imputation. Recorded source observations precede target dates by at least two calendar days. This confirms compliance with the date-based delay, while intraday release times and subsequent vendor revisions remain unverified. Predictor availability does not identify an economic mechanism or causal channel.

Table 13. Predictor timing and availability on the 68 reopened target dates, before imputation. Recorded source ages refer to daily observation dates, not independently audited release timestamps.

Predictor	Transformation	Available %	Minimum age	Maximum age
usd_irr	Log change × 100	100.0%	2	5
gold_global	Log change × 100	100.0%	2	5
sp500	Log change × 100	100.0%	2	5
vix	Log level	100.0%	2	5

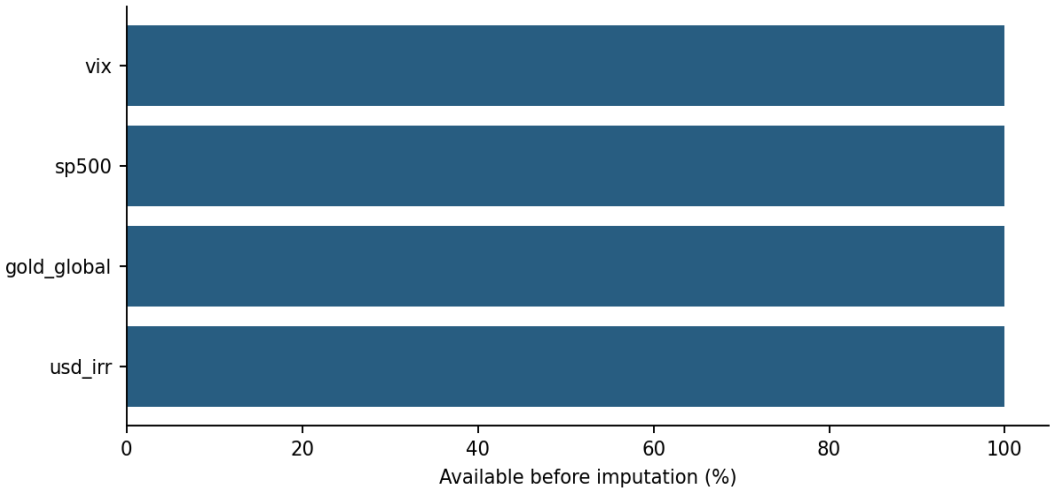

Fig. 12: Availability of the four delayed predictors before imputation.

6-10. Synthesis of Empirical Evidence

The main observed result is a substantial nominal rebound after reopening, concentrated in the first twenty sessions. The evidence is consistent with information accumulated during the interruption being incorporated after trading resumed, but does not isolate that mechanism from simultaneous geopolitical and administrative developments. Thus, the study does not conclude that closure caused delayed price discovery or failed to stabilize the market.

Historical windows and dependent-block resampling yield different assessments of rarity. In the historical-window design, small unadjusted probabilities do not generally remain significant after correction across eighteen comparisons. Resampling significance also depends on block length. The interrupted time-series estimates show positive early return differences, but allowing a post-event slope weakens some tests. These results support a qualified interpretation of the rebound.

Return magnitude and centered dispersion give different answers for the broad-market proxy. Equal-weight variability rises more consistently relative to its own baseline, but normalization times and sometimes their cross-index ordering change across matched

rolling definitions. Five- and twenty-seven-session estimates arise only under the permissive sensitivity criterion. The restricted forecast evaluation also supports no universal model superiority.

The contribution is therefore an auditable account of post-interruption repricing and definition-dependent resilience under a combined event. It distinguishes observed nominal changes from real investor recovery, conditional forecast gaps from causal counterfactuals, and historical rarity from policy effectiveness.

7. Policy and Risk-Management Implications

The results motivate transparent reopening calendars, company disclosure requirements and publication of trading restrictions. Because closure is not causally isolated, the analysis cannot prescribe an optimal suspension duration, quantify the benefit of protection from panic, or declare that uninterrupted trading would have been preferable. These are policy questions for richer comparison designs.

The distinction between broad-market and equal-weight measures supports monitoring more than a headline index. However, daily aggregate indices do not establish that smaller firms were less liquid or that their investors could execute transactions at quoted prices. Breadth, order-book conditions, spreads and firm-level trading status should be assessed alongside price changes before labeling a reopening successful.

Risk management should distinguish model validation from evaluation during a crisis and retain simple benchmarks. The short event sample does not support a general model-superiority claim or a trading strategy selected from event-period rankings. The forecasting exercise illustrates the limits of predictive stability during a major interruption.

Reopening protocols should state which firms may trade, the disclosure requirements for suspended firms, price-limit and sell-order rules, the treatment of leveraged positions and the criteria for restoring normal trading hours. Clear protocols would allow investors to interpret observed prices alongside the restrictions under which those prices were formed.

In inflationary settings, equity index levels can rise even when uncertainty remains elevated. Inflation expectations, currency changes, risk-premium revisions and administrative trading conditions may all contribute. The USD- and gold-relative comparisons below address valuation sensitivity but do not identify investor welfare or fundamental recovery. A positive post-reopening nominal return should therefore be evaluated together with trading access, liquidity and purchasing power.

8. Robustness Considerations and Limitations

This is a single-event, jointly treated market with no credible comparison market. Closure, conflict, policy intervention and reopening restrictions cannot be separated. Daily index data lack intraday prices, order books, volumes, spreads and firm-specific damage information, so information efficiency and liquidity resilience are not directly measured. The broad-market proxy is provider supplied, with no independently verified dividend convention or constituent reconstruction.

The first reopening return spans a long calendar gap, while the forecast models operate in observed-session time. Post-event estimates use only 68 observations, with 60 in the main event and regression window. Historical reference distributions span changing market regimes; moving blocks retain only dependence within their chosen block length. Holm adjustment addresses the explicitly defined 18 event comparisons, not every exploratory coefficient or every possible design choice. Regression and model-comparison intervals remain approximate.

External data are retrospectively downloaded daily records. The two-calendar-day delay addresses date-label look-ahead, but unrecorded intraday publication and later revisions cannot be audited. Conditional external forecasts may incorporate shock transmission channels. Predictive bands omit full model-selection and parameter uncertainty. Alternative-numeraire returns do not measure CPI-real recovery or investor welfare. These restrictions define the scope of the evidence and preclude a causal verdict on suspension policy.

The twenty-session rebound remains positive in the supplied USD and domestic-gold numeraires. Over sixty sessions, the broad-market USD-relative gain is 40.33% and the equal-weight gain is 55.03%, below their nominal gains because the USD/IRR quotation rises 14.21% over the matched interval. These comparisons address currency valuation mechanically, but do not isolate why stock prices rose. The gold and currency prices can themselves respond to conflict, market restrictions and changing expectations.

Continued firm suspensions may affect index representativeness as well as investors' ability to trade. In the absence of a matched CPI series, the analysis cannot determine whether the nominal rebound restored purchasing power. The currency- and gold-relative comparisons should therefore be interpreted as valuation checks rather than measures of investor welfare.

Tables A1–A3, included below, report the principal robustness checks. Table A1 summarizes alternative numeraires. Table A2 reports twenty-session return inference under

all three resampling block lengths. Table A3 shows the matched normalization definitions for a 252-session baseline and 10-session rolling windows.

Table A1: Alternative-numeraire robustness

Target	H	Numeraire	Change %	Relative return %
Broad market index	20	USD	-6.13	46.30
Broad market index	20	18k gold	-23.43	79.34
Broad market index	60	USD	14.21	40.33
Broad market index	60	18k gold	-3.33	65.81
Equal-weight index	20	USD	-6.13	51.18
Equal-weight index	20	18k gold	-23.43	85.32
Equal-weight index	60	USD	14.21	55.03
Equal-weight index	60	18k gold	-3.33	83.18

Common valuation base: 25 February 2026. Ending values use the corresponding observed equity-window end date. These are not CPI-real or executable-arbitrage returns.

Table A2: Dependence and multiplicity sensitivity

Target	Block length	Tail p	Holm 18
Broad market index	5	0.0020	0.0280
Broad market index	10	0.0025	0.0425
Broad market index	20	0.0030	0.0540
Equal-weight index	5	0.0005	0.0090
Equal-weight index	10	0.0020	0.0360
Equal-weight index	20	0.0035	0.0595

Circular moving blocks; 1,999 simulations; eighteen comparisons in each block-length family. The inference depends on the historical reference distribution.

Table A3: Matched normalization definitions

Target	Metric	Quantile	Onset	Confirmation
Broad market index	abs	0.75	28	32
Broad market index	abs	0.90	10	14
Broad market index	rms	0.75	29	33

Target	Metric	Quantile	Onset	Confirmation
Broad market index	rms	0.90	10	14
Broad market index	centered_sd	0.75	10	14
Broad market index	centered_sd	0.90	10	14
Broad market index	Permissive daily p75	0.75	5	Sensitivity only
Equal-weight index	abs	0.75	Not reached	Censored 68
Equal-weight index	abs	0.90	26	30
Equal-weight index	rms	0.75	28	32
Equal-weight index	rms	0.90	28	32
Equal-weight index	centered_sd	0.75	48	52
Equal-weight index	centered_sd	0.90	10	14
Equal-weight index	Permissive daily p75	0.75	27	Sensitivity only

The primary metric is abs at quantile 0.75. rms and centered_sd denote mean-squared-return and centered-variance thresholds; their square-root transforms have the same crossing dates under the corresponding transformed thresholds.

9. Conclusion

Following the 80-calendar-day equity suspension and reopening on 19 May 2026, both TSE measures recorded large nominal gains, concentrated in the early observed sessions. Correctly compounded twenty-session returns were 37.33% for the broad-market proxy and 41.90% for equal weight. Their forecast deviations were substantial, but historical-rarity inference was sensitive to multiplicity and temporal dependence. Return-magnitude elevation was greater relative to baseline for equal weight, whereas broad-market centered dispersion did not show the same increase.

The interrupted time-series estimates locate the rebound mainly in the early reopening intervals, although the division between level and slope changes is specification dependent. Differences between the two indices do not, by themselves, identify firm-size or liquidity mechanisms.

Normalization times depend on the metric and threshold. The five- and twenty-seven-session estimates arise only under a permissive retrospective criterion, while matched rolling thresholds give later confirmation or no confirmation within the sample. The restricted forecasting exercise likewise provides no general evidence of model superiority.

The study contributes a documented case of nominal repricing after a prolonged market interruption, with explicit cleaning rules and sensitivity to benchmark choice. Its policy implications concern transparent disclosure, reopening procedures and careful interpretation of index-based resilience measures. Establishing whether closure stabilized the market or delayed information incorporation requires a credible comparison design and richer trading data.

Acknowledgments

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Conflict of Interest

In adherence to ethical publication standards, the author affirms that there is no conflict of interest, either personal or financial, that could have influenced the content or conclusions presented in this research.

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آیا تعطیلی بازار به ثبات انجامید یا تعدیل را به تأخیر انداخت؟ کشف قیمت و تاب‌آوری نوسانات در بورس اوراق بهادار تهران تحت شوک ژئوپلیتیکی

هانیه صداقت‌کالمرزی[۱]

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چکیده

این پژوهش، تعدیل اسمی قیمت‌ها و تغییرپذیری بازده روزانه در بورس اوراق بهادار تهران را دربارهٔ توقف معاملات سهام از ۲۸ فوریه تا ۱۸ مه ۲۰۲۶م. و بازگشایی بازار در ۱۹ مه بررسی می‌کند. داده‌ها شامل شاخص کل بازار و شاخص هم‌وزن، با ۶۸ مشاهدهٔ معتبر پس از بازگشایی است. تحلیل، بررسی بازتولیدپذیر دورهٔ توقف معاملات، پنجره‌های مرجع تاریخی، بازنمونه‌گیری با حفظ ساختار وابستگی، اعتبارسنجی پیش‌بینی با داده‌های پیش از رویداد، رگرسیون‌های سری زمانی منقطع و آزمون‌های حساسیت بازگشت نوسان به سطح مبنا را دربر می‌گیرد. بازده اسمی تجمعی بیست جلسهٔ معاملاتی برای این دو شاخص به‌ترتیب ۳۷٫۳۳٪ و ۴۱٫۹۰٪ است. هر دو از معیارهای پیش‌بینی ساده فراتر می‌روند؛ با این‌حال، احتمال‌های دنباله‌ای مبتنی‌بر پنجره‌های تاریخی پس از تعدیل بابت مقایسه‌های متعدد میان متغیرهای پیامد و افق‌های زمانی، معناداری آماری خود را از دست می‌دهند و نتایج بازنمونه‌گیری نیز به طول بلوک وابسته‌اند. تغییرپذیری مبتنی‌بر قدرمطلق بازده در شاخص هم‌وزن، نسبت به سطح مبنای خود، افزایش بیشتری نشان می‌دهد؛ اما نتیجهٔ مربوط به شاخص کل بازار با جایگزینی قدرمطلق بازده با انحراف معیار حول میانگین تغییر می‌کند. برآوردهای پنج و بیست‌وهفت جلسه‌ای برای بازگشت نوسان به سطح مبنا تنها از یک قاعدهٔ پس‌نگر با شرایط سهل‌گیرانه حاصل می‌شوند. با استفاده از آستانه‌ای مبتنی‌بر توزیع پنجره‌های غلتان و الزام قرارگرفتن پنج مشاهدهٔ متوالی در محدودهٔ آستانه، بازگشت شاخص کل بازار به سطح مبنا در جلسهٔ سی‌ودوم تأیید می‌شود، ولی این وضعیت برای شاخص هم‌وزن طی ۶۸ جلسه تأیید نمی‌شود. مقایسهٔ محدود مدل‌های پیش‌بینی، با انتخاب مدل‌ها براساس اعتبارسنجی پیش از رویداد، برتری یکنواختی برای هیچ‌یک از مدل‌ها در دورهٔ پس از بازگشایی نشان نمی‌دهد. این یافته‌ها تعدیل قیمت را در شرایط هم‌زمان شوک ژئوپلیتیکی، تعطیلی بازار و بازگشایی کنترل‌شده توصیف می‌کنند، اما اثر علّی تعطیلی بازار را شناسایی نمی‌کنند و به‌معنای اثبات بازیابی واقعی بازار، کارایی اطلاعاتی یا تاب‌آوری نقدشوندگی نیستند.

کلیدواژگان: ریسک ژئوپلیتیکی، تعطیلی بازار، کشف قیمت، تاب‌آوری نوسانات، بورس اوراق بهادار تهران.
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Presenting Sign-Restriction in Vector Autoregressive Method for Examining the Impact of Unconventional Economic Policies on Increasing Production and International Trade

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Abstract

Unconventional monetary policy refers to a set of economic tools applied by central banks to stimulate the economy when conventional monetary policies are no longer effective. In this study, a new method is presented using a vector autoregressive model with a Sign-Restriction to assess the effects of unconventional monetary policy shocks. For this purpose, the impact of variables including real interest rate, inflation, and GDP, real exchange rate as well as quantitative easing is estimated for the period 1961-2021 in the case of positive and negative restrictions on these variables. The results show that when a negative restriction is imposed on the interest rate, production increases and unconventional monetary policy shocks are identified and estimated. Unconventional monetary policy can stabilize financial markets, reduce uncertainty, and provide more support to the public with low-interest loans to support low-cost production in the economy. SIR-VAR model reveals the effect of implementing unconventional monetary policies to reduce the effects of economic crises or deep recessions. SIR-VAR model allows economic planners to assess the situation of exiting stagflation with unconventional monetary policies leading to increased surplus production and more international trade in goods. SIR-VAR model determines the competitiveness of domestic and foreign goods and services through analyzing the effects of unconventional monetary policies.

Keywords: SIR-VAR Model, Unconventional Monetary Policy, Production.
JEL Classification: C22, E52, E42, E23.

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1. Introduction

Unconventional monetary policy (UMP) has emerged as a crucial set of tools for central banks, especially during periods when conventional levers—such as policy interest rates—approach their lower bounds and become ineffective. Since the global financial crisis of 2008, instruments like quantitative easing (QE), forward guidance, and negative interest rates have been widely adopted across advanced economies to mitigate recessionary pressures, manage inflation expectations, and stabilize financial systems (Joyce *et al.,* 2011). While these tools have been studied extensively in developed economies, their transmission mechanisms and macroeconomic consequences—particularly in small open and structurally volatile economies—remain less understood. Recent studies (e.g., Korobilis, 2025; Berend & Prüser, 2025) have expanded the econometric approaches used to estimate the effects of monetary shocks, employing models such as high-dimensional BVARs and SVARs with inequality constraints. Moreover, Kolasa *et al.,* (2025) show that in small open economies, exchange rate channels can amplify or mute the impacts of UMP, depending on the structure of the economy and fiscal policy stance.

In the context of Iran, a middle-income, resource-dependent, and heavily sanctioned economy, understanding the dynamics of UMP is even more critical. Iran has experienced a range of structural shocks over the past six decades—including the 1979 Revolution, the Iran–Iraq War, multiple rounds of international sanctions, and oil price volatility—all of which have significantly influenced its monetary transmission mechanisms. Unlike advanced economies, Iran's central bank does not formally implement QE or negative rates, but proxy forms of UMP (such as directed credit, open market operations in government bonds, and balance sheet expansion) have been used, particularly during times of fiscal stress and banking crises. Despite the relevance of these issues, there exists a significant research gap in assessing how UMP-like shocks affect key macroeconomic variables such as real interest rates, inflation, GDP, and exchange rates in Iran. Most existing literature on monetary policy in Iran focuses on traditional tools, without considering the broader toolkit or regime-switching behavior of the economy. This study aims to fill this gap by using a structural vector autoregressive (SVAR) model with sign restrictions to identify and quantify the effects of UMP shocks in Iran over the period 1961–2021. By considering time-varying dynamics and multiple economic regimes, this research provides a more nuanced understanding of Iran's monetary policy landscape and its implications for macroeconomic stability and long-term development. Ultimately, the findings of this research have practical relevance for monetary authorities, fiscal planners, and trade

policymakers, particularly as Iran seeks to navigate a challenging global financial environment and devise strategies for economic resilience and growth.

The subsequent sections are arranged as follows: Section Two delineates the theoretical Framework, Section three elucidates the literature review, Section Four outlines the methodology, Section 5 details the modelling and model specification, and the concluding section articulates the results.

2. Theoretical Framework

Unconventional monetary policy (UMP) has emerged as a crucial instrument for stabilizing economies during periods of severe shocks and abnormal financial conditions. Unlike conventional monetary policy that primarily operates through adjustments of short-term interest rates, UMP utilizes tools such as large-scale asset purchases, negative interest rates, and targeted credit facilities to exert influence when traditional policy space is constrained, particularly near the zero lower bound (Korobilis, 2025).

Recent advances reveal that the impact of UMP extends beyond short-term interest rates, significantly shaping the entire yield curve and inflation expectations. For instance, quantitative easing programs aimed at purchasing long-term securities reduce long-term yields and ease financial conditions, thereby lowering the cost of capital and stimulating output growth (Berend & Prüser, 2025).

A critical transmission channel of UMP is the exchange rate, which mediates the policy's effects on inflation and output through its influence on trade competitiveness and capital flows. Exchange rate movements can either amplify or dampen the real effects of UMP, particularly in small open economies where external trade and financial integration are substantial (Kolasa *et al.,* 2025). Moreover, the nonlinear and regime-dependent nature of exchange rate responses introduces complex feedback loops with fiscal policy, often attenuating the latter's effectiveness under UMP frameworks (Alberola *et al.,* 2021).

Despite these insights, the nonlinearity and time-varying nature of UMP effects across different economic regimes remain underexplored. The heterogeneous impact of UMP shocks on core macroeconomic variables—including real interest rates, inflation, GDP, and exchange rates—calls for more sophisticated econometric techniques that capture dynamic regime shifts and sign restrictions. Such approaches are essential for disentangling the nuanced mechanisms through which UMP shapes macroeconomic dynamics and for understanding its interplay with conventional policies (Korobilis, 2025; Berend & Prüser, 2025).

Finally, the research develops the theoretical framework on unconventional monetary policy, accompanied by a mathematical formalization to precisely characterize its mechanisms. It is apparent that unconventional Monetary Policy (UMP) operates through multiple dynamic channels beyond the traditional short-term interest rate rule. To capture its complex macroeconomic impacts on real interest rates, inflation, output, and exchange rates, recent literature employs sign restrictions.

Let the economy be characterized by a vector of macroeconomic variables:

$$X_t = \begin{bmatrix} rr_t \\ \pi_t \\ y_t \\ er_t \end{bmatrix} \qquad (1)$$

where rr_t is the real interest rate, π_t inflation, y_t output (GDP), and er_t the nominal exchange rate.

To capture the time-varying effects of UMP shocks ${\varepsilon^{UMP}}_t$, we specify a time-varying parameter VAR:

$$X_t = \sum_{t=1}^{p} A_{it} X_{i-t} + \varepsilon \qquad N(0, \sum t) \sim B_t \, \varepsilon_t \qquad (2)$$

where matrices A_{it} and covariance $\sum t$ evolve according to a stochastic volatility process, reflecting changing economic regimes.

The structural shocks $\varepsilon_t = ({\varepsilon^{conv}}_t, {\varepsilon^{fin}}_t, {\varepsilon^{UMP}}_t)$ include conventional monetary policy, financial shocks, and UMP shocks.

Sign restrictions identify the UMP shock by imposing theoretically-motivated constraints, for example:

$$0 > \frac{dr r_t}{d{\varepsilon^{UMP}}_t} \quad , \quad 0 < \frac{dy_t}{d{\varepsilon^{UMP}}_t} \quad , 0 > \frac{d\pi_t}{d{\varepsilon^{UMP}}_t} \quad , \quad 0 > \frac{der_t}{d{\varepsilon^{UMP}}_t}$$

These capture that UMP lowers real interest rates, stimulates output and reduces inflation, and induces exchange rate depreciation during the time.

This study seeks to fill this gap by employing a vector autoregressive model with sign restrictions, allowing for a refined identification of UMP shocks and their evolving effects on key economic variables over extended horizons. This framework aims to enhance our comprehension of UMP's transmission channels and provide robust policy insights relevant to diverse macro-financial environments.

The theoretical framework outlined above, emphasizing the critical role of unconventional monetary policy (UMP) in responding to severe economic shocks and abnormal financial conditions, highlights the importance of four key macroeconomic variables: the real interest rate, inflation, output (GDP), and the nominal exchange rate. In the context of Iran's economy, these variables are of paramount importance due to the

country's unique structural and external challenges, including international sanctions, oil price volatility, and financial market restrictions. The real interest rate serves as a vital transmission channel for monetary policy, influencing investment and firm-level costs; inflation is highly sensitive to policy shocks and expectations in a setting marked by pricing rigidities; output reflects the overall economic activity and welfare, which are frequently affected by both domestic and external factors; and the nominal exchange rate, as a primary mechanism transmitting monetary policy effects and external shocks in Iran's relatively open and externally integrated economy, plays a crucial role. (Akbari Dehbaghi *et al.,* 2020). Therefore, applying advanced modeling frameworks such as vector autoregressive (VAR) models with sign restrictions to identify UMP shocks is essential for capturing the nonlinear and evolving nature of economic dynamics in Iran. This approach greatly enhances our understanding of the transmission channels of unconventional policies and their interaction with conventional monetary and fiscal policies in Iran's specific macro-financial environment. Such rigorous analysis is imperative for designing targeted and effective policy interventions tailored to Iran's complex economic realities.

Unconventional monetary policy directly influences international trade by lowering borrowing costs and increasing liquidity, which can stimulate higher trade volumes. Additionally, such policies can lead to increased surplus production by boosting investment and consumption. This relationship highlights the significant role that monetary policy plays in shaping global economic dynamics (Schenkelberg and Watzka, 2013).

3. Background

Several studies have explored the impact of monetary policies—both conventional and unconventional—implemented by major economies such as the United States, the European Union, and China on green investment at the global level. For instance, Fukuda (2025) analyzes Japan's unconventional monetary policy—stretching from the late 1990s onward—using VAR technique. The study finds that while the BOJ's unconventional easing significantly narrowed the GDP gap during liquidity-trap conditions, it simultaneously exerted a considerable negative effect on total factor productivity (TFP) growth. In essence, Fukuda concludes that prolonged ultra-loose interest rate policies helped stabilize output in the short term but may have distorted capital allocation and depressed productivity over the medium to long run.

Ballabriga and Davtyan (2025) employ a unified empirical framework to examine the macroeconomic effects of conventional and unconventional monetary policy in the Euro Area and the United States. Their findings indicate that conventional monetary policy has

a stronger impact on prices, which they attribute to a higher natural interest rate compared to the unconventional period. Moreover, while the effects on unemployment and financial variables are relatively similar across both periods, the effectiveness of unconventional monetary policy is found to be lower in the Euro Area than in the U.S., due to institutional differences in central bank design.

Romero (2025) investigate the interaction between unconventional monetary policy and fiscal stabilization measures in the aftermath of the 2008 financial crisis, when traditional interest rate tools had become ineffective. Using annual macroeconomic data from 17 OECD countries over the period 1978–2019, and employing a novel country-specific instrument for unconventional monetary policy, he estimates the monetary–fiscal multiplier through a combination of local projections and the Kitagawa-Blinder-Oaxaca decomposition. Their results indicate that, under accommodative monetary conditions, the multiplier ranges from 1.7 to 5, highlighting strong complementarities between fiscal and unconventional monetary policies in enhancing macroeconomic stabilization.

Using a DSGE framework, Kolasa (2025) demonstrates that the exchange rate plays a pivotal role in amplifying the positive effects of unconventional monetary policies, while simultaneously dampening the efficacy of conventional fiscal measures in jointly enhancing output and inflation. He conducts a case study on the Swedish Riksbank's asset purchase program and negative interest rate policy between 2015 and 2019. The findings indicate that these unconventional monetary policy tools delivered substantial macroeconomic stimulus, boosting economic activity, while also contributing to a reduction in overall government debt by approximately 5 percent of GDP.

Muniz *et al.,* (2025) examines the European Central Bank's (ECB) use of unconventional monetary policy. By applying a numerical transformation, he investigates the impact of the ECB's green bond purchases, which consist of its Corporate Sector Purchase Programme (CSPP) data between 2018 and 2023. The findings suggest that the ECB's green bond purchases have successfully supported investment.

Pagliari (2024) evaluates the macroeconomic effects of the European Central Bank's unconventional monetary policies (UMPs) in the euro area, highlighting changes in transmission mechanisms over time. The study finds that since June 2014, the portfolio rebalancing channel has become more prominent than the signaling effect, and that the transmission of UMPs varies significantly between core and peripheral economies. He shows that unconventional monetary policy by the ECB significantly supported output growth in peripheral euro area countries, highlighting its effectiveness in boosting economic activity.

Laumer & Violaris (2024) examine unconventional monetary policy effects in the Euro Area from January 2007 to December 2019. Using a Bayesian FAVAR model to address policy foresight overlooked by traditional SVARs, they find that such shocks boost industrial production and reduce unemployment, with larger and more persistent effects than previously reported. The shocks also lower interest rates, spreads, and government bond yields, improving financial conditions. However, significant uncertainty remains about their impact on consumer and producer prices, indicating a need for further study.

Similarly, Tufail *et al.,* (2024) examined the influence of the US Federal Reserve's unconventional monetary policies, particularly quantitative easing (QE), on green bond issuance from 1985 to 2022. Using the Dynamic Autoregressive Distributed Lag (DARDL) model and Kernel-based Regularized Least Squares (KRLS), the study analyzed variables such as interest rates, green bond volumes, and market liquidity, finding that QE significantly lowered borrowing costs and incentivized green investment.

Overall, these studies underscore the critical role that both conventional monetary tools and unconventional measures play in directing financial resources towards investments. Despite methodological differences, the common finding is that accommodative monetary policies in the US, EU, and China facilitate increased investment, highlighting the interconnectedness of monetary policy and sustainability goals.

It also should be noted that in some studies, including those by Cheng & Yang (2020), Perdigao (2019), Arias *et al.,* (2018), Boeckx *et al.,* (2017), & Fry & Pagan (2011), the identification of unconventional monetary policy shocks is carried out with a Sign-Restriction using a structural vector autoregressive model. In the presence of unconventional monetary policy, the vector autoregressive model faces challenges in estimating. For example, the VAR cannot be estimated with a constant and zero endogenous variable. In addition, the sample is small and it is not known which variables should be used in the estimation. Therefore, it is necessary to identify the vector autoregressive model for correct estimating. There are identification methods as solutions including: 1) A vector autoregressive model with a zero long-term interest rate is considered, where the interest rate is positive. 2) The shadow rate can be used with a yield curve and can be negative when the short-term interest rate is zero. The shadow rate is the maturity rate applied in both conventional and unconventional monetary policy. 3) Heteroskedasticity-based Identification is a method in which additional constraints are imposed on the variance of shocks that change over time. On the days of monetary policy announcements, the variance of the shock is higher. 4) An instrumental variable can be used in which the instrumental variables are correlated with the interest rate shock but not

with other shocks. 5) High-frequency identification, which shows that it is needed more information than the interest rate set by the central bank. 6) VARs with Functional Shocks, which shows that the shock has a function for itself, the impulse-response is also obtained in the function applied for both conventional and unconventional monetary policy.7) The Sign-Restriction method is applicable to identifying conventional monetary policy shocks, and the goal of our research here was to apply this method to unconventional monetary policy. In fact, the response of the variable during unconventional monetary policy is uncertain, and the goal is to identify the sign of the interest rate and quantitative easing[1] as unconventional monetary policy instruments with Sign-Restriction method and identify unconventional monetary policy in Iran (Rossi, 2018).

To illustrate the scope of UMP, it should be noted that first, unconventional monetary policies fall under the broader category of balance sheet policy, whereby the central bank uses its balance sheet to affect asset prices and financial conditions beyond the short-term interest rate. Second, balance sheet policies can be decoupled from interest rate policies. This reflects the fact that the level of the short-term interest rate can be set independently of the amount of bank reserves in the system. Third, the main channel through which balance sheet policy operates is by altering the composition of private sector balance sheets. However, identifying unconventional monetary policy and implementing it play an important role in the economy. In this study, for example, using Sign-Restriction method in the vector autoregressive model, unconventional monetary policy is examined in Iran, which has not been considered in any of the foreign and domestic studies. The endogenous variables examined in the vector autoregressive model are real interest rate, gross domestic product, inflation, real exchange rate as well as quantitative easing.

4. Methodology

4-1. a Sign-Restriction method

The main methodology used in this study is the Sign-Restriction approach for identifying unconventional monetary policy shocks. Specifically, this method is implemented within a structural vector autoregressive (SVAR) model framework. First, the structural vector autoregressive model is formulated, which serves as the basis for imposing theoretically motivated sign restrictions to distinguish the effects of unconventional monetary policy from other shocks.

[1] Another name of quantitative easing is asset purchase program (app) showing that it is a type of central bank credit allocation.

$$\acute{y}_t A_0 = \sum_{l=1}^{p} \acute{y}_{t-l} A_l + c + \acute{\varepsilon}_t \qquad 1 \le t \le T \quad (1)$$

Where, y_t is $n \times 1$ vector of endogenous variables, $\acute{\varepsilon}_t$ is $n \times 1$ vector of structural shocks, A_l is matrix of structural parameters for $0 \le l \le p$ with A_0 invertible, c is $1 \times n$ vector of parameters, p is the lag length, and T is the sample size. The vector $\acute{\varepsilon}_t$ is conditional on the past information and initial conditions $y_0, \dots, y_{1-p}$, with zero mean and covariance matrix I_n ($n \times n$ identity matrix). The model of equation (1) can be written as follows:

$$\acute{y}_t A_0 = \acute{X}_t A_+ + \acute{\varepsilon}_t \qquad 1 \le t \le T \quad (2)$$

where $\acute{A}_+ = \left[\acute{A}_1 \dots \acute{A}_p \; \acute{c}\right]$ and $\acute{X}_t = \left[\acute{y}_{t-1} \dots \acute{y}_{t-p} \; 1\right]$ is for $1 \le t \le T$. A_0 and A_+ are structural parameters. The reduced form of the vector autoregressive model of equation (2) is expressed as follows:

$$\acute{y}_t = \acute{X}_t B + \acute{u}_t \qquad 1 \le t \le T \quad (3)$$

where $B = A_+ {A^{-1}}_0$, $\acute{u}_t = \acute{\varepsilon}_t A_0^{-1}$ and $E(u_t \acute{u}_t) = \Sigma = (A_0 \acute{A}^{-1}{}_0)$.

Starting from the reduced form of the vector autoregressive (VAR) model, we can derive the impulse response functions. Suppose the structural parameters (A_0, A_+) take specific values; then, the impulse response function of the i-th variable to the j-th structural shock at time horizon h is represented by the element in the i-th row and j-th column of the corresponding matrix. This function shows how the i-th variable reacts over time to a shock originating from the j-th structural disturbance.

$$L_h(A_0, A_+) = ({A^{-1}}_0 \acute{j} F^h J), F = \begin{bmatrix} A_1 {A^{-1}}_0 & I_n & \dots & 0 \\ \dots & \dots & \dots & \dots \\ A_{p-1} {A^{-1}}_0 & 0 & \dots & I_n \\ A_p {A^{-1}}_0 & 0 & \dots & 0 \end{bmatrix} \text{و } J = \begin{bmatrix} I_n \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

To identify unconventional monetary policy (UMP) shocks, this study applies a structural VAR (SVAR) model using the pure sign-restriction approach of Uhlig (2005). Instead of relying on recursive (Cholesky) identification, this method imposes economically motivated sign restrictions on impulse responses—for example, assuming that a surprise monetary tightening should not raise inflation or output in the short term. Impulse vectors are randomly drawn, and only those satisfying the sign restrictions across key variables (e.g., output, inflation, exchange rate, interest rate) are retained. This ensures internal consistency and avoids the scaling and ordering problems common in other identification methods.

This approach is especially useful when the goal is to impose minimal and plausible assumptions without overfitting. It leaves the reduced-form VAR model intact and provides a transparent interpretation of shocks, focusing only on those consistent with theoretical expectations. As Uhlig (1998) notes, monetary shocks can still explain a significant share of output variation even with weaker identifying assumptions, though stricter restrictions—like those used in this study—enhance the credibility of the identified shocks.

4-2. Identifying Shocks Using Sign Restrictions

In this study, shocks are identified using the Sign-Restrictions method, following the approach of Uhlig (2005), by applying sign restrictions on the matrix A_0. To do this, we decomposed the residual variance-covariance matrix into a lower triangular matrix P of size $n \times n$ as follows:

$$\acute{P}P = \Sigma \quad (5)$$

Where $P = A_0^{-1}$ is a factor of Σ and structural shocks in the structural vector autoregressive model are estimated by the column vectors of the matrix P. In other words, Σ is transformed into another decomposition and the lower triangular matrix P is multiplied by the orthogonal matrix R. The goal is to specify the structural shock to the real interest rate, GDP as well as inflation and all signs of the impulse-response vector (Chudik & Fidora, 2011). Given $\acute{P}P = \Sigma$, another decomposition is $\acute{A}A = \Sigma$ where $A = PR$ is constrained where R is the restriction matrix and $R\acute{R} = I$. After R is specified, the matrix Σ is also specified and by restricting the sign on five variables, the sign restriction is examined. To identify shocks of three variables, it is assumed that $n = 3$ and the variables are output (gdp_t), inflation ($\inf_t$) and real interest rate (r_t), real exchange rate (er_t) as well as quantitative easing (app_t) in the vector autoregressive model. In this case, $\acute{y}_t = (r_t, \inf_t, gdp_t, er_t, app_t)$ and $A_{s,ij}$ are the i-th row and j-th column of the A_s matrix, and the structural vector autoregressive model under consideration is as follows:

$$\acute{y}_t A_0 = \acute{c} + \acute{A}_1 \acute{y}_{t-1} + \acute{A}_2 \acute{y}_{t-2} + \cdots + \acute{A}_p \acute{y}_{t-p} + \varepsilon_t \quad (6)$$

By taking the inverse of the matrix A_0^{-1} after imposing restrictions, the following equation is obtained:

$$\acute{y}_t = A_0^{-1}\{\acute{c} + \acute{A}_1 \acute{y}_{t-1} + \acute{A}_2 \acute{y}_{t-2} + \cdots + \acute{A}_p \acute{y}_{t-p} + \varepsilon_t\} \quad (7)$$

To identify shocks, it is necessary to impose restrictions. Uhlig (2005) used the sign-restriction method to identify monetary policy shocks and showed that the output response to a contractionary monetary policy shock is negative. Uhlig (2005) introduced two methods for this approach, which are the rejection method and the penalty method. The

rejection method refers to accepting or rejecting restrictions in the estimation after a certain number of calculations or estimation draws[2], and the penalty method imposes a penalty for the constraints that are violated, instead of rejecting or accepting the restrictions and estimating the imposed restrictions as much as possible. The aim of our research is to identify and estimate the shock to the real interest rate and other variables with the sign-restriction method so that the impulse-response functions are calculated and the unconventional monetary policy model of Iran is estimated using various types of parametric restrictions.

4-3. Impulse Vectors and Responses in Sign-Restriction Method

In the Sign-Restriction method, the impulse vector a in the impulse-response functions is defined by $\acute{A}A = \Sigma$ where $a = \mathrm{A}\alpha$ is the impulse vector, α is an m-dimensional vector of length one, and a is a column of the matrix A. Therefore, with a monetary policy impulse vector named a and a time horizon T, the coefficient matrix $A = (A_1, \dots, A_p)$ and the variance-covariance matrix Σ , the monetary policy impulse vectors $\vartheta(A, \Sigma, \mathrm{T})$ are defined (Uhlig, 1997; 2005). In this study, with $\acute{u}_t$ as the one-period forecast error and $\acute{v}_t$ the vector of Fundamental innovations, the equation of $\acute{u}_t$ is $\acute{u}_t = A\acute{v}_t$ and assuming the non-uniqueness of the variance-covariance matrix $\acute{v}_t$ which is the identity matrix I_n, $\acute{v}_t = \acute{e}_t$ and finally, $\acute{u}_t = A\acute{e}_t$. Therefore, the tth column of the matrix A represents the tth impulse vector and the instantaneous effect on the model variables caused by changes in the innovation component. In this method, there are several principles as follows: Principle 1: If you know it, impose it! Principle 2: If you do not know it, do not impose it! Principle 3: The constraint is imposed on A and not the inverse of A . Unless there are reasons to impose a constraint on A^{-1}. Therefore, $R = R^{-1}$, $R\acute{R} = I$, and $A = PR$. First, it is necessary to calculate (A, Σ) from the reduced form and then, R is examined in order to estimate the sign-restriction. If the answer is no, the restriction is removed. If the answer is yes, a constant number is imposed to estimate the sign-restriction (Uhlig, 2017). When imposing a sign, there is a problem with how many periods after the shock the sign-restriction should be imposed. Uhlig (1998) shows that imposing a sign for a longer period has significantly different effects, and another principle is to impose a sign-restriction for more than one year. To create impulse-response figures, a large number of draws are repeated to examine the effect of multiple shocks on the variables for the impulse vector a. After imposing a sign-restriction on the shocks, a number of draws from the large number of draws are

[2]. Repetitions or times were applied for satisfying the signs in sign restriction method.

randomly estimated to estimate the sign-restrictions that are obtained for the impulse vector. Stability tests and diagnostic tests related to sign restrictions are crucial for ensuring the robustness and strength of the model.

The use of the sign-restriction model for analyzing Iran's economy, particularly in relation to the quantitative easing (QE) variable, is both appropriate and well-justified for several reasons:

1. Uncertainty and structural complexity in the Iranian economy: Due to factors such as international sanctions, exchange rate volatility, and non-linear policy interventions, Iran's economy has a complex and uncertain structure. Sign-restriction models, which rely on theoretical sign assumptions rather than rigid structural specifications, offer greater flexibility in identifying shocks under such conditions.
2. Identification of unconventional monetary policy shocks: QE is considered an unconventional and relatively new monetary policy instrument in the Iranian context. Sign-restriction models are well-suited to identifying the effects of QE, as they allow shocks to be defined based on the expected signs of macroeconomic responses rather than requiring precise structural formulations.
3. Suitability for limited or inconsistent data: Economic data in Iran may suffer from limitations in terms of accuracy, consistency, or availability. The sign-restriction approach, by focusing on directional responses rather than exact model parameters, can still provide meaningful and reliable results even when data constraints exist.

Therefore, applying the sign-restriction model to investigate the effects of QE and other UMP tools in the Iranian economy is a logical and effective approach, enabling a more realistic analysis of policy impacts and macroeconomic responses.

5. Results and Findings

This section presents the process of shock identification and the analysis of macroeconomic dynamics using three models based on sign restrictions. The objective is to examine the responses of key macroeconomic variables to monetary policy shocks, using data from reputable international sources.

For this purpose, data related to the variables including real interest rate, GDP, inflation, real exchange rate as well as quantitative easing were extracted from data from the World Bank, the International Monetary Fund and the Central Bank. The real interest rate is obtained by subtracting the inflation rate from the nominal interest rate. The data for quantitative easing has been measured using central bank reserve assets and international

liquidity. The data for GDP, inflation, and the real exchange rate has been extracted from the World Bank. It should be noted that excluding oil shocks and government budget deficits from the model does not compromise its validity. The model's robustness is maintained, ensuring reliable results despite not explicitly including these shocks. The data were then estimated and analyzed using Stata software. As an example, the following steps outline the procedure used to estimate shocks in models:

Step 1: The endogenous variables of real interest rate, GDP, inflation, real exchange rate, and quantitative easing are defined in the model, and the number of periods or time horizons is determined.

Step 2: The sign for each of the aforementioned variables is determined, and the corresponding shocks are defined.

Step 3: The 95% error band or confidence interval is set, and the bootstrap (bs) resampling method is applied for simulation.

Step 4: The number of draws to estimate the restrictions is set at 100, while the maximum number of draws without estimating the restrictions is limited to 4000.

Step 5: Random numbers (e.g., 123456) are generated for the imposed restrictions to prevent observational errors and bias in the calculations; by setting the initial value, the seed changes with each execution of the sign restrictions.

Step 6: The model is estimated using the defined endogenous variables: real interest rate, GDP, inflation, real exchange rate, and quantitative easing.

The first model includes the real interest rate, GDP, and inflation. Also, in the second model, the endogenous variables are real interest rate, GDP, inflation and real exchange rate. In the third model, the endogenous variables are real interest rate, quantitative easing and inflation. In fact, with the Sign-Restriction method, unconventional monetary policy shocks are identified. Sign-Restriction method was selected to examine monetary policy shocks, supply and demand shocks, real exchange rate shocks as well as quantitative easing shocks.

It should be noted that in the present study, supply shock represents inflation, demand shock represents GDP, monetary policy shock represents real interest rate, quantitative easing shock represents quantitative easing and exchange rate shock represents real exchange rate. Using these shocks together and examining their effects on the variables indicates that some of them help reduce uncertainty in predicting the path of interest rates. As Madeira *et al.,* (2019) classify supply, demand and monetary shocks based on the behavior of inflation, output and interest rates, we also included this in our model and in addition to these shocks, we added exchange rate shock and quantitative easing shock to

the model. For example, monetary policy or interest rate shock, which is an unconventional monetary policy tool, has a negative sign, and inflation and output also have a positive sign, which we included in our model and the estimate was made. Finally, we estimated three models with this method. In the first model, the endogenous variables were the real interest rate, GDP, and inflation, and in the second model, the endogenous variables were the real interest rate, GDP, inflation, and real exchange rate. In the third model, the endogenous variables were the real interest rate, quantitative easing, and inflation. Table 1 presents the estimated signs in the all models.

Table 1: sign restriction for the models

Models	**Variable or shock**	**r**	**Inf**	**GDP**	
First model	Supply shock	-	+	-	
	Demand shock	-	+	+	
	Monetary policy shock	-	+	+	
Second model					
		r	Inf	GDP	exchange rate
	Monetary policy shock	-	+	+	-
	Supply shock	-	+	-	+
	Demand shock	-	+	+	-
	exchange rate shock	-	-	-	-
Third model		app	r	Inf	
	quantitative easing shock	+	-	-	
	Monetary policy shock	+	+	-	
	Supply shock	+	-	+	

In fact, in these estimated models, the impulse vector was defined and the impulse vector was the same as the shocks of the variables and the responses were the variables that reacted to impulse. After estimation in the Sign-Restriction method, the Sign-Restriction is checked. If it is estimated, that sign is kept and if the sign is not estimated, that sign is rejected. In all three models, we estimated the signs that we had imposed and expected to have their effects on production, inflation and exchange rate and we kept the signs. Finally, three models were estimated to examine the effects of unconventional monetary policy shocks, and their results are presented in tables below. At first, the results of the unit root test and co-integration tests are reported in the tables below.

Table 2: Unit Root Test Results

Variable	Test Statistic	p-value	Order of Integration
r	-6.98	0.0000	I(1)
inf	-7.40	0.0000	I(1)
gdp	-5.25	0.0000	I(1)
er	-10.67	0.0000	I(1)
APP	-6.98	0.0000	I(1)

Table 3: co-integration Test Results

First model		
Maximum Rank	**Trace Statistic**	**Critical Value (5%)**
0	83.7606	29.68
1	24.4061	15.41
2	6.2903	3.76
3	—	—
Second model		
Maximum Rank	**Trace Statistic**	**Critical Value (5%)**
0	101.9590	47.21
1	42.7048	29.68
2	20.2404	15.41
3	6.5666	3.76
4	—	—
Third model		
Maximum Rank	Trace Statistic	Critical Value (5%)
0	72.9337	29.68
1	11.5940*	15.41
2	0.5747	3.76
3	—	—

Unit root and co-integration tests on the VAR model residuals confirmed the model's accuracy and a long-term equilibrium relationship among the variables. The first model shows three co-integrating relationships, the second model four, and the third model one, indicating that although variables are individually non-stationary, they move together over time. In fact, in the first model, trace statistics exceed critical values for ranks 0 to 2, indicating three co-integrating relationships among r, inf, and gdp. In the second model, this occurs for ranks 0 to 3, showing four relationships among r, inf, gdp, and er. In the

third model, only rank 0 exceeds the critical value, so there is one co-integrating relationship among app, r, and inf. When the trace statistic is greater than the critical value, it means a co-integrating relationship exists at that rank. Before estimating the models, lag length was tested for all three models, and the results confirmed a lag of 1 for each. Lag length and diagnostic tests results are presented in Appendix 1.

Table 4: Results of the first model with vector autoregressive method with Sign-Restriction method

Variables	Variables	Coefficient	Standard error	Z statistics	$P > \|z\|$	95 % confidence interval
r	rL1.	0.712	0.108	6.54	0.000	0.925 0.499
	infL1.	-1.259	1.564	-0.80	0.421	1.806 -4.324
	gdpL1.	8.733	13.484	0.65	0.517	35.162 -17.695
	_cons	-1.176	1.142	-1.03	0.303	1.062 -3.414
inf	rL1.	0.0106	0.0086	1.24	0.214	0.027 -0.006
	infL1.	-0.187	0.123	-1.51	0.130	0.055 -0.429
	gdpL1.	0.072	1.065	0.07	0.946	2.161 -2.016
	_cons	0.068	0.0902	0.75	0.451	0.245 -0.108
gdp	rL1.	0.00002	0.00095	0.03	0.978	0.0018 -0.0018
	infL1.	0.0013	0.0136	0.10	0.922	0.028 -0.025
	gdpL1.	0.488	0.117	4.15	0.000	0.719 0.257
	_cons	0.017	0.0099	1.78	0.075	0.0373 -0.0017

By applying the Sign-Restriction method and estimating three models with one lag, as determined by lag selection tests, the results in Table 4 reveal key macroeconomic dynamics. Notably, the real negative interest rate shock positively impacts GDP (coefficient: 8.733), indicating that a decrease in the real interest rate—typically resulting from an unconventional monetary policy shock—stimulates investment and economic activity. This finding is consistent with the liquidity effect, where lower interest rates enhance money supply availability, thereby promoting higher production levels. Furthermore, the imposed sign restrictions in Table 2 show that a reduction in the real interest rate is associated with a simultaneous decline in inflation (coefficient: -1.259). This evidence suggests that unconventional monetary policy measures can effectively support economic growth while contributing to price stability, highlighting their dual role in stabilizing the economy, which is consistent with the findings of Schenkelberg & Watzka (2013).

Table 5: Results of the second model with vector autoregressive method with Sign-Restriction method

Variables	Variables	Coefficient	Standard error	Z statistics	$P > \|z\|$	95 % confidence interval
r	rL1.	0.63	0.118	5.38	0.000	0.405 0.869
	infL1.	-1.21	1.53	-0.79	0.43	1.79 -4.22
	gdpL1.	1.28	14.17	0.09	0.92	29.06 -26.5
	erL1.	-9.60	6.50	-1.48	0.14	3.14 -22.36
	_cons	0.31	1.50	0.21	0.83	3.27 -2.64
inf	rL1.	0.014	0.009	1.55	0.12	0.03 -0.003
	infL1.	-0.189	0.122	-1.54	0.123	0.051 -0.042
	gdpL1.	0.46	1.131	0.41	0.679	2.68 -1.74
	erL1.	0.51	0.51	0.98	0.32	1.52 -0.5
	_cons	-0.01	0.12	-0.09	0.92	0.22 -0.24
gdp	rL1.	-0.0003	0.001	-0.34	0.732	0.001 -0.002
	infL1.	0.001	0.013	0.12	0.908	0.028 -0.025
	gdpL1.	0.45	0.125	3.59	0.000	0.69 0.204
	erL1.	-0.04	0.05	-0.86	0.391	0.063 -0.16
	_cons	0.025	0.013	1.91	0.056	0.051 -0.0007
er	rL1.	-0.001	0.002	-0.61	0.54	0.003 -0.006
	infL1.	0.00004	0.033	0.000	0.99	0.066 -0.06
	gdpL1.	-0.78	0.313	-2.52	0.01	-0.17 -1.40
	erL1.	0.14	0.14	0.98	0.32	0.42 -0.14
	_cons	0.14	0.033	4.32	0.000	0.209 0.07

In table 5, the results also indicate that a decrease in the real interest rate positively influences GDP growth (gdpL1, coefficient: 1.28), reflecting the expansionary impact of lower interest rates on investment and overall economic activity. Concurrently, the reduction in the real interest rate contributes to a decline in inflation (infL1, coefficient: -1.21), highlighting UMP's effectiveness in reducing inflation.

Moreover, the decline in the real interest rate is associated with a significant appreciation of the national currency, as evidenced by the negative coefficient on the exchange rate (erL1, coefficient: -9.60). This currency appreciation enhances external purchasing power, further bolstering GDP growth. Additionally, this appears to play a crucial role in suppressing inflation, as indicated by the negative coefficient on inflation

(infL1, coefficient: -0.189), highlighting the dual effectiveness of unconventional monetary tools in both stimulating output and controlling price levels.

Table 6: Results of the third model with vector autoregressive method with Sign-Restriction method

Variables	Variables	Coefficient	Standard error	Z statistics	$P > \|z\|$	95 % confidence interval
app	appL1.	0.99	0.033	29.70	0.000	1.06 0.92
	rL1.	0.001	0.001	1.27	0.204	0.004 -0.001
	infL1.	-0.01	0.021	-0.61	0.54	0.028 -0.05
	_cons	0.041	0.109	0.38	0.70	0.256 -0.17
r	appL1.	-6.52	2.34	-2.78	0.005	-1.92 -11.13
	rL1.	0.62	0.105	5.96	0.000	0.83 0.42
	infL1.	-1.34	1.47	-0.91	0.36	1.55 -4.23
	_cons	20.35	7.68	2.65	0.008	35.42 5.28
inf	appL1.	0.24	0.193	1.29	0.198	0.62 -0.13
	rL1.	0.014	0.008	1.71	0.087	0.031 -0.0021
	infL1.	-0.184	0.12	-1.51	0.13	0.05 -0.42
	_cons	-0.73	0.634	-1.17	0.24	0.50 -1.98

In table 6, the results indicate that quantitative easing (appL1, coefficient: 0.99) has a strong persistence effect, reflecting its sustained implementation over time. The real interest rate (rL1, coefficient: 0.001) shows a negligible direct effect on the variables in this model. Importantly, inflation (infL1, coefficient: -0.01) responds negatively to increases in quantitative easing, suggesting that expanding QE has contributed significantly to reducing inflation. This finding highlights the effectiveness of unconventional monetary policy tools like QE in controlling price levels, even as they support broader macroeconomic stability.

The restrictions related to all variables were successfully estimated 100 draws in all models. The low acceptance rate of sign restrictions reflects the inherent difficulty in precisely identifying shocks and the strictness of the restrictions. This acceptance rate highlights the challenge of aligning the imposed sign restrictions with the data, confirming the robustness of the estimation despite these limitations. The results indicate that in the first model, the restrictions related to the three variables were successfully estimated 100 times out of 3144 draws or times. In this model, the interest rate channel is emphasized and a decrease in the interest rate reduces the cost of capital so that it helps businesses to increase investment costs and consumers to increase their housing and durable

expenditures, which are considered a type of investment. This leads to an increase in aggregate demand and output. Therefore, here, a negative restriction on the interest rate is estimated and an unconventional monetary policy shock is identified in all models.

It should be noted that in the second model, the restrictions were estimated with 55880 draws and in the third model, the restrictions were estimated with 15725 draws until they could satisfy in 100 draws all signs imposed on variables.

Overall, the findings imply that currency appreciation, in conjunction with a lower real interest rate and subdued inflation, plays an important role in supporting economic conditions. These dynamics underscore the effectiveness of unconventional monetary policies in fostering a favorable macroeconomic environment by enhancing currency value and controlling inflationary pressures.

Also, in the figures below, the results of IRFs show the significant effect of considered variables on each other. Figures 1-2 shows that the monetary policy shock increases output and reduces inflation.



Fig. 1: IRF of inflation in respect to monetary policy shock for 40 periods

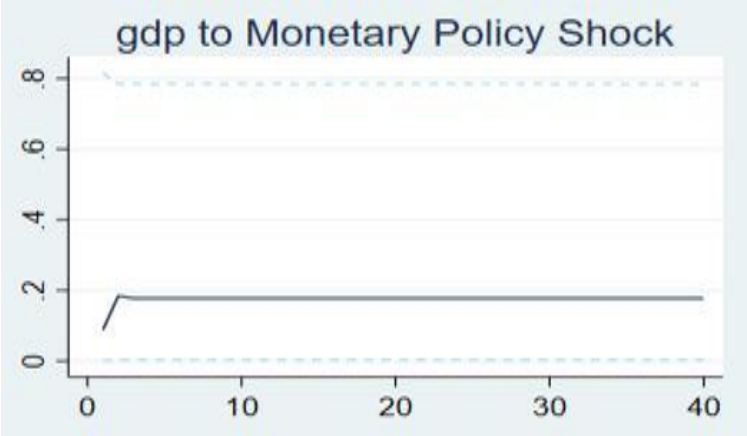

Fig. 2: IRF of GDP in respect to monetary policy shock for 40 periods

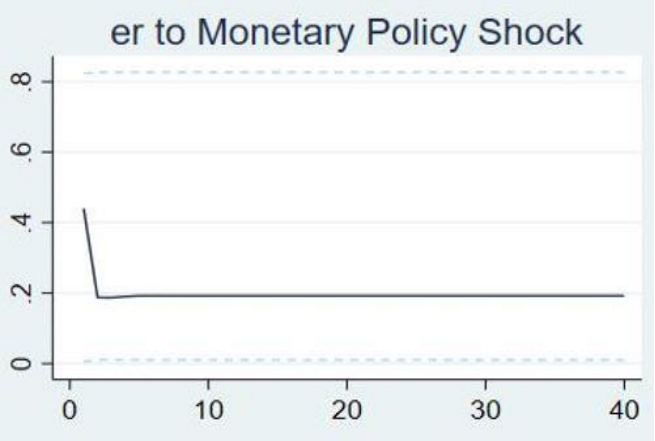

Fig. 3: IRF of exchange rate in respect to monetary policy shock for 40 periods

In the second model, the exchange rate was added to the variables of the first model. The exchange rate decreased in response to a monetary policy shock, which means that the value of the national currency increases.



Fig. 4: IRF of Asset purchase program (quantitative easing) in respect to supply shock for 40 periods

In the third model, the quantitative easing variable is added to the previous variables and the response of quantitative easing to the supply shock is positive. In other words, quantitative easing has become positive, which leads to an increase in loans and the supply of funds.

Finally, it is necessary to emphasize that the SIR-VAR model is superior to other structural identification techniques. Because, it estimates signs of shocks and it is easier to compute or more robust. The use of simulation methods and bootstrap methods in SIR-

VAR model also shows the robustness. The reason that simulation methods enter in SIR-VAR model is that the practical way to calculate signs is to use Monte Carlo methods to draw samples from the data generation process, and minimize the distance between the estimator from the observed sample and estimators obtained from a sample. Bootstrap methods in SIR-VAR model can be used to estimate the distribution of statistics, for purposes of estimating moments or critical levels, in situations where asymptotic analysis is intractable or tedious.

6. Discussion

This study introduces a novel approach to evaluating the impacts of unconventional monetary policy shocks by applying a vector autoregressive (VAR) model with sign restrictions. Unlike conventional monetary policies, unconventional tools such as quantitative easing and interest rate manipulations are employed when traditional measures lose effectiveness. Our method incorporates economic variables including the real interest rate, inflation, GDP, real exchange rate, and quantitative easing, providing a comprehensive framework to assess policy effects over a long period from 1961 to 2021.

The use of sign restrictions allows us to impose theoretical expectations on the direction of responses of key macroeconomic variables to policy shocks. For instance, in table 3, the negative sign assigned to the monetary policy or interest rate shock reflects the unconventional view that expanding monetary policy decreases interest rates, which in turn typically raises output (coefficient: 8.733). The first model focuses on the fundamental trio of real interest rate, GDP, and inflation, while the second model extends this framework by adding the real exchange rate, and the third introduces quantitative easing alongside interest rates and inflation.

The empirical findings suggest that imposing a negative restriction on the interest rate leads to an increase in production, confirming that unconventional monetary policy shocks can stimulate economic activity even when traditional policy channels are constrained, which is consistent with the findings of Schenkelberg & Watzka (2013) and Kolasa (2025). Furthermore, the models highlight the role of quantitative easing as an important tool for stabilizing financial markets and providing liquidity. These results underscore the multifaceted effects of unconventional policies—not only do they influence real economic variables, but they also help reduce market uncertainty and enable low-cost financing, supporting production at lower costs.

Overall, this study contributes to the understanding of how unconventional monetary policy operates in different economic contexts and how its impacts can be effectively measured using sign-restricted VAR models.

7. Conclusion

This study aimed to identify and assess the effects of unconventional monetary policy shocks in the Iranian economy using a vector autoregressive (VAR) model with sign restrictions. Three separate models were estimated, each with different combinations of macroeconomic variables including the real interest rate, inflation, GDP, real exchange rate, and quantitative easing. The use of sign restrictions enabled the imposition of economically meaningful expectations on the response of variables to monetary shocks, helping to identify unconventional policy effects even in the absence of clearly defined exogenous instruments.

The estimation results showed that in all three models, the imposed sign restrictions were successfully identified across multiple draws. Specifically, the results demonstrate that a negative interest rate shock, leads to a rise in GDP (coefficient: 8.733), consistent with the theoretical liquidity effect. The increased money supply resulting from a lower interest rate encourages investment and consumption, thereby stimulating aggregate demand and economic output. Additionally, the findings from the second model suggest that lower interest rates lead to a decline in the exchange rate (erL1, coefficient: -9.60), which indicates an appreciation of the national currency and further supports output growth.

Moreover, in the third model, the inclusion of quantitative easing (QE) as an unconventional policy instrument revealed its significant role in reducing inflation (infL1, coefficient: -0.01) and expanding credit availability.

The IRF (Impulse Response Function) analyses across all three models confirmed these dynamics: monetary policy shocks consistently increased output while reducing inflation, and, in models with additional variables, also contributed to exchange rate stability and financial expansion through credit channels. The empirical validation of these effects, based on data from the Iranian economy over the period 1961–2021, provides strong evidence in support of the strategic use of unconventional monetary policies, especially in developing economies facing structural limitations in monetary transmission.

7-1. Policy Recommendations

1. Continued Use of Unconventional Tools in Crisis Periods: Given the positive impact of lower interest rates and QE on GDP and inflation control, policymakers in Iran should consider maintaining flexibility in adopting unconventional monetary tools during economic downturns, particularly when traditional tools are ineffective.
2. Development of a Framework for QE Implementation: Since quantitative easing showed a notable effect in reducing inflation and increasing loan availability, a clear and transparent operational framework for QE policies should be designed to support liquidity provision to targeted sectors.
3. Exchange Rate Stabilization through Monetary Policy Coordination: The exchange rate's reaction to monetary shocks suggests that monetary policy can be effectively used to stabilize the national currency, thereby enhancing output.
4. Further Research with Broader Variables: It can be suggested that for future studies, variables such as the monetary base, real exchange rate, and oil prices in the Iranian economy should be included. This recommendation aims to enhance the analysis and understanding of economic dynamics in forthcoming research.

In conclusion, this study contributes to the understanding of unconventional monetary policy mechanisms in Iran and highlights their effectiveness in stimulating economic growth, stabilizing the exchange rate, and reducing inflation. The results suggest that such policies, when carefully designed and implemented, can serve as powerful tools in supporting macroeconomic stability and development in emerging markets.

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Observation Contribution

This research is derived from the first author's PHD thesis. The primary data collection, encompassing all observational and analytical components, was conducted by the first author under the direct supervision and mentorship of the second and third authors.

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1:

Prior to estimating models, it is essential to assess the lag length. A preliminary lag length order selection criteria test is conducted for all models, with results confirming a lag of 1.

Table 1-1: Test for Lag Length Selection (first Model)

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-206.585				0.313559	7.35385	7.39564	7.46138
1	-156.759	99.652*	9	0.000	0.074901*	5.92135*	6.08851*	6.35147*
2	-149.821	13.875	9	0.127	0.080768	5.99372	6.28625	6.74642
3	-145.972	7.6984	9	0.565	0.097473	6.17445	6.59235	7.24974
4	-140.31	11.324	9	0.254	0.111073	6.29157	6.83483	7.68945

Table 1-2: Test for Lag Length Selection (Second Model)

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-182.567				0.008186	6.5462	6.60192	6.68957
1	-129.601	105.93*	16	0.000	0.002242*	5.24917*	5.52776*	5.96603*
2	-121.11	16.982	16	0.387	0.002943	5.51264	6.01412	6.80299
3	-109.647	22.927	16	0.116	0.003528	5.67181	6.39616	7.53565
4	-100.39	18.512	16	0.295	0.004662	5.90843	6.85566	8.34576

Table 1-3: Test for Lag Length Selection (third Model)

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-299.307				0.149444	10.6072	10.649	10.7148
1	-176.445	245.72*	9	0.000	0.149444*	6.6121*	6.77926*	7.04222*
2	-169.899	13.092	9	0.158	0.163378	6.6982	6.99073	7.45091
3	-168.757	2.2829	9	0.986	0.216821	6.97394	7.39184	8.04923
4	-163.703	10.108	9	0.342	0.252401	7.1124	7.65566	8.51028

In addition to the Lag Length test, diagnostic, Normality, and stability tests were summarized in the tables below. These were conducted for robustness.

Table 1-4: Results of diagnostic tests, Normality and stability tests

	First model	Second model	Third model
LM Test (Prob.)	0.63004	0.88393	0.92881
Normality (Skewness)	0.99621	0.83045	0.89070
Eigenvalue Modulus	0.699104 0.486666 0.17173	0.613606 0.578531 0.164522 0.011929	0.957833 0.636319 0.156043

Diagnostic tests including the LM test (with probabilities 0.63, 0.88, and 0.93 for the three models respectively), Normality tests (skewness values near 0.83 to 1), and Eigenvalue modulus results were conducted for all three models. These results confirm the robustness and stability of the models, indicating that the models are well-specified and reliable according to econometric criteria.

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ارائه روش محدودیت علامت در رویکرد خودرگرسیونی برداری برای بررسی تأثیر سیاست‌های غیرمتعارف اقتصادی بر افزایش تولید و تجارت بین‌الملل

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چکیده

سیاست پولی غیرمتعارف به مجموعه‌ای از ابزارهای اقتصادی اطلاق می‌شود که توسط بانک‌های مرکزی برای تحریک اقتصاد در زمانی به‌کار گرفته می‌شوند که سیاست‌های پولی متعارف دیگر اثربخشی خود را از دست داده‌اند. در این مطالعه، روشی جدید با استفاده از مدل خودرگرسیونی برداری با محدودیت علامت ارائه شده است تا اثر شوک‌های سیاست پولی غیرمتعارف مورد ارزیابی قرار گیرد. بدین‌منظور، تأثیر متغیرهایی ازجمله نرخ بهرهٔ واقعی، تورم، تولید ناخالص داخلی (GDP)، نرخ واقعی ارز و همچنین تسهیل مقداری برای دورهٔ زمانی ۱۳۴۰ تا ۱۴۰۰هـ.ش. در شرایط محدودیت‌های مثبت و منفی بر این متغیرها برآورد شده است. نتایج نشان می‌دهد، هنگامی‌که محدودیت منفی بر نرخ بهره اعمال می‌شود، تولید افزایش یافته و شوک‌های سیاست پولی غیرمتعارف شناسایی و برآورد می‌شوند. سیاست پولی غیرمتعارف می‌تواند بازارهای مالی را تثبیت کرده، عدم اطمینان را کاهش دهد و از طریق ارائه وام‌های کم‌بهره، از تولید کم‌هزینه در اقتصاد حمایت کند. مدل خودرگرسیونی برداری با محدودیت علامت اثر اجرای سیاست‌های پولی غیرمتعارف را در کاهش اثرات بحران‌های اقتصادی یا رکودهای عمیق آشکار می‌سازد. این مدل به برنامه‌ریزان اقتصادی امکان می‌دهد تا شرایط خروج از رکود تورمی را ازطریق سیاست‌های پولی غیرمتعارف ارزیابی کنند که درنهایت منجر به افزایش تولید مازاد و گسترش تجارت بین‌الملل کالاها می‌شود. مدل خودرگرسیونی برداری با محدودیت علامت همچنین رقابت‌پذیری کالاها و خدمات داخلی و خارجی را ازطریق تحلیل اثرات سیاست‌های پولی غیرمتعارف تعیین می‌کند.

کلیدواژگان: مدل خودرگرسیونی برداری با محدودیت علامت، سیاست پولی غیرمتعارف، تولید.
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Bu-Ali Sin University

Regional Spillover Effects of Natural Resource Extraction on Ecological Footprint in the Middle East

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Abstract

The extraction of oil and gas resources in the Middle East region is a primary source of income and economic growth. These resources have not only failed to drive these countries towards development but have also put pressure on the environment. However, the environmental consequences, particularly the regional and transboundary impacts on the ecological footprint, remain insufficiently examined. Then, this research examines the impact of gas extraction on the ecological footprint in the Middle East over the period 2000 - 2021. The main contribution of this paper lies in revealing the regional and cross-border ecological impacts of gas extraction, which were previously unexplored in the literature. The spatial panel SDM framework allows for robust estimation of these effects. The estimated spatial Rho coefficient indicates that the ecological footprint determinants in a country have spillover effects on neighboring countries' environmental quality. This result highlights the necessity of enforcing intra-regional environmental regulations in the Middle East. In addition, focusing on technical coordination, the support of neutral third parties, and flexible, non-binding arrangements can be especially effective in the geopolitically fragmented Middle East. Moreover, our results show that local natural gas extraction significantly increase environmental degradations in the home country. Therefore, implementing new technologies for energy extraction to reduce the emissions intensity of oil and gas operations, enforcing stricter environmental protection regulations, and adopting policies to reduce the economy's dependence on natural resources can decrease their ever-increasing reliance on natural resources, ultimately improving environmental quality. Additionally, the hypothesis of Environmental Kuznets' Curve is rejected in the Middle East region, denoting that environmental preservation policies are not accompanied by an economic acceleration process in the Middle East. They still prioritize economic growth issues over environmental concerns.

Keywords: Ecological Footprint, Spatial Econometrics, Gas Extraction, Middle East.
JEL Classification: O13, P48, Q51, R11.

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1. Introduction

The Middle East hosts some of the world's leading oil and gas producers, including five of the top ten major oil-exporting nations. In 2022, out of 3998 billion cubic meters of gas production worldwide, 701 billion cubic meters were from the Middle East, representing 17.5% of the world's total gas production, a 32% increase compared to 2021 (IEA 2022). Among Middle Eastern countries, in 2022, Iran produced the highest volume of natural gas at 251 billion cubic meters, followed by Qatar and Saudi Arabia. In addition, the Middle East region holds the most reserves of natural resources, particularly oil and gas, with their economies heavily reliant on energy exports. For example, over 98% of Iraq's GDP depends on oil exports, while in Qatar, more than 70% of government revenue, over 60% of the GDP, and almost 85% of export revenues come from oil and gas.

In one hand, the growing trend of the global economy and the increase in energy demand has posed significant challenges for the Middle East in fulfilling the world's growing energy demand (Energy Institute, 2025). It has led to significant expansion in oil and gas industries in the mentioned countries in recent decades (especially in Qatar, Oman, United Arab Emirates, Saudi Arabia, Iran, and even Iraq). On the other hand, the development of these industries has led to environmental degradations that threaten the health of living organisms and the ecosystem (Razzaghi & Fotros, 2025). Operations in the oil and gas sector can lead to contamination of the land, atmosphere, and climate through processes such as drilling, hydraulic fracturing, and wastewater disposal. In this context, Ben Salha & Zamim (2023) argued that in Saudi Arabia, a 10% increase in gas extraction reduces environmental quality by 4 percent. Razzaghi and Fotros (2024) also indicate that a 1% increase in gas extraction in neighboring countries contributes to a 4% rise in the fisheries footprint within the Middle East region. Therefore, considering the adverse environmental effects of energy extraction is an important issue, especially for the resource-reach region of the Middle East.

Environmental degradation is one of the most critical challenges in sustainable development issues. Human activities affect adversely the environment quality in many ways. Constructions on sea beds and in forest areas, building roads, overconsuming of fossil fuels, resource extraction, urbanization, overpopulation, and deforestation are examples of destructive actions of humans on the planet. These operations result in significant environmental impacts, including pollution of air and water, climate alteration, destruction of habitats, and reduction of biodiversity. For example, Nadim *et al.* (2008) showed that coastal developments in the Persian Gulf led to stress on marine life and reshape shoreline habitats. In addition, an environmental group report indicates that the

construction of the Botaş Saros FSRU Terminal along the northeastern shore of the Gulf of Saros resulted in the cutting of more than 10,000 trees for pipeline routes (Nadim *et al.*, 2008). Then, on the one hand, along with the rapid economic growth of societies, the global demand for fossil fuels, such as coal, oil, and natural gas increases sharply. On the other hand, the extraction of the non-renewable resources gives rise to considerable environmental concerns about the atmosphere, aquatic animals, terrestrial fauna, and the biosphere in general, especially when this process is going on for a long time. Several environmental indicators measure the depth of environmental degradation caused by human activities. Ecological footprint is an integrated indicator used to assess and indicates ecological sustainability (Zafar, 2019). In contrast to other indices as the greenhouse gas emission indicator, the ecological footprint index comprehensively measures a set of pressures on cropland, grazing land, forest, fishing ground, build-up land and the air (Uddin *et al.* 2017, Wilson & Anielski 2004). According to the Living Planet Report in 2022, the worldwide ecological footprint was more than 20 billion global hectares. The average footprint per person was 2.58 global hectares, while the biological capacity was 1.51 global hectares per capita; meaning that humans consume almost 50% more than reserves. For sustainable exploitation, natural resources must be used at a rate as fast as they are replenished by nature (WWF, 2022). The ecological deficit index reflects the degree to which humanity's consumption of natural resources surpasses the biological capacity of the region that supports it. According to Ecological Footprint Data (2024), the ecological deficit in the Middle East region has increased in the last decade.

The primary objective of this study is to investigate the environmental degradation effects associated with natural gas extraction in 12 selected Middle Eastern countries[1] during the period 2000–2021. As highlighted by numerous researchers[2], the environmental damages caused by gas extraction are not confined to the extraction sites but extend across the entire region. In the context of the Middle East, countries in the region are highly interconnected through shared ecosystems, cross-border energy infrastructure, trade in energy-intensive goods, and transboundary air and water pollution. Therefore, ignoring spatial spillover effects may lead to biased and incomplete conclusions regarding the environmental consequences of natural gas**.** Therefore, the key contribution of this study is to examine the spillover effects of environmental degradation in the Middle East resulting from gas extraction activities. In addition, considering natural gas extraction as one of the

[1] These countries include: Saudia Arabia, Qatar, Iraq, Iran, Kuwait, Oman, Türkiye, Jordan, Yemen, Bahrain, Syria, and United Arab Emirates.
[2] See for example: Karimi *et al.* (2022), Hjorth *et al.* (2021)

most critical factors in affecting the ecological footprint in the Middle East area, for the first time, is another distinction of this study. The rest of the article is compiled as follows: After the introduction in Section 1, Section 2 provides the theoretical framework and literature review. Sections 3 and 4 present the research methodology and empirical results, respectively. Finally, Section 5 offers the concluding remarks.

2. Literature Review

Ecological footprint is a comprehensive indicator that indicates the extent of environmental degradation (in terms of: air, water, and soil) caused by human activities. It shows the biological capacity of the environment in the regeneration of all its natural resources that have been consumed and absorb the wastes generated by people. Therefore, excessive use and extraction of natural resources will weaken the environment's ability to regenerate and ecological footprint exceeds biological capacity an ecological deficit will arise (Khezri *et al.* 2023a). According to a bulk of empirical studies, lots of economic variables affect ecological footprint that leads to ecological deficit, like: extraction of natural resources, GDP growth, energy consumption, renewable energy consumption, urbanization, income inequality, foreign direct investment, etc. The channels through which these factors affect ecological footprint are reviewed below.

2-1. The ecological footprint of energy extraction

Oil and gas resources bring abundant effortless income to countries. These revenues vast governments' financial capacity and make their budgetary programs feasible. Therefore, countries have more tendency to exceedingly extract natural resources. However, the existence of a positive correlation between natural resource extraction and the emission of various pollutants is noticeable[3]. According to World Energy Outlook, approximately 15% of world greenhouse gas pollution originates from oil and gas operations and consuming gas and oil results in another 40% of emissions (IEA 2022). Hence, regions endowed with richer resources are likely to experience more severe environmental challenges (Lee & He 2022). For the first time, Humboldt proposed the theory of ecological balance, which is based on the principle that any change in an environmental factor can have a chain effect on other environmental factors; for example, over-extraction of natural resources can lead to a reduction in water and soil resources, destruction of natural habitats, and climate change (Jahangard, 2018). Indeed, oil and gas exploration and extraction activities include

[3] For example, the coal capital of China, Shanxi province, is known as the most polluted city in the world.

multiple stages, as: exploration, construction, installation, extraction, production, transportation, and decommissioning, each of which creates pollution according to the type of activity (Ebrahimi *et al.* 2016). Danish et al. (2019) argued that oil and gas extraction lead to the leakage of toxic chemical contaminants into the water, where, processing and transition of oil and gas lead to deforestation, air pollution, and limitation of agricultural production. In addition, consuming fossil fuels in all stages of natural resource extraction leads to increased greenhouse gas emissions and global warming (Ahmed *et al.* 2020). Kwakwa *et al.* (2018) and Wu *et al.* (2017) stated that continuous extraction of natural resources can fuel environmental degradations through an increase in energy consumption, air and water pollution, destruction of natural habitats, and decrease in biodiversity. A large number of studies explain how natural resource extraction destroys fishing grounds[4]. In this context, Razzaghi and Fotros (2024) argued that fossil fuel extraction causes toxic microplastic smog, noise pollution, and artificial lightening which resulting in alterations in fish migration patterns, breeding behavior, and feeding habits. Chekouri (2023) shows that higher natural resource extraction intensifies the ecological footprint in Algeria, while lower extraction may have less harmful effects. Makhdum *et al.* (2022) show that natural resources noticeably increase ecological footprint levels in the short and long term in China.

2-2. The ecological footprint of economic growth

According to economic theories, the human activities arising from economic development (shown by GDP and GDP^2 in the early and advanced stages of development, respectively) have adverse effects on the environment. Kolstad & Golub (1993) believe that economic growth and increased production require greater use of natural resources and energy, especially fossil fuels, which in turn leads to environmental degradation. In addition, economic development leads to importing energy-intensive technologies (especially in oil-rich countries), industrialization, urbanization, infrastructures and more international trade that all cause pollution haven (Cole, 2004). However, in the advanced levels of development, public awareness of the necessity of a sustainable environment rises which leads to the establishment of legislative and regulatory institutions to protect the environment (Ahmed *et al.,* 2021). Gradually, increasing the use of renewable energy, reducing the use of fossil fuels, and other protectionary actions subside the destructive environmental effects of economic growth (Khezri *et al.,* 2023a). This relationship between economic growth and environmental quality is known as the inverted U-shaped Environmental Kuznets Curve, which was first proposed by Grossman and Krueger (1991,

[4] See for example: Sharif *et al.* (2020), Danish *et al.* (2019) and Hassan *et al.* (2019) among others

1995). The results of empirical research about the existence of the environmental Kuznets Curve are mixed. For example, Arif *et al.* (2023), and Ullah *et al.* (2023) confirm the environmental Kuznets curve (EKC) hypothesis for Pakistan and Turkey. However, Li *et al.* (2023) rejects the environmental Kuznets curve in 158 countries.

2-3. The ecological footprint of urbanization

The relationship between urbanization and environmental quality is still uncertain. Urbanization shows the process of rural people's migration to urban areas which is associated with rapid industrialization, population growth and social and economic structural changes (Hashmi *et al.* 2021). Some theories argue that urbanization is accompanied by increased energy consumption and exploitation of natural resources resulting in carbon dioxide emission. In addition, urbanization increases demand for more transportation infrastructures, increases deforestation to accommodate expanding human habitats, increases consumption of crop lands, and livestock, increases demand for manufactured products, increases discharge of factory waste material into the environment, which all lead to environmental degradations (Salman *et al.,* 2022; Ahmed *et al.,* 2020). However, other theories argue that modernity could decrease ecological devastation by applying advanced clean technologies (such as renewable energy) and using energy more efficient (Fan *et al.,* 2006). In this context, Sarwar *et al.* (2024) showed that urbanization increases the ecological footprint in OECD countries and decreases the ecological footprint in non-OECD countries. Ullah *et al.* (2023) showed that urbanization hurting the ecological footprint in Turkey.

2-4. The ecological footprint of inequality

The impact of income inequality on ecological footprint is significant. According to Jorgenson *et al.* (2017) as the income gap among households gets raised, then consumption competition and working long hours occur in society that aggravate environmental pressure. Ravallion *et al.* (2000) argue that income inequalities could change consumers' preferences and change the marginal emission trend by households that affect the environment quality. People with higher incomes excessively consume more natural resources and they have more willingness to buy goods and services that can increase waste and environmental pollution. The lower-income consumers also apply more inefficient technologies and goods in their consuming bundle that could devastate the environment (Uzar and Ayupoglu, 2022). In addition, Wolde-Rufael and Idowu (2017) argue that income inequalities result in an undemocratic decision-making process which disrupts the

implementation of environmental protection policies and then the high-income groups could implement their economic projects and impose environmental costs. However, the Keynesian effect introduces a different mechanism in the relationship between income inequality and ecological degradation. According to the Keynesian effect, the reduction of the income gap among social groups encourages lower-income groups to demand activities such as heating, electricity, transportation, and travel, which are closely related to pollution emissions (Ravallion *et al,.* 2000). The results of empirical studies are conflicting. Idrees *et al.* (2022), Uzer and Ayupoglu (2022), and Kazemzadeh *et al.* (2021) showed that income inequality promotes environmental pollution; however, Anderson (2024) argued that the relationship between income inequality and ecological footprint is insignificant. Langnel *et al.* (2021) show that income inequalities improve environmental quality in Burkina Faso, Nigeria, and Senegal and worsen it in Benin.

2-5. The ecological footprint of foreign direct investment

Foreign direct investment (FDI) is one of the best solutions to trigger economic development in developing countries. FDI brings new knowledge, technology, and new methods of management to the host countries and has three different effects on the supply side of the host economy such as 1) scale effect: it refers to stimulating economic activities and occurring big-push in the host economy where a large proportion of environmental degradation is rooted in the intensification of economic activities. 2) Composition effect: it refers to changing the mixture and the combination of industries in host countries. The environmental outcome depends on the nature of industries that are interred to receiving countries through foreign direct investment. 3) Technological effect: it refers to new production and management knowledge and technologies that are transferred to the host country by FDI that make the production phase more productive and efficient. Therefore, the environmental degradation effects of manufacturers are reduced (Doych, 2020). On the demand side, foreign direct investment increases household income which leads to increased consumption demand by households (in the case of equal income distribution) that raises environmental degradations (Doych, 2020). In this concept, Jahangir *et al.* (2023) show that technological innovation is crucial in reducing the adverse environmental effects of natural resource consumption across all regions in 73 developing countries.

In addition, the empirical literature on the nexus between FDI and ecological footprint examines three kinds of hypotheses: 1) the pollution haven hypothesis 2) the FDI halo hypothesis and 3) the Environmental Kuznets curve. According to the pollution haven hypothesis, foreign investors are more eager to invest in countries with low regulatory

policies on conserving the environment. Then they impose the destructive environmental burden of their production and consumption on developing countries (Gallagher, 2009). The FDI halo hypothesis explains how multinational firms in less developed countries could awaken public opinion regarding environmental protection policies in host countries (Jorgenson, 2007). Finally, according to the environmental Kuznets curve, the deterioration of the environment increases in the first stages of industrialization triggered by FDI, and at the high level of economic growth these degradations will be decreased (Dinda, 2004). Kızılgöl & Önde (2022) show that foreign direct investment decreases ecological footprint in 31 OECD countries.

2-6. Ecological footprint of renewable energy

According to most theories and empirical studies, energy is at the heart of environmental degradation. Energy production and consuming traditional energy sources such as oil, coal, and natural gas damage ecological quality by polluting the air and releasing greenhouse gases. Burning fossil fuels raises global temperature and causes climate change. It is expected that utilizing renewable energy based on wind, water, sun, and waste can gradually reduce pressure on the environment and guarantee environmental sustainability (Chen *et al.,* 2019). However, the nexus between ecological footprint and renewable energy consumption is complex. For example, Akpanke *et al.* (2024) released that consuming renewable energy in OECD countries significantly reduced ecological footprint and carbon emission. Azimi and Mohammad (2024) argued that there is a nonlinear relationship between renewable energy and ecological footprint in 74 developing countries and consuming renewable energy mitigates the ecological damages. Abid *et al.* (2022) showed that renewable energy consumption in Saudia Arabia caused environmental quality progress. Nan *et al.* (2022) argued that renewable energy has a long-term negative impact on the ecological footprint in China. In contrast, Raghutla *et al.* (2022) showed that renewable energy consumption increases the ecological footprint in N-11 countries. In addition, Nathaniel *et al.* (2022) showed that renewable energy usage couldn't control the ecological footprint in emerging countries. Ansari *et al.* (2021) also found that renewable energy harms the environment. Kongbuamai *et al.* (2021) found that renewable energy's growth led to environmental degradation growth.

3. Model Specification and Data

To examine the spillover effects of gas extraction on ecological footprint in the Middle East area, this study applied Karimi *et al.* (2022) conceptual model as follows:

$$\ln EFP_{it} = \beta_1 + \beta_2 \ln GDP_{it} + \beta_3 \ln GDP_{it}^2 + \beta_4 \ln GINI_{it} + \beta_5 \ln FDI_{it} + \beta_6 \ln URB_{it} + \beta_7 \ln EC_{it} + \beta_8 \ln REC_{it} + \beta_9 \ln GAS\ EX_{it} + \varepsilon_{it} \quad (6)$$

Where EFP indicates Ecological Footprint Index as the dependent variable, GDP shows gross domestic production, GDP^2 is the squared form of gross domestic production[5], GINI is the Gini coefficient, FDI is foreign direct investment, URB is urbanization, EC is energy consumption, REC is renewable energy consumption, and GAS EX is gas extraction. A detailed description of the research variables is presented in Table 1.

Table 1: Description of Variables

	Variables	Theoretical definitions	Operational Definitions	Source
Dependent	EFP	environmental pressure of human activities by measuring the biologically productive land and water area required to supply consumed resources and absorb generated waste, given existing technology and management practices.	Global Hectares per person	GFN
Independent	GDP	Gross Domestic Product (GDP) is an economic indicator that measures the total monetary value of all final goods and services produced within a country's borders over a specific period	Real GDP (constant 2015US$)	WDI
	Gini	measure of income inequality that summarizes the extent to which income distribution within an economy deviates from perfect equality, with higher values indicating greater inequality	standardized Gini index, ranging from 0 (perfect equality) to 100 (perfect inequality)	WDI
	FDI	Foreign Direct Investment (FDI) refers to cross-border investment in which a resident entity in one country obtains a lasting interest and a significant degree of influence in the management of an enterprise operating in another country, facilitating capital accumulation, technology transfer, and production expansion.	net inflows of foreign direct investment as a percentage of GDP	WDI

[5] The squared form of GDP is included in the model to capture nonlinear relationships between economic growth and environmental pressure, specifically to test the Environmental Kuznets Curve (EKC) hypothesis. According to the EKC theory, at early stages of economic development, environmental degradation (e.g., ecological footprint) tends to increase with income due to higher industrial activity, energy use, and consumption. However, after a certain level of income is reached, further growth leads to improvements in environmental quality as societies adopt cleaner technologies, implement stricter regulations, and shift toward service-oriented economies.

	Urban	Urbanization refers to the process by which an increasing proportion of a country's population resides in urban areas, reflecting structural changes in economic activity, land use, and consumption patterns that can intensify environmental pressure.	percentage of the total population living in urban areas	WDI
	EC	Energy consumption refers to the total amount of energy used by economic agents within an economy to support production, transportation, and household activities, and is a key driver of economic growth and environmental pressure through resource use and emissions.	per capita energy use, measured in kilograms of oil equivalent	EIA
	REC	Renewable energy consumption refers to the use of energy derived from naturally replenishing sources such as solar, wind, hydro, biomass, and geothermal	share of renewable energy in total final energy consumption	EIA
	Gas ex	Gas extraction refers to the process of locating, drilling, and producing natural gas from underground reservoirs	natural gas production in billion cubic meters (bcm),	IEA

(Source: Author. Note: GFN – Global Footprint Network, WDI – World).

4. Development Indicators, IEA – International Energy Agency, EIA-Energy Information Administration

Figures 1 and 2 illustrate the increasing trend of natural gas extraction and the corresponding upward trend in the ecological footprint in gas-rich countries of the Middle East from 2000 to 2021. According to Figure 1, countries such as Iran, Qatar, and Saudi Arabia have experienced a particularly sharp increase in natural gas extraction during the last decade compared to the previous one, while other countries in the region show a more moderate rise. Simultaneously, as shown in Figure 2, the average ecological footprint in these countries has also increased over the same period. This parallel rise suggests a strong link between intensified gas extraction and increased environmental pressure. In particular, the data indicate that countries with the most aggressive extraction policies not only face local ecological impacts, such as land degradation and water stress, but may also contribute to regional environmental pressures through cross-border effects.

Additionally, the figures highlight heterogeneity among Middle Eastern countries: while some nations maintain relatively stable extraction and ecological footprints, others exhibit a steep upward trajectory, reflecting differences in energy policies, technological adoption, and resource management strategies. The combined interpretation of Figures 1

and 2 underlines the environmental costs of rapid energy expansion in the region and emphasizes the need for implementing sustainable extraction practices and regional environmental cooperation to mitigate these impacts.

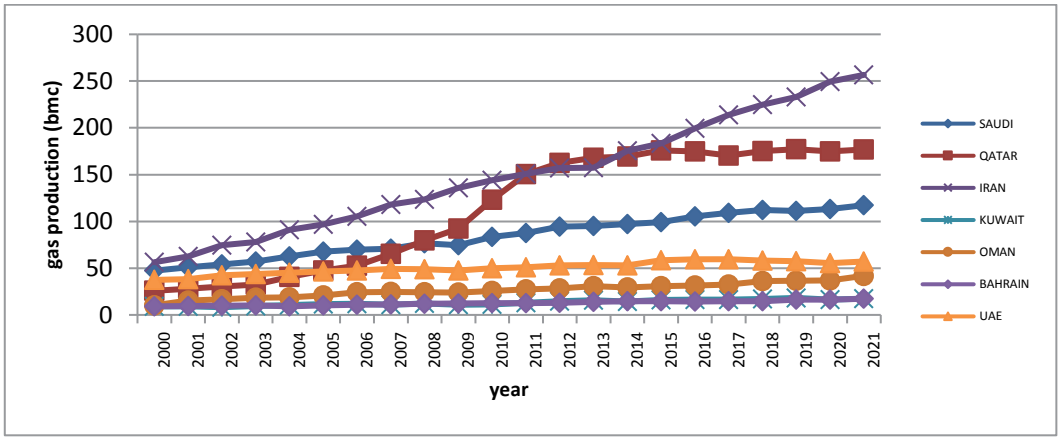

Fig. 1: Gas Production During 2000 to 2021

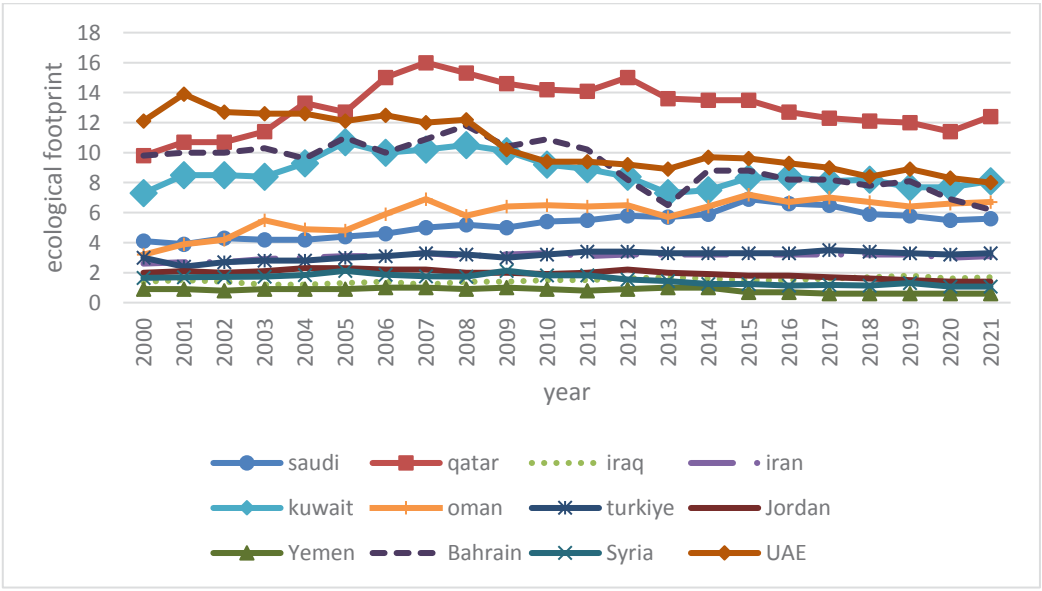

Fig. 2: Ecological Footprint During 2000 to 2021

5. Methodology and Data

Analyzing the spatial interaction effects is a considerable issue in regional span studies. Many scientific theories and empirical observations in environmental studies show that changes to explanatory variables in a unit country i could change the dependent variable not only in country i, but also in neighboring countries of j. Based on the hypothesis of Wang *et al.* (2016) that "all issues related to environmental problems are inherently spatial", this study utilizes a spatial panel data methodology to consider spillover effects.

Spatial panel data econometrics considers the interaction among economic units which originates from physical (spatial) conditions or economic characteristics. In general, there are three types of spatial interaction effects which consumed as: endogenous interaction effects (where the dependent variable of a country is affected by the dependent variable of a neighboring country), exogenous interaction effects (where the dependent variable of a country is affected by independent variables of neighboring country), and interaction between error terms (where the error term of a country is affected by error terms of neighboring country and the error terms are spatially correlated) (Elhorst 2017).

The general nesting spatial panel data model is as follows (Belotti *et al.* 2017):

$$Y_{it} = \alpha + \tau Y_{i,t-1} + \rho \sum_{j=1}^{n} W_{ij}\, Y_{jt} + \sum_{k=1}^{k} X_{itk}\, \beta_k + \sum_{k=1}^{k} \sum_{j=1}^{n} W_{ij}\, X_{jtk} \theta_k + \mu_i + \gamma_t + \nu_{it}$$

$$\nu_{it} = \lambda \sum_{j=1}^{n} W_{ij}\, \nu_{it} + \varepsilon_{it}\ ; \quad i = 1,2,\ldots,n\ ; \quad t = 1,2,\ldots,T; \qquad (1)$$

Where Y_{it} represents the dependent variable, X denotes the explanatory variables ranging from 1 to k, W_{ij} is the spatial weight matrix and $W_{ij}Y_{jt}$ indicates the spatial lag effect of the dependent variable Y_{jt} on Y_{it} . ρ represents the coefficient of spatial autoregressive. β_k and θ_k represent the non-spatial and spatial effects of the explanatory variables, respectively. α denotes the intercept, μ_i represents the spatial fixed (random) effects, and γ_t denotes the time fixed effects. Additionally, with the presence of the τ coefficient, the model can be both static and dynamic. In the static model, τ=0, while in the dynamic model, $\tau \neq 0$. In addition, ν_{it} is the error term of the model that can also incorporate spatial effects, and λ represents the spatial effect from the error terms named spatial autocorrelation coefficient. The general nested spatial model is rarely used because of overfitting problems. However, based on the variety of spatial dependencies between countries, some of the regular different variants of spatial regression models are as follows:

1. The Spatial Autoregressive model (SAR): captures the endogenous interaction effects, where the dependent variable's disturbance term depends on the neighboring dependent factor.

$$(\lambda = \theta = 0) \Rightarrow Y_i = \alpha + \tau Y_{i,t-1} + \rho \sum_{j=1}^{n} W_{ij}\, Y_{jt} + \sum_{k=1}^{k} X_{itk}\, \beta_k + \mu_i + \gamma_t + \nu_{it} \qquad (2)$$

2. The Spatial Error Model (SEM): captures the interaction effect among the error terms.

$$(\rho = \theta = 0) \Rightarrow Y_i = \alpha + \tau Y_{i,t-1} + \sum_{k=1}^{k} X_{itk}\, \beta_k + \mu_i + \gamma_t + \nu_{it}$$

$$\nu_{it} = \lambda \sum_{j=1}^{n} W_{ij}\, \nu_{it} + \varepsilon_{it} \qquad (3)$$

3. The Spatial Autoregressive with Spatial Autoregressive Combined Model (SAC): captures both endogenous interaction effect and error interaction effect.

$$(\theta = 0) \Rightarrow Y_{it} = \alpha + \tau Y_{i,t-1} + \rho \sum_{j=1}^{n} W_{ij}\, Y_{jt} + \sum_{k=1}^{k} X_{itk}\, \beta_k + \mu_i + \gamma_t + \nu_{it}$$

$$\nu_{it} = \lambda \textstyle\sum_{j=1}^{n} W_{ij}\, \nu_{it} + \varepsilon_{it} \qquad (4)$$

4. The Spatial Durbin Model (SDM): captures both endogenous and exogenous interactions.

$$(\lambda = 0) \Rightarrow Y_{it} = \alpha + \tau Y_{i,t-1} + \rho \textstyle\sum_{j=1}^{n} W_{ij}\, Y_{jt} + \sum_{k=1}^{k} X_{itk}\, \beta_k + \sum_{k=1}^{k} \sum_{j=1}^{n} W_{ij}\, X_{jtk} \theta_k +$$

$$\mu_i + \gamma_t + \varepsilon_{it} \quad (5)$$

In order to justify the application of spatial model, the presence of spatial autocorrelation and special dependencies should be examined. In this context, the LM test, Moran's test, Geary-C test, and Getis-ords test applied. The LM test examines the null hypothesis of $\rho = 0$, and existence of spatial autocorrelation among observations is approved by the rejection of null hypothesis. The Moran's I test, Geary-c test, and Getis-ords examine the null hypothesis of $\lambda = 0$ where the rejection of this hypothesis indicates the existence of spatial autocorrelation among error terms.

In addition, the spatial weighting matrix (W) specifies the values of spatial aspects in the model. It shows how much potential spillover there is from one country to another neighboring country. The elements of this matrix are based on the contiguity, revealing the border sharing among countries. Zero element in this matrix shows that two countries share no water or land border, hence no spillover effect could exist between them. In addition, number 1 element in the contiguity matrix shows that two countries share common borders and the potential for spillover effects between two countries is very high.

6. Model Estimation

Before estimating the model to analyze the spillover effects of ecological footprint in the Middle Eastern countries, the stationarity of the variables was tested and reported in Table 2. The results using the Levin *et al.* (2002) test indicate that all variables are stationary at a significance level of 5%.

Table 2: results of stationary test

Variables	Test statistics	prob	result
$\ln EFP_{it}$	-1.84	0.032	Stationary
$\ln GDP_{it}$	-3.96	0.000	Stationary
$\ln GDP_{it}^2$	-2.95	0.0016	Stationary
$\ln GINI_{it}$	-3.53	0.0002	Stationary

$lnFDI_{it}$	-3.25	0.0006	Stationary
$lnURB_{it}$	-5.25	0.000	Stationary
$lnGAS\ EX_{it}$	-5.42	0.000	Stationary

In addition, Moran's I test, Geary's GC test, and Getis' G test were utilized in order to examine the existence of spatial error autocorrelations. The results of these tests are presented in Table 3.

Table 3: Diagnostic tests of spatial autocorrelation

Test Statistic	Moran-I-Statistic	Getis-Ords	Geary GC	LM Error	LM lag
Value Significance) (level	٠/0.1939 *(0.000)	-0.8566 *(0.0000)	1.1505 **(0.0509)	40.8200 *(0.0000)	12.7932 *(0.0003)

* Significance at the 1% level,** Significance at the 5% level

Based on the results of Moran's I and Getis' G tests, the existence of positive spatial dependencies among errors are confirmed. In addition, the results of the LM Error test reject the null hypothesis of no spatial autocorrelation and the results of the LM lag test confirm the existence of spatial autocorrelation among lagged dependent variables in the region. Therefore, the spillover effect of ecological footprint in the Middle East area exists and the ecological footprint of a country is not solely a result of its characteristics and location but is also influenced by other countries. Then, we are allowed to apply the spatial panel data method. After confirming the presence of spatial autocorrelation, selection between different spatial models is done using diagnostic tests. The first step in choosing the optimal model is to compare the SAR model with the SDM model using the Wald test.

Table 4: Wald test

Hypothesis Test	Statistical Value	Significance level
$\theta = 0$ **(SAR V.S SDM)**	86.05	0.0000

(Source: Authors' estimations).

According to the results of Table 4, the null hypothesis of the Wald test which states that the SAR model is optimal at a 5% significance level is rejected, and the SDM model is chosen. In the second step, the Multiple Wald test is used to compare the SEM model against the SDM model and the result is presented in Table 5.

Table 5: Multiple Wald test

Hypothesis Test	Statistical Value	Significance level
$\theta = -\beta\rho$	84.38	0.0000

(SEM VS SDM)		

(Source: Authors' estimations).

According to the results, the null hypothesis which suggests the superiority of the SEM model is rejected, and the SDM model is chosen as the optimal model in this step. In the next step, Akaike's information criterion and Bayesian criterion are utilized to select the optimal model between the SAC and SDM models and the results are presented in Table 6.

Table 6: Akaike's information criterion and Bayesian information criterion

Model	Bayesian(**BIC**)	Akaike(**AIC**)
SAC	-360.0057	-399.3411
SDM	-399.2611	-463.6282

(Source: Authors' estimations).

According to the results in Table 5, between the SAC and SDM models, the optimal model is the SDM. A prominent feature of the spatial Durbin model compared to other spatial models is the consideration of spatial lag of the dependent variable and spatial lag of explanatory variables as new explanatory variables. The spatial Durbin model decomposes total effects into direct and indirect effects (spillover effects), meaning that linear regression parameters are interpreted through direct and indirect effects (Lesage & Pace 2009). After selecting the optimal model, the Hausman test is used to choose between models with fixed or random effects.

Table 7: Hausman test

Test Statistic	**Statistical Value**	**Significance level**
Hausman	16.85	0.4644

(Source: Authors' estimations).

According to the result in Table 7, the existence of random effects is accepted, indicating that our spatial Durbin model includes random effects. Therefore, we will estimate the research model, which is defined as follows for the spatial Durbin model:

$$\ln EFP_{it} = \beta_1 + \rho \sum_{j=1}^{n} W_{ij} \ln EFP_{it} + \beta_2 \ln GDP_{it} + \beta_3 \ln GDP_{it}^2 + \beta_4 \ln GINI_{it} + \beta_5 \ln FDI_{it} + \beta_6 \ln URB_{it} + \beta_7 \ln EC_{it} + \beta_8 \ln REC_{it} + + \beta_9 \ln GAS\ EX_{it} + \theta_{10} \sum_{j=1}^{n} W_{ij} \ln GDP_{it} + \theta_{11} \sum_{j=1}^{n} W_{ij} \ln GDP_{it}^2 + \theta_{12} \sum_{j=1}^{n} W_{ij} \ln GINI_{it} + \theta_{13} \sum_{j=1}^{n} W_{ij} \ln FDI_{it} + \theta_{14} \sum_{j=1}^{n} W_{ij} \ln URB_{it} + \theta_{15} \sum_{j=1}^{n} W_{ij} \ln EC_{it} + \theta_{16} \sum_{j=1}^{n} W_{ij} \ln REC_{it} + \theta_{17} \sum_{j=1}^{n} W_{ij} \ln GAS\ EX_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (7)$$

Where ρ represents the spatial effect resulting from the dependent variable, β shows the effects of explanatory variables on the dependent variable, and θ represents the neighbor effects or spillover effects of independent variables.

Table 8: Results of Spatial Models Estimation

Model / Variable		SDM Model				
		Contiguity Matrix	**Inverse Distance Matrix**		**Contiguity Matrix**	**Inverse Distance Matrix**
EFP		Coef. (z)	Coef. (z)		Coef. (Z)	Coef. (z)
Main Effects	LnGDP	0.37 (7.48)*	0.56 (11.34)***	Weighted Spatial Effects	-0.6876 (-5.99) *	0.34 (1.20)
	$LnGDP^2$	0.0024 (1.75)***	0.003 (1.93)**		0.0094 (2.72) *	0.003 (0.78)
	LnGINI	0.16 (0.69)	0.44 (1.81)*		2.2195 (4.40) *	1.36 (1.31)
	LnFDI	-0.13 (-0.32)	0.001 (0.02)		0.2883 (4.96) *	0.28 (1.88)**
	LnURBAN	0.43 (-6.45) *	-0.57 (-9.38)***		0.5258 (4.14) *	-0.13 (-0.46)
	LnGASEX	0.01 (1.62) ***	0.01 (1.68)***		0.0110 (0.51)	0.025 (0.48)
	LnEC	0.05 (5.62) *	0.04 (2.36)*		0.0461 (2.36) *	0.04 (2.35)*
	LnREC	-1.4664 (-1.85) ***	-1.70 (-1.9)**		1.3777 (1.14)	1.37 (1.15)
Spatial	Rho	0.0012 (0.01) ***		Number of observations	264	
R^2	Within	0.6243		Number of Groups	12	
	Between	0.5520		Panel Length	22	
	Overall	0.5491		Log-Likelihood	201.7361	

Note: p-value, ***, **, and * show significance at 1%, 5%, and 10% levels, respectively (Source: Authors' estimations).

Table 8 shows the results of SDM model estimation, where, in order to examine the robustness of the results, the model is re-estimated using two alternative spatial weight matrices: (i) a binary contiguity matrix[6], and (ii) an inverse distance matrix constructed from the geographical distances between the countries' capital cities. The estimation results

[6] The spatial contiguity matrix is constructed such that two countries are considered neighbors if they share at least one common land or maritime boundary.

of the Spatial Durbin Model (SDM) based on the inverse distance matrix are reported in Table 8 and highlighted in grey. Based on the results, the estimated spatial Rho coefficient is positive and considerably significant at a 99% confidence level. This result indicates that the ecological footprint determinants in a country have spillover effects in neighboring countries around the Middle East region. In addition, according to the results, local natural gas extraction has a strictly positive and significant effect on the ecological footprint. Each percent increase in gas extraction leads to approximately 0.01 increase in ecological footprint in the home country. The Middle East region contains developing countries which are endowed with enormous natural resources and their economy is mostly based on oil and gas export. They always increase the amount of natural resource extraction in order to support the increasing trend of global energy demand. These countries not only suffer from insufficient technologies and up-to-date methods of exploitation, but the lack of environmental protection policies has also contributed to environmental degradation. This result is consistent with the results of Razzaghi and Fotros (2024), who concluded that gas extraction destroys the environment in the Middle East, and is inconsistent with the results of Zeraibi and Khan (2024) who showed that gas extraction reduces the ecological footprint in the USA. In addition, according to the spatial coefficients released in Table 7, the spillover effects of gas extraction in the Middle East region are insignificantly positive. It means that the adverse spillover effect of the gas extraction process in the home country on the ecological footprint in neighboring countries is not considerable.

In the context of the Environmental Kuznets Curve (EKC) hypothesis, the effects of local GDP and squared form of GDP on the ecological footprint in the home country are positive and significant which means that the higher the GDP, the larger the ecological footprint, resulting in environmental degradations. According to the EKC hypothesis, economic growth initially leads to increased environmental degradation, but after reaching a certain level of economic growth, environmental quality improves. Therefore, our results reject the EKC hypothesis. This result indicates that the environmental reservation policies are not accompanied by an economic acceleration process in the Middle East and they still prioritize economic growth issues over environmental concerns, leading to an increase in the ecological footprint in the region. This result is in line with the results of Razzaghi and Fotros (2024) and Luzzati and Orsini (2009) who strictly reject the existence of the Environmental Kuznets Curve hypothesis in the Middle East area.

According to the results in Table (8), the effect of foreign direct investment (FDI) in the home country on the local ecological footprint is not significant. Whereas, according to the estimated spatial coefficients in Table 7, the FDI in the home country has a negative and

significant effect on the region-wide ecological footprint. This result is in line with the results of Doych (2020), and Gallagher (2009). If foreign direct investment were accompanied by the transferring of clean and efficient technologies to the host country, as well as compliance with environmental standards and investment in sustainable projects, then the destructive effects of FDI would be reduced. However, most foreign direct investments in the Middle East area are in energy industries or mostly are based on energy-intensive technologies which intensify energy consumption and adversely impact the environment.

The main and the weighted spatial coefficients presented in Table 8 indicate that the Gini variable positively and significantly affects the ecological footprint and raises environmental degradations locally and region-wide in the Middle East area. These results show that increasing income inequality leads to consumption competition between low-income and high-income households and working for long times which consequently triggers resource consumption and leads to high environmental degradations. This result is consistent with the results of Idrees *et al.* (2022) and Uzer and Ayupoglu (2022).

Further, since urbanization is associated with modernization, it mitigates environmental pressures. Accordingly, the relationship between urbanization and the ecological footprint in this region is significantly negative. However, the spillover effect of urbanization on the level of ecological footprint in neighboring countries is positive. In addition, the effect of energy consumption on ecological footprint in the Middle East area is significantly positive, locally and regionally. As the production process and the household consumption pattern in the Middle East are deeply energy-intensive, then energy consumption degrades the environment. Renewable energy consumption also has a considerable negative effect on the ecological footprint in this region. These results confirm the results of Akpanke *et al.* (2024) and Abid *et al.* (2022).

In order to gain further inferences, we decomposed coefficients into direct, indirect and total effects. The direct and indirect effects are marginal effects of the changes in explanatory variables on the dependent variables and show how a 1 per cent change in an explanatory variable leads to a change in ecological footprint in home and neighboring countries, respectively. The total effect shows the sum of direct and indirect effects. The results of coefficient decomposition are presented in Table 9, below.

Table 9: Results of Direct Effects,Indirect Effects and Total Effects.

Model		SDM		
	Variable	Coef. (Significance level)	Std. Err	Z
Direct	LnGDP	0.3804(∗)	0.5053	7.53
	$LnGDP^2$	0.0023 (∗∗∗)	0.0013	1.79
	LnGINI	0.1846	0.2203	0.84
	LnFDI	-0.1286	0.0410	-0.31
	LnURBAN	-0.4361 (∗)	0.0629	-6.93
	LnGASEX	0.0156 (∗∗)	0.0092	1.70
	LnEC	0.0566 (∗)	0.0103	5.46
	LnREC	-1.5006 (∗∗)	0.7519	-2.00
Indirect	LnGDP	-0.6909 (∗)	0.1202	-5.74
	$LnGDP^2$	0.0093 (∗)	0.0034	2.73
	LnGINI	2.1994 (∗)	0.4900	4.49
	LnFDI	0.2819 (∗)	0.0572	4.92
	LnURBAN	0.5293 (∗)	0.1270	4.16
	LnGASEX	0.0103	0.0208	0.50
	LnEC	0.0462 (∗∗)	0.0196	2.35
	LnREC	1.5107	1.2341	1.22
Total	LnGDP	-0.3104 (∗∗)	0.1382	-2.25
	$LnGDP^2$	0.0117 (∗)	0.0037	3.14
	LnGINI	2.3840 (∗)	0.4768	5.00
	LnFDI	0.2690 (∗)	0.0703	3.83
	LnURBAN	0.0931 (∗∗)	0.1344	0.69
	LnGASEX	0.0260 (∗∗∗)	0.0240	1.08
	LnEC	0.1029 (∗)	0.0259	3.96
	LnREC	0.0100	1.4767	0.01

Note: p-value, ***, **, and * show significance at 1%, 5%, and 10% levels, respectively (Source: Authors' estimations).

The predominant driving factors of ecological degradation inside a country located in the Middle East are GDP, energy consumption, and gas extraction operation, respectively. In addition, the findings reveal significant and noteworthy direct and total effects of gas extraction on the ecological footprint. The direct impact of gas extraction on the ecological footprint at a 5% level is notably positive, increasing the ecological footprint in the home country by an average of 0.015. However, the indirect effect of natural gas extraction on the ecological footprint of neighboring countries is positive but insignificant. A 1% increase in gas extraction leads to a 0.02 increase in environmental degradations all over the Middle East region. These results align with the results of Nassani *et al.* (2021) and Ben Salha & Zmami (2023).

In terms of GDP and the squared form of GDP, the direct effect of these variables on the ecological footprint is positive and significant. More precisely, a one percent increase in GDP and squared form of GDP, leads to a 0.38 and 0.002 percent increase in the ecological footprint respectively, in the home country. As a large share of GDP in the

Middle East region is based on natural resource extraction and consumption, then higher economic growth will lead to environmental pollution. This finding is in line with studies by Li *et al.* (2023), Khezri *et al.* (2023b), and Mrabet *et al.* (2021). However, the indirect effects of GDP and the squared form of GDP on the ecological footprint of neighbor countries are respectively negative and positive; indicating that accelerated economic growth in countries puts more environmental pressure on neighbor countries.

The direct effect of Urbanization on the ecological footprint is significantly negative. In other words, urbanization reduces the country's ecological footprint by an average of 0.43 percent. In general, the negative impact of the urban population on ecological footprint is consistent with the results of Ahmed *et al.* (2020). In terms of indirect effects, the effect of urbanization on the ecological footprint is positive and significant. This result is inconsistent with studies by Faith & Kai (2022) and Kızılgöl & Öndes (2022) and consistent with studies by Ullah *et al.* (2023) and Chekouri (2023). The direct effect of FDI is insignificantly positive and the indirect effect of FDI is significantly positive. This result shows that foreign direct investment in a country adversely leads to environmental degradation in neighboring countries. This result is in line with the results of Ekeocha (2021) and inconsistent with the results of Zafar *et al.* (2019). According to the results presented in Table 8, increasing energy consumption in a country leads to considerable environmental degradation inside the country and neighboring countries. However, applying more renewable energy in this region could increase the environmental pressure inside the country, though its spillover effect is not noticeable.

5. Conclusion

The natural resource extraction process has multiple significant threats to environmental quality. The scope of environmental damages caused by energy extraction ranges from air pollution, water pollution, and fisheries ground pollution to ecosystem damage, deforestation, and destruction of agricultural land and construction areas in order to facilitate the transportation of oil and gas. Therefore, the Middle East is one of the most natural resource-abundant regions and faces terrible environmental stresses. The main purpose of this study is to investigate the demolition environmental effects of gas extraction in the Middle East Area. Given that the adverse environmental effects rising by gas extraction operations not only affect the home country, but also involve neighboring countries, then this study applied the spatial panel data method in order to consider these spillover effects.

The hypotheses of the existence of spatial autocorrelation among both error terms and spatial units around the Middle East region are accepted through related tests. In addition, the significant positive coefficient of ρ indicates that any change in local ecological footprint leads to a change in environmental quality in neighbor countries in the Middle East area. This result highlights the necessity of enforcing intra-regional ecological regulations in the Middle East. Environmental cooperation can be framed as technical rather than political coordination. For example, the use of environmental data-sharing mechanisms, the application of harmonized emission monitoring standards, and the establishment of transboundary pollution early-warning systems could facilitate cooperation and enhance mutual trust among countries. Enhancing oversight and coordination among countries through a regional intermediary institution can also be an effective solution in this regard. According to the results, gas extraction has a positive and significant effect on ecological footprint in home countries, although, its spillover effect is positive and not significant. Most Middle Eastern countries are categorized as developing countries and they suffer from low production diversifications, and their economies are mostly based on only energy exports. They are more eager to extract energy to achieve economic growth. In addition, they are applying obsolete technologies in the extraction process that exacerbate environmental hazards. Therefore, enacting policies that promote investment in cleaner and more efficient technologies can directly reduce the environmental burden of resource extraction. In addition, enforcing stricter environmental protection regulations, adopting policies to reduce the economy's dependence on natural resources, and strengthening the industrial foundations of the countries mentioned above can reduce their ever-increasing reliance on the extraction of natural resources that consequently results in improving environmental quality.

In addition, the environmental Kuznets curve hypothesis is rejected in this region. It indicates that the Middle Eastern countries are still moving on the left-hand side of the environmental Kuznets curve such that both GDP and ecological pollution increase simultaneously. Therefore, environmental protection policies need to be explicitly incorporated into national development plans, rather than treated as secondary concerns. Foreign direct investment in host countries affects adversely the ecological quality in neighboring countries. Indeed, the foreign direct investment inflow to the Middle Eastern countries is not accompanied by the transfer of new and cleaner technologies, reducing the ecological footprint in the region. Moreover, the bulk of the foreign investments flowed into the Middle East are mainly in energy extraction projects or apply energy-intensive technologies, which consequently leads to environmental degradation. Thus, attracting

foreign investments that are more labor-intensive rather than energy-intensive or investment projects that use new technologies should be at the top of the priorities for attracting foreign investment in these countries. Accordingly, energy consumption has a destructive effect on the environment both in the home country and region-wide. However renewable energy consumption decreases the ecological footprint in the home country. Therefore, transitioning to renewable energy sources and improving energy efficiency can reduce reliance on fossil fuels and mitigate the environmental impacts of gas extraction.

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Author Contributions

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Conflict of Interest

All authors declare that they have no conflicts of interest. This research received no specific grant from any funding agency.

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چکیده
استخراج منابع طبیعی در منطقهٔ خاورمیانه یکی از مهم‌ترین منابع درآمدی و محرک‌های رشد اقتصادی کشورهای این منطقه می‌باشد. با این‌حال اتکای گسترده به این منابع نه‌تنها به تحقق توسعهٔ پایدار در این کشورها منجر نشده، بلکه فشار فزآینده‌ای بر محیط‌زیست وارد کرده است. باوجود اهمیت این موضوع، پیامدهای زیست‌محیطی فعالیت‌های استخراجی، به‌ویژه آثار منطقه‌ای و فرامرزی آن بر ردپای بوم‌شناختی، تاکنون کمتر مورد بررسی قرار گرفته است. از این‌رو، پژوهش حاضر با هدف بررسی تأثیر استخراج گاز طبیعی بر ردپای بوم‌شناختی کشورهای خاورمیانه طی دورهٔ زمانی ۲۰۰۰ تا ۲۰۲۱م. انجام شده است. در این‌راستا، از چارچوب اقتصادسنجی فضایی داده‌های تابلویی و الگوی دوربین فضایی (SDM) برای برآورد آثار مستقیم و سرریز فضایی استفاده شده است. ضریب خودهمبستگی فضایی (Rho) برآوردشده نشان می‌دهد که عوامل تعیین‌کنندهٔ ردپای بوم‌شناختی در یک کشور از طریق سازوکارهای سرریز فضایی بر وضعیت زیست‌محیطی کشورهای همسایه نیز تأثیرگذار هستند. این یافته بر ضرورت تدوین و اجرای مقررات و سیاست‌های زیست‌محیطی هماهنگ در سطح منطقه‌ای در خاورمیانه تأکید دارد. همچنین، نتایج برآوردها نشان می‌دهد که استخراج داخلی گاز طبیعی، به‌طور معناداری موجب افزایش تخریب محیط‌زیست در کشور استخراج‌کننده می‌شود. بر این‌اساس، به‌کارگیری فناوری‌های نوین در فرآیند استخراج انرژی با هدف کاهش شدت انتشار آلاینده‌ها در عملیات استخراج نفت و گاز، تقویت و اجرای مقررات سخت‌گیرانه‌تر حفاظت از محیط‌زیست و اتخاذ سیاست‌هایی در راستای کاهش وابستگی ساختاری اقتصاد به منابع طبیعی، می‌تواند به کاهش فشارهای زیست‌محیطی ناشی از فعالیت‌های استخراجی و بهبود کیفیت محیط‌زیست کمک کند. افزون‌بر این، فرضیه منحنی زیست‌محیطی کوزنتس در منطقهٔ خاورمیانه تأیید نمی‌شود. این نتیجه بیانگر آن است که در کشورهای موردمطالعه، فرآیند رشد و شتاب‌گیری اقتصادی با بهبود متناسب شاخص‌های حفاظت از محیط‌زیست همراه نبوده و ملاحظات رشد اقتصادی همچنان در مقایسه با دغدغه‌های زیست‌محیطی از اولویت بیشتری برخوردارند.

کلیدواژگان: ردپای بوم‌شناختی، اقتصادسنجی فضایی، استخراج گاز طبیعی، خاورمیانه.
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Bu-Ali Sin University

Electricity Reallocation During Shortages Economic and Legal Constraints on the Value of Lost Load (VoLL)

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Abstract

The growing frequency of power outages resulting from imbalances between electricity supply and demand has heightened the need to allocate scarce electricity efficiently across competing uses. Although the Value of Lost Load (VoLL) is widely used to measure the cost of outages and assess reliability, it remains unclear whether it can also serve as an operational criterion for allocating scarce electricity. This study adopts a descriptive–analytical approach and uses a mathematical optimization model, simulated in GAMS, to examine the adequacy of VoLL from both economic and legal perspectives. From the economic perspective, the study first shows that, under ideal conditions of complete information and no institutional constraints, allocating electricity on the basis of VoLL can yield an efficient allocation. It then assesses the operational feasibility of VoLL as a basis for centralized decision-making by examining information constraints, the dynamic nature of VoLL, and the simulation results. From a legal perspective, this research examines the legal basis for the reallocation of electricity among consumers during periods of shortage, within the framework of regulations governing electricity supply in Iran. The results indicate that, despite its validity as an indicator of outage costs, VoLL lacks the informational and institutional–legal prerequisites to serve as an operational criterion for allocating scarce electricity. Mechanisms based on consumer choice and tradable rights for utilizing existing capacity represent a potential approach for revealing the value of electricity during periods of scarcity, and they warrant further research.

Keywords: Value of Lost Load (VoLL), Electricity Allocation, Electricity Scarcity, Planned Power Outages, Electricity Market.
JEL Classification: L94, D61, D82, K23.

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1. Introduction

Electricity is a fundamental input to economic activity and a critical component of modern infrastructure. Disruptions in electricity supply can therefore cause production interruptions, supply-chain disruptions, revenue losses, and broader social and economic damages. These consequences become particularly important when rising electricity demand is accompanied by constraints on the expansion of generation capacity and network infrastructure. Although expanding capacity may provide the main long-term solution, short-term supply shortages may require electricity systems to impose consumption restrictions on some users.

Under such conditions, the challenge is not only the scarcity of electricity but also how the available supply should be allocated among competing users. When electricity supply falls below demand, policymakers and system operators must determine which uses should be prioritized and where the burden of scarcity should be imposed. This creates an economic allocation problem because the consequences of an electricity interruption are not uniform across consumers and economic sectors.

A key economic measure for capturing these differences is the Value of Lost Load (VoLL). VoLL represents the economic value of unserved electricity and has long been used in electricity economics to assess the value of reliability, inform investment decisions in generation and network capacity, and compare the costs of improving reliability with the benefits of reducing outages (Schröder & Kuckshinrichs, 2015). Gorman (2022) shows that VoLL has also been considered in decisions concerning electricity rationing and allocation. However, an important distinction exists between using VoLL for long-term reliability planning and using it to determine supply priorities during an actual electricity shortage. The latter requires VoLL estimates that are sufficiently timely, reliable, and actionable for operational decision-making.

This requirement is challenging because VoLL is inherently heterogeneous and context-dependent. The economic cost of an interruption varies with the type of consumer, the timing and duration of the outage, production conditions, and other characteristics of the interruption. Consequently, a single fixed VoLL cannot necessarily represent the actual cost imposed on consumers under different circumstances (Leahy and Tol, 2011). Recent studies have documented substantial variation in VoLL across sectors, consumer characteristics, outage conditions, and estimation methods (Ovaere *et al.*, 2019; Jin *et al.*, 2024; Matsubara *et al.*, 2025; Jin, 2025a). Evidence based on observed consumer behavior further suggests that the value of reliability may vary with both consumer characteristics and interruption conditions (Brown and Muehlenbachs, 2024).

Despite this extensive literature on the estimation and application of VoLL, an important gap remains between estimating the economic cost of unserved electricity and using that estimate as an operational rule for allocating scarce electricity. An economically valid estimate of VoLL does not necessarily provide sufficient information to establish supply priorities or determine feasible load-shedding allocations. Moreover, technical, temporal, network, institutional, and legal constraints may prevent a simple ranking based on VoLL from being implemented in practice. This gap between the economic valuation of unserved electricity and its operational applicability constitutes the central research problem addressed in this study.

The issue is particularly relevant in Iran, where the growing mismatch between electricity supply and demand, especially during peak-load periods, has increased the need for supply restrictions and load shedding. Figure 1 illustrates the widening gap between electricity generation and consumption during annual peak-load periods in recent years. The economic consequences of electricity interruptions also differ substantially across sectors, and domestic studies have documented significant losses associated with electricity restrictions in different economic activities (Nikzad Hoseini and Sadeghi Shahdani, 2024; Pasandideh *et al.*, 2024).

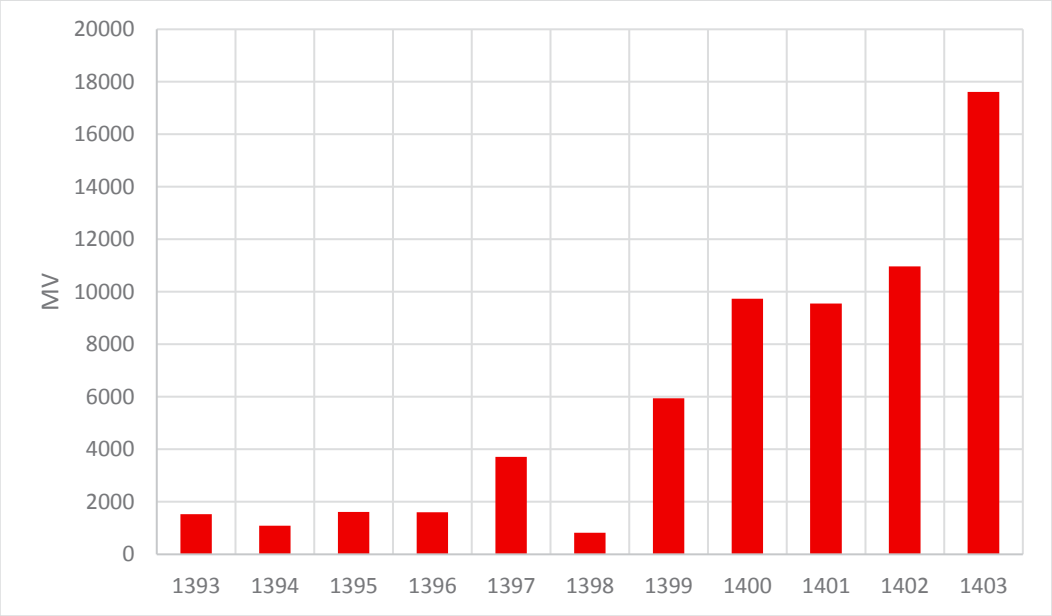

Fig. 1: Increasing gap between electricity generation and consumption during annual peak-load periods in Iran (Source: 57 Years of the Electricity Industry).

Against this background, this study asks whether VoLL can serve not only as an economic measure of the value of unserved electricity, but also as an operational rule for

determining supply priorities and allocating scarce electricity among consumers. To address this question, the study first examines the logic of VoLL-based allocation under an idealized benchmark of complete information and no technical or institutional constraints. This benchmark clarifies that the problem examined here does not arise from an inherent inconsistency in the economic logic of VoLL-based allocation. The study then relaxes these assumptions and examines the informational, operational, and institutional–legal constraints that may limit the practical application of VoLL. Using an optimization model and alternative valuation and allocation scenarios, the study evaluates the sensitivity of electricity allocation across economic sectors to these assumptions.

The study makes three main contributions. First, it develops a conceptual framework that distinguishes between the economic validity of VoLL as a measure of outage costs and its operational sufficiency as an allocation rule under scarcity. Second, using an optimization model under alternative valuation and allocation scenarios, it examines how the allocation of scarce electricity across economic sectors changes under different assumptions about the measurement and use of VoLL. Third, it identifies the informational, operational, and institutional conditions required for moving from VoLL as an economic indicator to an operational allocation instrument, highlighting why theoretical efficiency under complete information does not necessarily imply feasibility in real-world shortage management. The study further discusses the potential role of alternative allocation mechanisms that reduce reliance on centralized information about consumers' electricity values, while recognizing that their design and evaluation are beyond the scope of this study.

The remainder of the article is organized as follows. Section 2 reviews the relevant literature and identifies the research gap. Section 3 presents the theoretical framework and methodology. Section 4 applies the proposed framework using an optimization model and alternative scenarios and discusses the informational, operational, and institutional–legal constraints of VoLL-based allocation. Finally, Section 5 concludes the study and discusses its implications.

2. Literature Review

2-1. The Emergence and Concept of the Value of Lost Load

The concept of the Value of Lost Load (VoLL) emerged in electricity economics to capture the economic value of unserved electricity and the cost incurred by consumers or society as a result of interruptions in electricity supply. The theoretical foundation of VoLL lies in

the economic valuation of electricity reliability and the comparison between the benefits of reducing outages and the costs of providing additional reliability.

Unlike the price of electricity, VoLL does not represent the cost of supplying electricity. Rather, it reflects the value or cost that consumers and society attribute to the lack of access to electricity. Accordingly, VoLL has assumed an important role in studies of reliability assessment, capacity planning, and network development.

In their review of the VoLL literature, Schröder and Kuckshinrichs (2015) showed that estimates of VoLL depend on the valuation method, consumer type, characteristics of the interruption, and prevailing economic conditions. Gorman (2022) likewise argues, in a critical review of the literature, that VoLL is not a single, fixed concept but encompasses different dimensions of the economic value of electricity and interruptions in its supply.

This feature, on the one hand, explains the importance of VoLL in the economic analysis of electricity reliability and, on the other hand, raises the question of whether it can be used as an operational criterion for ranking consumers.

2-2. Heterogeneity of VoLL across Consumers and Conditions

A robust finding in the literature is that the cost of electricity interruptions is not uniform across consumers. Leahy and Tol (2011) showed that VoLL varies with consumer type and the timing of the interruption. Schröder and Kuckshinrichs (2015) likewise highlighted the role of consumer characteristics, valuation methods, and interruption scenarios in explaining differences in VoLL estimates. Ovaere *et al.* (2019) further showed that using more granular information on VoLL, including differences across consumers and interruption characteristics, can alter decisions concerning reliability.

Recent studies have extended this line of research. Brown and Muehlenbachs (2024), using households' actual investments in solar-plus-battery systems, provided a revealed-preference estimate of the value of reliability and showed that outage experience can affect consumers' investment behavior. In Japan, Matsubara *et al.* (2025) estimated household VoLL separately for predictable and sudden outages and identified differences between the two. Similarly, Jin (2025a), comparing stated-preference and revealed-preference approaches for households in South Korea, found substantial differences between the estimates obtained from the two methods.

Broberg *et al.* (2026) also showed that the actual cost of electricity outages varies across sectors, firms, and production sites, and that relying solely on lost output cannot capture all the consequences of an interruption. Therefore, VoLL estimates depend on factors beyond

the quantity of electricity not supplied, which limits the use of a fixed or average VoLL for ranking consumers.

These findings are particularly relevant to the present study because they demonstrate that the issue is not simply to determine a value for VoLL, but rather to determine which VoLL, for which consumer, at what time, and under what conditions should form the basis of a decision.

2-3. Reliability Planning and Electricity Allocation under Scarcity

The traditional application of VoLL in the literature has been the economic assessment of the appropriate level of electricity reliability. Within this framework, the expected cost of outages is compared with the investment costs required to increase capacity or reliability, thereby determining the economically optimal level of electricity supply.

However, some studies have also used VoLL to analyze electricity allocation under conditions of scarcity. Gorman (2022), in his critical review, draws attention to this distinction and differentiates between the use of VoLL in cost–benefit analyses of reliability investment and its use in electricity rationing.

A separate strand of the literature addresses how scarce electricity can be rationed when consumers differ in the value they place on reliability. Panzar and Sibley (1978) analyze self-rationing, in which consumers' own choices determine who is curtailed, and Chao and Wilson (1987) develop priority service, in which consumers choose among reliability levels at different prices, so that the supplier does not need to know each consumer's valuation in advance. Joskow and Tirole (2007) show that where consumers cannot be curtailed selectively, rationing cannot reflect differences in the value of electricity across users. Interruptible contracts, in which consumers accept curtailment in exchange for compensation, are a related approach (Baldick *et al.*, 2006). These studies indicate that the informational difficulty examined here is not specific to the VoLL, and that the manner in which the value is revealed is as significant as the method used to measure it. This distinction is fundamental to the present study. In long-term planning, knowledge of the average or expected cost of outages may be sufficient to determine the optimal level of capacity. Under scarcity management, however, the decision-maker must make decisions concerning specific consumers, at specific times, based on information that may itself change over time.

Consequently, the question of whether VoLL can be used for short-term electricity allocation cannot be answered merely by establishing the economic value of the indicator.

2-4. Methods for Estimating VoLL and Information Constraints

VoLL has been estimated using a variety of approaches, including stated-preference methods, revealed-preference methods, direct cost approaches, value-added approaches, economic models, and combinations thereof. Each approach has its own advantages and limitations.

Recent studies also indicate that the choice of estimation method can have a substantial effect on the resulting VoLL. For example, Jin (2025a), in a study of households in South Korea, showed that VoLL estimates based on willingness to pay differ considerably from estimates derived from the opportunity cost of time. Similarly, Jin (2025b), in a meta-analysis, showed that VoLL estimates depend on the estimation method, economic sector, and macroeconomic variables.

Along the same lines, Matsubara *et al.* (2025) showed that household characteristics, such as income and electricity expenditure, affect willingness to pay to avoid power outages. These findings indicate that VoLL is not a fully observable characteristic; rather, in many cases, it must be inferred from behavioral or economic information.

From the perspective of the present study, this issue becomes particularly important when VoLL is intended not merely to evaluate a general policy, but to rank consumers and determine outage priorities. Under such circumstances, estimation error, methodological differences, and the absence of private information may directly alter the ordering of consumer priorities.

2-5. The Dynamic Nature of VoLL and the Importance of Temporal Granularity

Another important issue is the dynamic and time-dependent nature of VoLL. The economic value of unserved electricity may vary according to the time of day, season, duration of the outage, production conditions, market conditions, and the specific characteristics of the consumer.

Ovaere *et al.* (2019) showed that using more granular VoLL information can alter reliability decisions. Recent studies have reinforced this point. For example, Kachirayil *et al.* (2025) estimated household VoLL at an hourly level across different regions of Germany and showed that incorporating temporal heterogeneity can affect decisions regarding curtailment and the level of reliability.

Therefore, if VoLL is to be used for operational decisions concerning power outages, the issue is not merely the estimation of VoLL, but also its continuous updating.

This issue represents an important gap in the literature. Much of the existing research has focused on obtaining more accurate VoLL estimates or improving its use in reliability

planning, whereas the present study asks whether the information required to use this indicator operationally and repeatedly for ranking consumers under scarcity is fundamentally available and sufficiently reliable.

2-6. Evidence from Iran

In Iran, VoLL and outage costs have also been employed in various studies to assess the economic consequences of electricity shortages. For example, Faridzad *et al.* (2022), using a combination of input–output analysis and linear programming, estimated the cost of electricity shortages in Iran and examined the allocation of electricity curtailments across economic sectors. Najafi *et al.* (2021), focusing on an industrial unit in Iran, showed that VoLL estimates may depend not only on consumer characteristics and outage conditions but also on equipment reliability and the probability of component failure within the industrial facility. By incorporating failure probabilities into the estimation process, they developed a probabilistic model of VoLL.

These studies are particularly relevant to the present research because they demonstrate that VoLL and outage costs can be incorporated into quantitative frameworks for analyzing electricity allocation under scarcity. However, they also give rise to a different question:

Are the information and estimates required for such allocation observable, verifiable, and updatable at the consumer level?

In other words, existing studies have largely asked: if the cost of an outage is known, how should scarce electricity be allocated optimally? The present study takes a step back and asks: can the actual cost of an outage be known with sufficient accuracy in practice to implement such an allocation based on it?

2-7. Research Gap

The literature review indicates that research on VoLL has largely developed along four main lines: the development of estimation methods, examination of heterogeneity in VoLL across consumers, application of VoLL to reliability planning, and, more recently, increasing the temporal and behavioral granularity of VoLL estimates.

Despite the importance of these studies, an important issue remains relatively underexplored: can VoLL, even if accepted as a valid economic indicator, provide a reliable basis for decisions regarding electricity supply priorities and the imposition of outages across specific consumers under conditions of scarcity?

This question has two dimensions. The first concerns the informational and economic feasibility of VoLL: can its actual and dynamic value be identified and updated with

sufficient accuracy? The second concerns its institutional and legal feasibility: does a difference in the economic value of electricity consumption, by itself, provide a sufficient basis for reallocating existing access rights to electricity?

By focusing on these two questions, the present study goes beyond the conventional VoLL literature. Rather than developing a new method for calculating VoLL, it critically examines its applicability as a tool for managing electricity scarcity.

3. Research Methodology

3-1. Research Approach

This study is an applied analytical study with an economic and institutional approach that evaluates the applicability of the Value of Lost Load (VoLL) for managing electricity scarcity and determining electricity supply priorities among consumers.

The methodological logic of the study is based on a sequential test. First, it is shown that, under complete information about VoLL, allocating scarce electricity on the basis of this indicator is economically feasible. The assumption of complete information is then progressively relaxed to examine the informational and economic limitations of this approach. Subsequently, the issue is considered at the institutional level by asking whether a higher economic value of electricity consumption, by itself, can provide a basis for reallocating access to electricity among consumers.

In addition, to identify and analyze the likely behavior of selected consumers under different scenarios, a mathematical optimization model is developed and implemented in GAMS. The model examines the optimal allocation of load across different sectors under supply constraints, with the objective of minimizing outage costs and, thereby, maximizing economic efficiency.

It should be emphasized that the methodology is not intended to develop a new allocation algorithm, but rather to assess the adequacy of VoLL as a tool for managing electricity scarcity.

3-2.Data

This study does not directly estimate the outage damages incurred by individual consumers. Instead, for the simulation component, the required data and information are collected primarily through desk research, including a review of published official documents.

The data required to determine the economic value of electricity across different sectors include information on electricity consumption, production or economic activity, and other relevant economic indicators. These data are obtained from official sources and previous

studies and are used to determine the value of electricity in each sector. Data on electricity consumption, tariffs, and production statistics are collected from official reports of the Ministry of Energy (2025), Tavanir (2025), and the Ministry of Agriculture-Jahad.

3-3.Theoretical Framework: Simulation–Optimization

The theoretical foundations of outage management based on the Value of Lost Load can be traced to centralized electricity network expansion planning models. Accordingly, this section first introduces the framework of these models and then presents an outage-management algorithm based on VoLL, which is critically examined in the subsequent sections.

3-3-1. Centralized Generation Capacity Expansion Planning and the Role of VoLL

Electricity generation capacity expansion planning models provide a framework for determining the amount and type of new generation capacity required to meet cost, environmental, and technical criteria over a specified planning horizon. The planning horizon is divided into several periods or years, and the required capacity to meet projected demand is determined while satisfying the relevant cost and operational objectives

In such models, the objective function generally consists of the sum of discounted investment costs, operating costs, and social costs, such as pollution costs. In a multi-objective model, objectives such as the simultaneous minimization of costs and emissions may also be incorporated, using approaches such as weighting or Pareto analysis. A representative general form of the objective function is presented below (Jadidoleslam and Ebrahimi, 2023; Ehsanbakhsh and Ahmadian, 2018).

$$Min\ C = \sum_{t=1}^{T} (I(U_t) + M(X_t) + O(X_t) - S(U_t))$$

where:

- $I(U_t)$: initial investment costs;
- $M(X_t)$: fixed and variable operating costs, including fuel costs;
- $O(X_t)$: including the cost of unserved electricity, represented by the Value of Lost Load (VoLL);
- $S(U_t)$: salvage value of depreciated assets;
- X_t: cumulative system capacity vector;
- T: planning horizon;
- t: planning periods (years within the development-planning horizon).

The minimization of the above objective function is subject to several constraints, the most important of which are:

- Supply–demand balance: total available capacity must be at least equal to peak demand in each period.
- Reserve margin: additional capacity relative to demand to ensure system reliability.
- Technical constraints: maximum capacity of each unit, annual construction and retirement rates, and maintenance or availability constraints.
- Environmental constraints: emission limits or requirements regarding the share of clean energy.
- Investment constraints: annual or total investment ceilings.

Optimization of the development plan generally follows a two-stage structure. In the first stage, the capacity expansion plan, including the type and amount of capacity from different technologies, is determined. At this stage, total investment and operating costs are minimized. In the second stage, short-term operational optimization is conducted primarily on the basis of variable operating costs. Such models are commonly implemented and solved using software such as GAMS and linear or nonlinear programming solvers.

What is the relationship between VoLL and the above modeling framework, and why can this framework be used to allocate outages during periods of electricity scarcity? The answer to these questions is embedded in the objective function presented above. The next section addresses this issue by presenting a simple allocation algorithm.

3-3-2. Allocation of Scarce Electricity Based on VoLL

To examine the applicability of VoLL as an allocation criterion under conditions of electricity scarcity, an idealized case is first considered in which the VoLL of all consumers can be identified completely and without error, and no technical, operational, or institutional constraints exist on reallocating electricity among consumers. Under these conditions, the electricity allocation problem can be formulated as a simple optimization problem.

Suppose that E_i denotes the amount of electricity demanded by consumer i, and x_i denotes the amount of electricity allocated to that consumer. Let V_i represent the Value of Lost Load of consumer i, and let S denote the total amount of electricity that can be supplied under scarcity conditions. The amount of unserved electricity for consumer i is therefore $E_i - x_i$, and the total economic cost of outages can be defined as follows:

$$\min C_{outage} = \min \sum_i V_i(E_i - x_i)$$

subject to:

$$0 \leq x_i \leq E_i$$

and

$$\sum_i x_i \leq S$$

The objective function indicates that, under supply constraints, electricity should be allocated in such a way as to minimize the total economic cost of unserved electricity. Rewriting the objective function yields:

$$\min \left[\sum_i V_i E_i - \sum_i V_i x_i \right]$$

Because, for a given scenario, E_i and V_i are assumed to be known and fixed, the term $\sum_i V_i E_i$is constant. Therefore, minimizing outage costs is equivalent to maximizing the economic value of the electricity allocated:

$$max \sum_i V_i x_i$$

This relationship has an important implication for the allocation problem. Under ideal conditions, each available unit of electricity should first be allocated to the consumer with the highest VoLL. Consequently, under scarcity, consumers with lower VoLL would be subject to supply restrictions first, whereas consumers with higher VoLL would be protected from curtailment to the greatest extent possible.

Thus, under complete information and in the absence of technical, operational, and institutional constraints, VoLL can be transformed from an economic indicator of the value of unserved electricity into a theoretical rule for prioritizing electricity allocation. This result constitutes the theoretical benchmark of the present study.

However, this result depends critically on the assumptions outlined above. In real-world conditions, VoLL is subject to uncertainty and heterogeneity; operational constraints may prevent a simple ranking of consumers; and the reallocation of electricity among consumers is also governed by institutional and legal arrangements. Accordingly, the subsequent sections examine these constraints and assess the robustness of the VoLL-based allocation rule.

4. Application and Critique of VoLL for Electricity Allocation under Scarcity

This section initially assumes that all required information is fully available and continuously updated in real time. It also assumes that the institutional framework imposes no legal restrictions on differential treatment among electricity consumers. Accordingly,

the system operator is assumed to be authorized to impose any necessary degree of additional curtailment on one group of consumers to enhance the security of electricity supply for another group. The objective is to maximize the benefits from allocating limited electricity among consumers with different outage costs.

4-1. Efficiency of VoLL under Complete Information and in the Absence of Legal Constraints

As a first step toward optimal allocation, assume that all required information is complete and that the institutional framework imposes no legal restrictions on differential treatment among electricity consumers. Suppose that the electricity network under consideration has Nconsumers or electricity demanders. The amount of electricity demanded, and the corresponding Value of Lost Load for each consumer are presented in Table 1. For example, consumer 4 demands E_4units of electricity, and if its demand is not supplied, the resulting loss is $VoLL_4$.

Table 1. Characteristics of Consumers in the Selected Electricity Network

Consumer	Electricity Demand	Value of Lost Load
C_1	E_1	$VoLL_1$
C_2	E_2	$VoLL_2$
C_3	E_3	$VoLL_3$
C_4	E_4	$VoLL_4$
C_5	E_5	$VoLL_5$
C_n	E_n	$VoLL_n$

Source: Research findings

If the available electricity is equal to or greater than the total electricity demand of all consumers, that is, if $S \geq \sum_i E_i$, there is no constraint on electricity supply. However, if available electricity is less than total demand, some consumers must inevitably be selected for curtailment and excluded from electricity supply.

As noted above, VoLL is an important criterion in this process. For example, if the VoLL of consumer 2 ($VoLL_2$) is higher than that of consumer 4 ($VoLL_4$), consumer 2 should be given priority over consumer 4 in electricity supply. If, despite this difference, consumer 4 remains supplied while consumer 2 is deprived of access to electricity, the resulting allocation would not maximize economic value and would therefore be considered economically inefficient.

In general, if this criterion is accepted, all consumers can be ranked according to their outage costs or VoLL, and curtailment can then begin with the consumer having the lowest VoLL. Consumers are progressively subjected to curtailment until the total remaining demand is equal to the amount of electricity available to supply the remaining consumers. This process continues until the electricity demand of the remaining consumers can be reliably met. For example, the elimination process would continue up to consumer C^*, as shown in Table 2.

Table 2. Stopping Point of the Consumer-Curtailment Algorithm and Achievement of the Equilibrium Condition and Optimal Allocation

Consumer	Electricity Demand	Value of Lost Load
C_1	E_1	$VoLL_1$
C_2	E_2	$VoLL_2$
C^*	E^*	$VoLL^*$
C_4	E_4	$VoLL_4$
C_5	E_5	$VoLL_5$

Source: Research findings.

Overall, this process indicates that, assuming complete information, the absence of institutional and legal constraints, and the ability of the system control center to impose curtailment on any group of consumers to ensure electricity supply to selected consumers, VoLL-based allocation minimizes the economic costs of electricity outages-that is, minimizes the total value of lost load- and thereby achieves economic efficiency.

4-2.Critique of the Application of VoLL in Electricity Scarcity Management

The previous section showed, under two simplifying assumptions, that allocating available electricity according to the Value of Lost Load (VoLL) can be economically efficient. The first assumption was that the decision-maker has complete access to the true VoLL of all consumers, while the second was the absence of any institutional or legal constraints on reallocating electricity among consumers. Under these assumptions, consumers can be ranked according to the economic cost of unserved electricity, and limited available electricity can be allocated to uses for which interruption would cause the greatest economic loss.

Accordingly, the critique developed here does not concern the economic logic of VoLL itself, but rather the feasibility of transferring this theoretical efficiency to real-world scarcity management. To this end, the two assumptions are examined sequentially from informational and institutional–legal perspectives.

4-2-1. The Assumption of Complete Access to Information

The assumption of complete access to information is vulnerable to serious limitations through at least two important channels. First, obtaining the true Value of Lost Load as the underlying measure of outage costs involves substantial uncertainty. Second, continuously updating VoLL in real time at the individual-consumer level is highly complex.

A. Difficulty in Identifying the True Value of Lost Load

VoLL is not a directly observable variable; rather, it must be estimated using various economic and behavioral methods. The literature indicates that the estimation method, consumer type, and characteristics of the interruption can significantly affect the estimated value of VoLL (Schröder & Kuckshinrichs, 2015; Gorman, 2022). Recent studies further confirm this uncertainty. For example, Jin (2025a) obtained different VoLL estimates for households in South Korea using stated-preference and revealed-preference methods and showed that the measurement method can significantly affect the estimated value. Her and Jin (2026) likewise documented differences across alternative estimation methods and implicit VoLL values embedded in reliability standards, highlighting the methodological challenges associated with the use of VoLL.

This issue becomes particularly important at the firm level because part of the actual cost of an outage depends on firm-specific characteristics that may not be observable to the decision-maker. These include the structure of the production process, the possibility of recovering lost output, restart costs, delivery delays, and other consequences of production disruptions. Firm-level evidence also indicates that outage costs can vary substantially across firms and industries, and that a single VoLL value may not adequately capture these differences (Broberg *et al.*, 2026). Accordingly, part of VoLL is private and potentially strategic information, and it cannot be assumed that the decision-maker has complete access to it.

This issue becomes even more important when the objective is not to estimate average outage costs at the sectoral or economy-wide level, but rather to rank individual consumers for electricity supply priorities. Under such conditions, estimation error is not merely an error in a parameter; it can alter the ranking of consumers and consequently lead to a

different allocation decision. Empirical evidence also indicates that estimates obtained using different methods can differ substantially (Jin, 2025a; Her & Jin, 2026).

Therefore, applying VoLL to scarcity management requires much more than merely estimating it using an appropriate method. The critical question is whether the true VoLL of all consumers can be identified simultaneously, reliably, and comparably for allocation decisions. The assumption of complete knowledge of consumers' VoLL is therefore a particularly strong assumption.

B. The Dynamic Nature and Updatability of VoLL

Even if the problem of initially identifying VoLL could be partially resolved, assuming that VoLL remains constant would still be inappropriate for scarcity management. The economic cost of an outage depends on the type of consumer, the time at which the interruption occurs, its duration, and prevailing operational and economic conditions. Accordingly, the VoLL required for operational decision-making should be regarded as a state-dependent variable rather than a fixed value.

Ovaere *et al.* (2019) showed that VoLL varies with interruption characteristics and timing, and that the use of more granular data can alter reliability-related decisions. More recent studies reinforce this finding. For example, Kachirayil *et al.* (2025) estimated household VoLL in Germany at regional and hourly levels and showed that incorporating temporal and spatial detail can affect both system costs and curtailment patterns.

This finding has an important implication for the operational use of VoLL. Increasing the detail and accuracy of VoLL may improve decision-making quality, but it simultaneously increases the amount of information required for decision-making. If the value of unserved electricity depends on the time, duration, consumer type, location, and other characteristics of the outage, it is no longer appropriate to assign a single fixed VoLL to each consumer. Instead, the economic value of electricity must be determined for a particular consumer under a particular outage condition.

Consequently, the more precisely and granularly VoLL is defined for allocation decisions, the more complex the collection, processing, and updating of the required information becomes.

From this perspective, the operational use of VoLL requires more than a reliable estimate: the decision-maker must be able to update VoLL in a timely manner. Generation conditions, contracts, inventories, market conditions, expected outage duration, and the possibility of recovering lost production may change over a short period, thereby changing the actual cost of an electricity interruption for a given consumer.

The shorter-term and more granular the allocation decision becomes, the greater the information requirements. Accordingly, the literature's movement toward hourly, sectoral, and regional VoLL estimates, while improving analytical precision, also illustrates the increasing informational complexity involved in using this indicator for operational decisions (Kachirayil *et al.*, 2025).

Thus, two problems arise simultaneously: first, the lack of direct observability and uncertainty in measuring VoLL; and second, the variation of VoLL over time and the difficulty of updating it. Consequently, the informational condition required to transfer the theoretical efficiency of VoLL to real-world scarcity management—namely, accurate, reliable, and timely knowledge of consumers' VoLL—cannot simply be assumed.

C. Testing the Applicability of VoLL to Electricity Allocation under Alternative Scenarios

This section uses the algorithm introduced above and a GAMS-based simulation to examine alternative scenarios for allocating a limited amount of electricity among different consumers under conditions of scarcity, where some degree of curtailment is unavoidable. In addition to VoLL, which may be used as a criterion for curtailment based on either the electricity tariff or the intrinsic value of electricity, other criteria arising from technical and operational constraints of the power system may also affect the allocation decision. The main considerations incorporated into the simulation are as follows:

- Household electricity consumption can be curtailed for a maximum of two hours per day and only during the 09:00–19:00 period.
- Certain industries, such as refineries, cannot be curtailed because of their need to maintain the production of gasoline, diesel, and processed gas products.
- A reduction in exports by dollar-denominated industries increases the exchange rate with a seasonal lag; the estimated effect is an increase of 700 tomans in the exchange rate for every USD 1 billion reduction in exports.

Accordingly, to simulate electricity curtailment and calculate the optimal allocation of outages in Iran, the peak load in 1403 is used as the reference point, representing the highest load observed by the Iranian power sector up to that time. To examine the sensitivity of electricity allocation to the method used to value electricity, as well as to selected allocation constraints and criteria, four scenarios are considered:

Scenario 1: Electricity valuation based on current electricity tariffs.

Scenario 2: Electricity valuation based on the real economic value of electricity.

Scenario 3: Electricity valuation based on network considerations.

Scenario 4: Electricity valuation based on the share of demand.

In these calculations, the analysis is based on the load recorded on 15 Mordad 1403, approximately 79,712 MW, while national power-plant generation at that hour was approximately 61,000 MW. This implies an electricity shortfall of approximately 18,000 MW, for which the model determines the optimal curtailment allocation under each scenario. It is assumed that no sector can be subject to more than 70% load management. The rate for other industries is set equal to the average industrial rate, while the rate for other uses is assumed to be 90% of the household rate.

Table 3. Simulation Results for the Proposed Curtailment Allocation under Different Scenarios (MW)

Consumer group	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Steel	0	0	857	1,944
Petrochemicals	0	0	1,991	648
Refineries	0	0	0	324
Aluminum and copper	0	2,986	2,986	972
Cement	1,593	0	0	518
Other industries	0	0	0	2,074
Residential and commercial	370	7,272	2,765	6,300
Agriculture	8,395	0	8,295	2,700
Other uses	7,742	7,742	1,106	2,520

Source: Authors' calculations.

The results of the four selected scenarios show that the optimal allocation changes significantly as the underlying conditions and assumptions change. The difference between Scenarios 1 and 2 is particularly evident. Given the possibility of shifting agricultural working hours and water-pumping schedules, together with the relatively low electricity tariff for agriculture, this sector is prioritized for curtailment under the first scenario. However, once the estimated economic value of agricultural output and the associated reduction in production are taken into account, agricultural consumers are no longer subject to curtailment.

For residential electricity consumption, even when the estimated economic value of electricity is incorporated, the residential sector remains a major candidate for curtailment. However, when the two-hour restriction is imposed, only approximately 10% of residential load is curtailed. Furthermore, if residential consumers can reveal their preferences—for

example, by accepting the consequences of outages during hot periods in a city such as Bushehr or by paying to avoid curtailment—the resulting allocation could be substantially different.

The simulation results are consistent with the literature in showing that decisions based on outage costs are sensitive to how those costs are measured. Ovaere *et al.* (2019) and Kachirayil *et al.* (2025) found that more detailed VoLL data, including temporal and spatial detail, can change reliability and curtailment decisions. Similarly, Faridzad *et al.* (2022) indicated that sectors with high electricity consumption do not necessarily bear the highest shortage costs. In our results, changing only the valuation criterion shifts agriculture from bearing the largest share of curtailment (Scenario 1) to bearing none (Scenario 2), so allocation outcomes depend on the valuation basis as well as on available supply. Broberg *et al.* (2026) showed that outage costs also vary across firms and production sites, which matters here because our sectoral values are averages that cannot reflect differences within a sector.

Overall, the scenario results indicate that the application of VoLL as an allocation criterion under electricity scarcity depends on the ability to identify the indicator and on its relative stability, as well as on how operational constraints are incorporated. Therefore, even if the informational problem could be resolved, examining institutional and legal constraints remains necessary for transferring the theoretical VoLL rule into operational decision-making.

4-2-2. Institutional and Legal Conditions for the Application of VoLL

Even if the informational problem were assumed to be completely resolved and the true VoLL of all consumers were available to the decision-maker at every moment with complete accuracy, a fundamental question would remain: Does the decision-maker have the authority to reduce one consumer's access to electricity and allocate that electricity to another consumer solely on the basis of their difference in economic value?

In the theoretical model, such authority is assumed. In the actual electricity system, however, the relationship between the electricity company and the consumer is not merely an abstract economic relationship. Rather, it is structured through electricity connections, contracts, supply obligations, and regulations governing the relationship between the utility and its consumers.

Under the *Supplementary Electricity Tariff Regulations*, electricity connection is defined in Clause 4-14 as authorized access to electrical energy, while Clause 4-13 identifies the electricity connection agreement as a contract between the company and the

applicant. Clause 4-15 also defines electricity supply as the provision of the power and energy contractually committed by the company at the delivery point under standard conditions. Accordingly, consumer access to electricity is established within a contractual and regulatory framework and cannot simply be treated as a momentary allocation from a common social resource.

The same logic is reflected in Clause 4-48, which recognizes the company's responsibility for continuity of electricity supply to the consumer, while providing exceptions including events beyond the company's control, cases agreed upon with the consumer, and circumstances specified in the regulations. Thus, continuity of supply is not an absolute and unconditional right. At the same time, however, electricity curtailment cannot simply be justified on the grounds that another consumer derives greater economic value from electricity consumption.

Clause 4-50 specifies the circumstances under which temporary interruption of electricity supply is permitted, including a consumer's request, failure to comply with obligations and regulations, outstanding debts, unauthorized use, judicial orders, and specific cases established by the regulations. The list does not identify a higher VoLL of another consumer, or a higher economic value of another consumer's electricity use, as an independent basis for disconnecting a consumer.

At the same time, Clause 4-57 permits electricity disconnection when necessary to prevent or reduce immediate risks arising from disturbances in the operational system. This provision is fundamentally important for maintaining system security. However, a distinction must be made between disconnection to preserve the technical security of the system and economic reallocation of electricity among consumers. The former is an action intended to preserve system operation, whereas the latter involves choosing one consumer over another based on differences in the economic value of their electricity consumption. The existence of the former authority does not, by itself, establish the latter. In other words, the authorization to disconnect electricity to prevent operational disturbances does not necessarily imply authorization to economically rank consumers and reallocate electricity from a consumer with lower VoLL to one with higher VoLL.

On the other hand, Clause 4-16-2 indicates that the regulations recognize differences in the interruptibility of consumers, but manage these differences through predefined load-management arrangements. For example, under Type A, the consumer reduces consumption during peak periods following prior notification; under Type B, electricity is not disconnected even when the control center must impose planned outages to prevent frequency or voltage declines or overloads; and under Type C, the consumer avoids

consumption during peak hours. Thus, the existing load-management framework recognizes differences in interruptibility, but links these differences to predefined arrangements rather than to real-time calculation and comparison of VoLL across consumers.

Clause 4-58 also recognizes the possibility of declaring the sensitivity of consumers' equipment to electricity interruptions, thereby acknowledging differences in the consequences of outages across consumers. However, such differences do not, by themselves, establish a right to priority in electricity supply.

Overall, the regulation examined indicates that electricity supply relationships have contractual and regulatory foundations, that electricity disconnection is permitted under specified circumstances, and that differences in interruptibility can be defined within predetermined arrangements. However, VoLL is not explicitly provided for in the provisions examined as an independent criterion for withdrawing or reducing one consumer's access to electricity in favor of another.

Therefore, even assuming complete access to VoLL information, implementing a VoLL-based allocation rule would require an institutional and legal basis for reallocating electricity among consumers. Such a basis is not explicitly provided for VoLL in the provisions of the regulation examined.

5. Conclusions

The growing incidence of electricity outages in Iran and the intensifying competition among different electricity uses have increasingly highlighted the need for a sustainable and efficient mechanism for allocating scarce electricity. Under such conditions, the objective of allocation should not be limited to distributing the available electricity among consumers, but rather should be to maximize social welfare and the economic value generated by electricity consumption. This requires a mechanism capable of reflecting differences in the value of electricity consumption in allocation decisions while remaining compatible with the actual economic conditions and institutional arrangements governing the electricity market.

Focusing on the Value of Lost Load (VoLL), which occupies an important position in the literature and in centralized electricity supply planning, this study shows that although VoLL can provide a basis for the efficient allocation of scarce electricity under ideal conditions—assuming complete access to information and the absence of institutional and legal constraints—it is not adequate as an operational tool for determining which consumers should receive electricity and which should be curtailed. The main limitations

are the difficulty of observing the true value of lost load and of estimating it accurately and in a timely manner, substantial differences in this value across consumers and over time, and the lack of a sufficient institutional and legal basis for translating an economic ranking into authority to reallocate electricity among consumers.

This conclusion does not imply that electricity should be allocated under scarcity without regard to the economic value of different uses. On the contrary, differences in the value of electricity consumption should remain at the core of the allocation mechanism. However, this objective cannot necessarily be achieved by centrally determining VoLL and using it to decide which consumers should be disconnected or supplied. What is required is a mechanism that, while avoiding the informational and institutional limitations associated with VoLL, enables the true value of scarce electricity to be discovered through freedom of choice, consumer participation, and the direct involvement of consumers in the allocation process. Such an approach could provide a basis for allocating electricity to uses that generate greater social and economic value, without requiring a centralized decision-maker to determine in advance the true value of electricity consumption for each individual consumer.

From this perspective, the main finding of the study can be summarized in one proposition: the central issue is not to abandon economic value as a criterion for allocating scarce electricity, but to identify a more appropriate mechanism for discovering and realizing that value. Market-based mechanisms that allow greater consumer choice and participation may offer a potential direction for further investigation. However, the feasibility of mechanisms involving the transferability of electricity-use rights depends on the legal status of existing contractual rights, the contractual and regulatory arrangements governing their transfer, and the institutional framework required for implementation and oversight. These issues require further legal and operational assessment before such mechanisms can be recommended for practical adoption.

Accordingly, the policy recommendations of this study are as follows:

1. Avoid relying on VoLL as an independent and operational criterion for determining electricity curtailment priorities. VoLL can continue to be used as an indicator of outage costs and as a tool for economic analysis; however, it is not sufficient for directly reallocating electricity among consumers.
2. Reconsider centralized approaches to electricity allocation under scarcity and move toward mechanisms that enable the value of scarce electricity to be discovered in a decentralized manner.

3. Explore market-based mechanisms as a potential alternative for allocating scarce electricity, subject to further research on their design, feasibility, and consumer protection.
4. Conduct further research on an alternative mechanism to VoLL. The design and evaluation of such a mechanism—one capable of simultaneously incorporating economic efficiency, consumer rights, and the technical requirements of the electricity network—will be pursued as part of a broader research program by the authors.

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Author Contributions

Kioumars Heydari: Conceptualisation, methodology, formal analysis, literature review, writing the original draft, and writing & reviewing the final version. Pouyan Kiani: Literature review, writing and editing the final version. Elahe Sabouripour: Literature review, Data collection, writing the first version. Seyed Peyman Mousavi Mobarekeh: Data collection, simulation, writing the first version. Amir Doudabi Nezhad: Conceptualisation and methodology.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No new data were generated or analyzed in support of this research. All data used in this study are publicly available from the cited sources (see References). In addition, the data are available on request.

Declaration of Generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work, the authors used AI-based tools (Claude, Anthropic; ChatGPT, OpenAI) to assist with translation, language editing, and the identification and

correction of grammatical and clarity-related errors. These tools were not used to generate original scientific ideas, arguments, analysis, or conclusions. All conceptual content, theoretical development, and interpretations in this paper are the authors ' own. After using these tools, the authors reviewed and edited all resulting content and take full responsibility for the content of this publication.

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بازتخصیص انرژی الکتریکی در دوره‌های کمبود
محدودیت‌های حقوقی و اقتصادی ارزش بار از دست رفته به‌عنوان معیار بازتخصیص

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چکیده
افزایش دفعات قطعی برق، ناشی از عدم تعادل میان عرضه و تقاضای انرژی الکتریکی، ضرورت تخصیص بهینه این منبعِ محدود را میان مصارف رقیب دوچندان کرده است. اگرچه شاخص «ارزش بار از دست‌رفته» (VoLL) به‌طور گسترده‌ای برای سنجش هزینهٔ قطعی‌های برق و ارزیابی قابلیت اطمینان شبکه به‌کار می‌رود، اما همچنان مشخص نیست که آیا می‌توان از آن به‌عنوان معیاری قابل‌اتکاء برای تخصیص برقِ محدود نیز استفاده کرد یا خیر. این پژوهش با اتخاذ رویکردی توصیفی-تحلیلی و با بهره‌گیری از یک مدل بهینه‌سازی ریاضی (شبیه‌سازی‌شده در نرم‌افزار GAMS)، کفایت شاخص VoLL را از دو منظر اقتصادی و حقوقی مورد بررسی قرار می‌دهد. از منظر اقتصادی، مطالعهٔ حاضر نخست نشان می‌دهد که در شرایط آرمانی، یعنی وجود اطلاعات کامل و نبودِ محدودیت‌های نهادی، تخصیص برق برمبنای شاخص VoLL می‌تواند به تخصیصی کارآمد منجر شود؛ سپس، با بررسی محدودیت‌های اطلاعاتی، ماهیت پویای شاخص VoLL و نتایج حاصل از شبیه‌سازی، امکان‌پذیری عملیاتیِ استفاده از این شاخص به‌عنوان مبنایی برای تصمیم‌گیری‌های متمرکز ارزیابی می‌شود. از منظر حقوقی، این پژوهش مبانی قانونیِ بازتوزیع برق میان مصرف‌کنندگان در دوره‌های کمبود را در چارچوب مقررات حاکم‌بر تأمین برق در ایران بررسی می‌کند. نتایج نشان می‌دهند که شاخص VoLL، باوجود اعتبارش به‌عنوان معیاری برای سنجش هزینه‌های قطعی برق، فاقد پیش‌نیازهای اطلاعاتی و نهادی-حقوقی لازم برای ایفای نقش به‌عنوان معیاری عملیاتی جهت تخصیص برقِ محدود است. سازوکارهایی که برپایهٔ انتخاب مصرف‌کننده و حقوق قابل‌معامله برای بهره‌برداری از ظرفیت موجود استوارند، رویکردی بالقوه برای آشکارسازی ارزش برق در دوران کمبود محسوب می‌شوند و شایستهٔ پژوهش‌های بیشتر هستند.

کلیدواژگان: ارزش بار از دست رفته (VoLL)، تخصیص انرژی الکتریکی، کمیابی برق، خروج برنامه‌ریزی شده، بازار برق.
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Bu-Ali Sin University

Analysis And Study of The Effects of the Blue Economy on the Economic Structure of the Islamic Republic of Iran

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Abstract

The blue economy is an ocean economy that aims to improve human well-being and social equity while also reducing environmental risks. The blue economy refers to the sustainable use of ocean resources for economic growth, improved livelihoods and jobs, and the health of ocean ecosystems is also ensured. By accessing the sea and taking advantage of its opportunities and potential, Iran can take steps towards economic growth and development. The present study seeks to identify the economic benefits of focusing on a sea-based economy, and the main research question is: What is the overall impact of focusing on the blue economy on the welfare and economy of Iran? In this study, the economic effects of focusing on the blue economy (fishery and aquaculture sector, maritime transportation, and oil and gas extraction from the seabed), based on the Multi-Regional Computable General Equilibrium Model (GTAP) and version 10 of its database, have been analyzed through 3 scenarios: 1. 90% reduction in tripartite tariff rates 2. Increased productivity of tripartite employees 3. Increased productivity in tripartite intermediate production factors with the GEMPACK software package. The results of this study show that by reducing the tariff on the aquaculture sector, the volume of aquaculture production will decrease, by increasing the productivity of intermediate inputs in the three sectors of fishing and aquaculture, maritime transportation, and oil and gas extraction from the seabed, the welfare of Iran will increase, and by increasing the productivity of labor and intermediate inputs in the three sectors of fishing and aquaculture, maritime transportation, and oil and gas extraction from the seabed, the trade balance of these two sectors will become positive.

Keywords: Blue economy, Maritime Transportation, Global Trade Analysis Project (GTAP).

JEL Classification: F17, L62, L92, Q22.

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1. Introduction

The definition of a marine economy, which is generally referred to as a blue economy in the global literature, is the sustainable use of the capacity of water resources and areas, including oceans, seas, lakes and islands, for economic growth, improving livelihoods and creating employment, and ultimately increasing gross domestic product. Therefore, the field of marine economy goes beyond fisheries and marine tourism and requires the emergence and support of water and sea-related industries, including maritime transport, maritime tourism, renewable energy, aquaculture and fisheries, marine biotechnology, biometeorology and marine mining.

Iran can take steps towards economic growth and development by accessing the sea and taking advantage of its opportunities and potentials. The country's potentials in the field of sea-based economy include access to open waters, small and large islands, port cities with diverse commercial, fishing, tourist and industrial functions, fishing (fishing, aquaculture), marine tourism, maritime transport, shipbuilding, subsurface resources, oil and gas mines and refineries, ports, wharves and marine structures, bunkering (fuelling ships) and environmental activities. Today, more than 90 percent of world trade is carried out through maritime transport. Ports play an active role in the economic growth of countries. Ports are not only active in the field of transportation, but are also effective in the management cycle and have a strategic role in domestic and foreign development for developing and developed countries.

Sea-based development and the marine economy, which have recently received more attention than ever before and have also been mentioned in the Seventh Development Plan, can have great economic effects for Iran. Accordingly, the present study seeks to identify the economic benefits of focusing on the marine economy. The main question of the study is: What effect does focusing on the blue economy have on welfare, changes in the trade balance and employment, and the country's economic structure in general?

For this purpose, in this study, the economic effects of focusing on three important sectors of the sea-based economy, namely fishing and aquaculture, maritime transport, and oil and gas extraction from the seabed, on welfare, trade balance, and employment, based on the Global Trade Analysis Project (GTAP) model and version 10 of its database (version 10 of the GTAP database was published in 2020), through three scenarios: 1. 90 percent reduction in the tripartite tariff rates of the three sectors of fishing and aquaculture, maritime transport, and oil and gas extraction from the seabed 2. Increasing the productivity of the labour force employed in the three sectors of fishing and aquaculture, maritime transport, and oil and gas extraction from the seabed 3. Increasing the productivity of

intermediate inputs in the three sectors of fishing and aquaculture, maritime transport, and oil and gas extraction from the seabed, using the GEMPACK software package. It should be noted that, so far, the effects of focusing on the sea-based economy have not been examined using the GTAP model, which is a multi-regional computable general equilibrium model. For this purpose, the GTAP model has been used in this study.

This paper is organized as follows: After this introduction, the literature on the subject, including theoretical foundations and empirical studies, is presented. Then, in the third section, the model, the database used in the research, and statistical facts are specified. The fourth section is dedicated to the simulation of the model and the presentation of the research findings, and finally, in the fifth section, conclusions and suggestions are presented.

2. Theoretical Foundations

2-1. Blue Economy

Definition of the Blue Economy: Oceans are considered as a repository of living and non-living resources. Since ancient times, the ocean economy has had a distinct place in economic analysis. With the increase in environmental concerns and the unlimited use of marine resources, a new concept called the “blue economy” emerged in parallel (Hazreh and Bukta, 2022). In 2012, the concept of the blue economy was first introduced at the United Nations Conference on Sustainable Development held in Rio de Janeiro (UNCTAD, 2016). Since then, the promotion of the blue economy by various international institutions has begun in order to protect and preserve precious ocean resources. However, initially this new and ambiguous term was often used to mean the “ocean economy” or the “marine economy”. To remove the ambiguity of these terms, the United Nations provided a completely distinct definition of the term blue economy in 2016. According to the United Nations definition, the blue economy is an ocean economy that aims to improve human well-being and social equity, while reducing environmental risks and environmental degradation (United Nations, 2016). In 2017, the World Bank introduced a new definition, according to which the “blue economy” refers to the sustainable use of ocean resources for economic growth, improved livelihoods and jobs, and the health of ocean ecosystems is also ensured (World Bank, 2017). In this definition, the blue economy has been described differently by different organizations and different authors, some of these definitions are mentioned below.

The “blue economy” seeks to increase economic growth, social inclusion, and maintain or improve livelihoods while ensuring the environmental sustainability of oceans and

coastal areas. In this definition, socio-economic development and ocean-related activities are separated from environmental and ecosystem degradation (World Bank, 2017).

The blue economy encompasses a wide range of economic sectors and related policies that determine the sustainable use of ocean resources. This definition considers aspects of ocean sustainability, sustainable fisheries, ecosystem health and pollution prevention (World Bank and United Nations, 2017). The blue economy encompasses all sectoral and cross-sectoral economic activities based on or related to oceans, seas and coasts (European Commission, 2020). The sustainability of the ocean economy is ensured when the long-term capacity of economic activities and the preservation of ocean ecosystems are in balance (Economist Information Unit, 2015).

In summary, the above definitions state that the blue economy includes all types of economic activities that directly or indirectly ensure the sustainable use of coastal and marine resources. Among these definitions, the World Bank definitions are relatively more acceptable in that they focus on the multifaceted role of the oceans and the sustainable use of their resources (Hazreh and Bukta, 2022). The blue economy emphasizes economic activities dependent on the sea and related sectors such as fishing, transport, maritime tourism and energy (Günter Pauli, 2010). Since the 21st century, the concept of "blue economy" has become increasingly common, with international communities believing that the blue economy consists of 3 main parts: economic coping with the global water crisis (McGlide *et al.*, 2012), innovative and creative economic development (Pauli, 2009), and marine economic development (Behnam, 2012).

The economic effects of various economic policies can be evaluated in various ways. Methods for examining the economic effects of various economic policies are divided into two categories: ex-ante studies and ex-post studies (Elliott and Ikemoto (2004) and Romalis (2008). The time period and study method of ex-ante studies and ex-post studies are different. Ex-ante studies are used to predict or simulate the potential effects of various economic policies. Today, computable general equilibrium (CGE) and partial equilibrium (PE) models are used to conduct ex-ante studies of various economic policies. CGE models are used to predict the effects of various economic policies at a general level and it is not possible to analyze a specific market (Elliott and Ikemoto (2004) and Jayasingh and Sarker (2004). Partial equilibrium (PE) models are used to examine the effects of various economic policies in a specific market or a specific product. Ex-post studies are also used to examine the actual effects of various economic policies. Today, in order to conduct ex-post studies, computable general equilibrium (CGE) and partial equilibrium (PE) models are used to examine the effects of various economic policies at a general level.

Econometric methods are used, taking into account data before and after various economic policies (Jayasingh & Sarker, 2004). In the present study, a general equilibrium model (GTAP) has been used. In the present study, the effect of productivity shocks and the elimination of trade tariffs in the aquaculture and maritime transport sectors on the entire Iranian economy has been investigated. In the same framework, studies related to the effects of productivity on the economy, the elimination of trade tariffs, and studies related to the aquatic economy have been presented. First, foreign studies and then domestic studies have been presented.

Bari (2017), in a study titled "Our Oceans and the Blue Economy: Opportunities and Challenges", has examined the concept of blue economy in the context of sustainability. The results of this study show that Bangladesh as well as South Asia have great potential in the blue economy. The concept of blue economy is quite new in South Asia and Bangladesh. Blue economy is the long-term well-being of a country or a region by preserving the environment and systematically using ocean resources. Political will, commitments, rigorous research, promoting social awareness and paying attention to the principles of blue economy can be important in the success of a sea-based economy.

In the study of Thompson *et al.* (2017), sustainable development methods of marine biotechnology, capacities and challenges are discussed. In this study, investment, infrastructure development and human capital are mentioned as important and effective factors in the development of this sector with marine resources.

In the study by Tigar and Garning (2018), factors affecting the development of marine and coastal tourism were examined. The results of this study show that in order to develop marine and coastal tourism, attention should be paid to such things as attractions (quality of natural landscapes and diversity of tourism activities), facilities (banking services, hotels and shops), accessibility (quality of roads and public transportation), human resources (quality of human resource skills, response to complaints, adequacy of human resources), mental image (quality of environmental conditions in terms of cleanliness, air pollution, noise pollution, etc.), and price of services.

In the study by Rogerson and Rogerson (2019), the challenges of the marine-based economy in South Africa were examined with an emphasis on coastal and marine tourism. The results of this study show that investment is the most important factor that can be effective in tourism development.

Al-Hariti and Hanif (2020), in the study titled "The Effects of the Water Economy on Economic Growth in SAARC Countries" using the generalized least squares technique and data from 1995 to 2018, examined the impact of water economy factors on economic

growth in the South Asian Association for Regional Cooperation (SAARC) countries. The results of this study show that the water economy plays a statistically significant role in the economic growth of SAARC countries. In this study, total aquaculture production, total fisheries and agriculture production, forestry and fishing, trade, and inflation rate were used as control variables. Proper management and use of water resources is effective on economic growth and addressing food insecurity challenges by improving the supply of seafood in developing countries in South Asia.

Bir *et al.* (2020), in a study titled "Review of the Blue Economy in Bangladesh: Prospects and Challenges," examined the opportunities and challenges of the ocean-based economy in Bangladesh. The results of this study show that the opportunities and potential of the ocean-based economy for Bangladesh can be summarized in the fields of tourism and biotechnology. They also mentioned the challenges of the ocean-based economy in Bangladesh, such as frequent floods, marine pollution, including ocean acidification, lack of trained personnel, and poor ocean management.

Askari *et al.* (2024), in a study titled “Pakistan’s Water Economy: Challenges and Prospects”, examined the opportunities and challenges related to the water economy in Pakistan. The results of this study show that in Pakistan, governments have not paid enough attention to the growth of the ocean economy. Pakistan’s maritime sector has huge potential for growth, but it needs favorable policies and substantial investment to realize the dream of sustainable growth. Pakistan’s future is linked to the development of the water economy, and a comprehensive strategy in the maritime sector by the government can pave the way for Pakistan’s prosperity.

In the study by Amogan Hagiwara (2024), the economic effects of Ethiopia’s import tariff reduction with the East and Southern African Common Market (EASM) were examined. The results of this study, which used a multi-regional and stationary computable general equilibrium (GTAP) model, show that the reduction in import tariffs reduces Ethiopia’s welfare through two terms of trade effects and the savings investment effect under full employment conditions.

Akomulafe *et al.* (2022), in a study titled “Challenges and Prospects for the Establishment of the Blue Economy in the Coastal Areas of Ondo State”, examined and identified the strengths and weaknesses of the blue economy. The results of this study indicate that the oceans and seas are the engines of the global economy and there is great potential for the growth and development of coastal areas. The natural environment of Ondo State is suitable for tourism and hospitality. The natural occupation of the people of this area is fishing, and the fishing method currently used is outdated and cannot guarantee

the welfare of the people. In addition to the oil that is being explored, other resources and minerals have not yet reached their maximum exploitation. Despite the availability of marine resources in this area, the strategies and components of the blue economy have not yet been fully implemented.

In the study of Mehrara and Ahmadzadeh (2009), the contribution of total factor productivity growth to the growth of production in major economic sectors (agriculture, industry and services) was examined. The results of this study show that during the three economic, social and cultural development programs of the country, the contribution of the service sector productivity to the growth of non-oil economy production is higher than that of other sectors and the contribution of the agricultural sector total factor productivity is lower than that of other sectors.

In the study of Mohammadi and Akbarifard (2008), the contribution of productivity shocks to Iran's economic growth was examined. The results of this study show that total factor productivity has a significant effect on economic growth.

Adeli (2019) has studied strategies for the fisheries economy in Iran in a study. The results of this study show that in addition to the necessity of economic studies in the field of fishing and aquaculture and related industries, drawing a clear vision of the fisheries economy requires proper planning based on collective wisdom and stakeholders, development of entrepreneurship and sustainable employment, healthy competition, and customer satisfaction while maintaining the capacity of reserves.

In the study by Hosseini *et al.* (2019), in order to investigate the development of employment in three dimensions of the marine economy (marine tourism, marine aquaculture, and marine biotechnology) in Bushehr province in Iran, futures research approaches and reliance on planning models were used. The results of this study show that urban competitiveness, model areas and tourism villages, local people's investment in the tourism sector, private sector investment, desirable and extensive coastal lands in the aquaculture sector, and the existence of a special marine science and technology zone, support for domestic production, and export of biotechnology products in the marine biotechnology sector will have the greatest impact on the process of employment development in Bushehr province.

In the study by Nejati *et al.* (2019), the economic effects of reducing import tariffs between Iran and the Eurasian Economic Union member countries were examined. The results of this study, which used a multi-regional and static computable general equilibrium model (GTAP), show that reducing import tariffs between Iran and the Eurasian Union member countries can increase the welfare of the countries.

In the study by Akbarpour *et al.* (2021), the historical obstacles to the sea-based development of the northern shores and hinterlands of the Persian Gulf and the Makran Sea were examined. The results of this study show that the lack of development of these regions is due to two main reasons; the first reason is due to the lack of investment, which itself is due to numerous political, historical, cultural and environmental reasons. The second reason is related to the interference of foreign governments in these regions.

The summary of the studies conducted shows that the productivity of production factors has a positive effect on economic variables, the elimination of trade tariffs can have different effects on the economies of countries and depends on the initial economic conditions of the countries, and studies have also been reported on the effects of the water economy on the economies of countries and coastal regions.

3. Methodology and Data

3.1 Global Trade Analysis Project (GTAP)

In this study, the empirical analysis and quantification of the results were carried out based on the Global Trade Analysis Project (GTAP) model. This model is a computable general equilibrium (CGE) model. The designers of this model provide researchers with the database, software related to solving the model (RunGTAP and GEMPACK), and other necessary documentation. Over the years, various versions of the GTAP model have been created and published, and its scope of application has also expanded. This study used version 10 of the GTAP database (updated in 2020). This data includes the Social Accounting Matrix (SAM) of 143 countries (or regions) and 67 sectors. The data in this matrix are grouped into specific sectors and regions based on the research objectives. GTAPagg software was also used for this purpose. In order to process the data in GEMPACK software, based on the research objectives, the model closure and the policy impulse (reducing bilateral tariffs in different industrial sectors between Iran and Eurasia) have been considered appropriate. In the model output, the values of the changes of different variables and their decomposition can be seen. The social accounting matrix, equations and behavioral parameters can be extracted from the database.

Figure (1) presents the graphical structure of the GTAP model. The regional household is the core of the model, collecting all income and distributing it through the Cobb-Douglas utility function. In a closed economy without taxes, the only source of income for the regional household is the income from the sale of primary factors of production at factor endowment (VOA(endow)) and represents the value of all goods produced in the economy. Intermediate inputs are also used to produce goods, which is expressed in the figure as

VDFA (value of goods sold by firms to other firms at factor endowment). Producers use three sources of income to purchase primary factors of production and intermediate inputs. On the one hand, private households and the government purchase goods from firms, which are represented in the figure by VDPA (value of domestic goods purchased by private households at factor prices) and VDGA (value of domestic goods purchased by government at factor prices). Before this, private households and the government are allocated a certain proportion of regional income, which is expressed as PRIVEXP (regional household expenditure allocated to private households as income) and GOVEXP (regional household expenditure allocated to government as income), respectively. The third source of firms' income is investment (NETINV), this amount is determined by the savings rate determined by the performance of the regional household and is then transferred to producers through the bank (Global Savings). In order to complete this cycle in a closed economy without taxes, it is assumed that saving equals investment. In an open economy, private households, the government, and producers can interact with the rest of the world. Thus, private households and governments can import goods, the value of imported goods purchased by private households at factor prices and the value of imported goods purchased by the government at factor prices are shown in the figure as VIPA and VIGA, respectively. Producers can also interact with the rest of the world, producers can substitute foreign intermediate inputs (VIFA) for domestic intermediate inputs (VDFA). In the figure, the value of imported intermediate inputs by firms is shown as VDFA. However, firms can also export their goods to the rest of the world. In the figure, the value of total goods exported by firms is shown as VXMD.

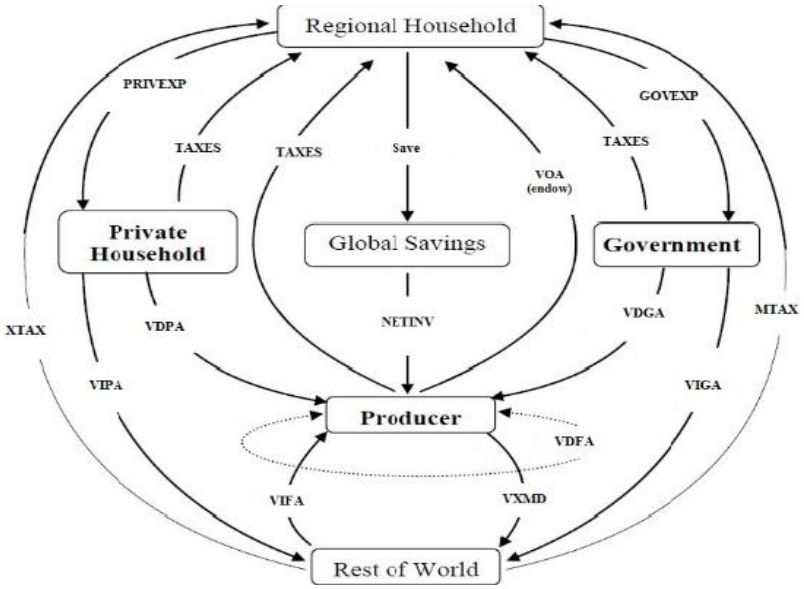

Fig. 1: Graphical structure of the GTAP Source: Brockmeier, M. (2001).

Taxation leads to price distortions and it is necessary to use market prices instead of factor prices in calculations. The range of applicable taxes is very wide, the regional household receives all taxes (types of taxes received from private households, government and enterprises (TAXES), taxes on imported goods (MTAX) and taxes on exported goods (XTAX)), which are redistributed through a Cobb-Douglas function. Finally, by considering this cycle and the accounting relationship between them, a general equilibrium model can be designed, the quantitative values of the accounting relationships can be calculated through the Social Accounting Matrix (SAM) provided in the GTAP database. The general equilibrium model is designed in an environment where all markets are settled. The macro-structure of the model presented in this study is a Savings-Driven Model, in which total investment depends on the total savings of the model.

Given the large number of relationships and equations in the GTAP model, a complete presentation of the model equations is beyond the scope of this article and is beyond the scope of this discussion. For further reading, it is recommended to refer to Hertel & Tsigas (1997), Rutherford (1998), Burfisher (2021), and the Gtap.tab or TABmate file from the RunGTAP and GEMPACK software packages.

In this study, changing policies will lead to a new set of global and domestic prices, which directly change the trade balance of different regions. Such a policy will lead to a change in the price of the commodity as well as the production relations associated with the commodity in question. Therefore, within the framework of the general equilibrium model, other sectors will also be affected by such changes.

Database and aggregation of sectors, regions and data: In this study, various scenarios were analysed based on the Global Trade Analysis Project (GTAP) model and version 10 of its database. Version 10 of the GTAP database was published in 2022 and includes 143 regions and 67 sectors that indicate the global economy, and the years 2012, 2016 and 2020 are considered as the benchmark (baseline). In this study, the simulation was carried out based on the base year 2020 and with GEMPACK software.

The data includes the social accounting matrix of 143 countries (or regions) and 67 sectors in 2020 and are aggregated into specific sectors and regions based on the research objective. For this purpose, the GTAPag software is attached to the GTAP database, which is used to aggregate data for use in regional general equilibrium models. The data is aggregated in the form of 67 sectors and 4 factors of production (labour, natural resources, land and capital) and 2 regions (Iran and other countries of the world).

3-2. data

In this section, statistical facts related to the three sectors of fishing and aquaculture, maritime transport and oil and gas extraction from the seabed are presented. Next, Iran's trade dependence with other countries of the world (exports and imports), tariff rates and employment levels in the three sectors of fishing and aquaculture, maritime transport and oil and gas extraction from the seabed are examined. Statistical facts can be effective in determining the potential effects of policy shocks. Table (1) shows Iran's exports to the whole world and the whole world's exports to Iran in the three sectors of fishing and aquaculture, maritime transport and oil and gas extraction from the seabed in 2012, 2016 and 2020 in world prices in million dollars.

Table 1: Iran's imports and exports in world prices (million dollars) Source: GTAP Database Version 10

Exports from all over the world to Iran			**Iran's exports to the whole world**			
2020	2016	2012	2020	2016	2012	Sea-oriented sectors - Year
11.87	13.54	5.20	25.38	125/52	10.54	Fisheries and Aquaculture Department
196	248	256	9350	11350	25212	Oil and gas extraction sector from the seabed
796.58	984.55	586.79	765/01	940/80	570.70	Maritime transportation sector
1004/45	1246/09	847/99	10140/39	12416/32	25793/24	Total of all sections

For example, in relation to the "Maritime Transportation" sector in 2020, it can be stated that Iran's exports to the whole world at world prices are equal to 765 million dollars and the whole world's exports to Iran at world prices are equal to 796.58 million dollars. The simultaneous export and import of goods and services in a field of activity or a specific industry can be explained based on the theory of intra-industry trade. Intra-industry trade is the simultaneous export and import of goods and services that are categorized in one or more similar industrial groups. Intra-industry trade is divided into two sectors: horizontal and vertical intra-industry trade, which are defined by the trade of products in one similar quality and the other with different qualities, respectively (Younespour and Tayyibi, 2010). Iran's exports in the maritime sectors are very small compared to exports in other sectors and can be increased with appropriate planning.

Table (2) presents the tariff rates for Iran's imports from countries around the world and the tariff rates for imports from countries around the world from Iran in the three sectors of

fishing and aquaculture, maritime transport, and oil and gas extraction from the seabed in 2012, 2016, and 2020 in percentage terms. As shown in Table (2), the tariff for the maritime transport and oil and gas extraction sectors is zero.

Table 2: Tariff rates for imports from Iran to other countries in the world and tariff rates for imports from other countries in the world to Iran (percentage) Source: GTAP Database Version 10

Tariffs for imports from Iran to countries around the world			Iran's import tariffs from countries around the world			
2020	2016	2012	2020	2016	2012	Sea-oriented sectors - Year
3.94	0.69	1.13	14.47	15.02	19.43	Fisheries and Aquaculture Department
0.00	0.00	0.00	0.00	0.00	0.00	Maritime transportation sector
0.00	0.00	0.00	0.00	0.00	0.00	Oil and gas extraction sector from the seabed
3.94	0.69	1.13	14.47	15.02	19.43	Total of all sections

Table (3) presents the amount of payment for labour employment in Iran and other countries of the world in the three sectors of fishing and aquaculture, maritime transportation, and oil and gas extraction from the seabed in 2012, 2016, and 2020, in millions of dollars.

Table 3: Amount of payment for labor employment in the three sectors of fishing, aquaculture, maritime transportation, and oil and gas extraction from the seabed (million dollars) Source: GTAP Database Version 10

Other countries in the world			Iran			
2020	2016	2012	2020	2016	2012	Sea-oriented sectors - Year
5334.36	4692.47	2925.22	10.11	14.69	5.25	Fisheries and Aquaculture Department
37657.46	37943.87	30689.02	41.14	86.99	42.36	Maritime transportation sector
45817.36	45699.32	45698.18	55.23	89.25	49.25	Oil and gas extraction sector from the seabed
16582796	14982781	12363659	30658.18	3125925	26212.31	Total of all sections

4. Experimental results and analysis

One of the main goals of using computable general equilibrium models is simulation or scenario building. With scenario building, the effects of different policies can be examined quantitatively (Nejati, 2021). The three sectors of fishing and aquaculture, maritime

transportation, and oil and gas extraction from the seabed are among the important economic sectors that are considered in the ocean-based economy. Evaluating the economic effects of focusing on these two sectors is of particular importance on the country's economy, and this issue has also been mentioned in the Seventh Development Plan. In this regard, in this study, the economic effects of focusing on these two sectors, based on the Multi-Regional Computable General Equilibrium Model (GTAP) and version 10 of its database, have been analysed through 3 scenarios (1. 90% reduction in tripartite tariff rates for sea-based sectors, 2. Increasing the productivity of the workforce employed in the three sectors of fishing and aquaculture, maritime transportation, and oil and gas extraction from the seabed, 3. Increasing the productivity of intermediate inputs in the three sectors of fishing and aquaculture, maritime transportation, and oil and gas extraction from the seabed) using the GEMPACK software package. In the following, the effects of the three mentioned scenarios on the welfare, trade balance, and production of Iran have been examined and analysed.

Scenario 1: 90% reduction in trilateral tariff rates for maritime sectors

With changes in tariff rates, the cost of a commodity changes in different regions (Iran and other countries in the world). With changes in tariff rates in sea-based sectors, new trade flows are created in different regions and in different economic sectors. These changes lead to changes in the level of welfare and changes in the trade balance of different sectors in different regions. In this section, the economic effects of a 90 percent reduction in bilateral tariffs between Iran and other countries in the fishing and aquaculture sector are analysed (the tariff rate for maritime transportation and oil and gas extraction from the seabed is zero). In Table (4), the change in the trade balance (DTBALi) is presented separately in terms of the change in the value of exported goods DVXW(i,r) and the change in the value of imported goods DVIW(i,r) in terms of thousand dollars. In Iran, with a 90 percent reduction in the tripartite tariff rates of sea-based sectors, a positive change is created in the trade balance of the aquaculture sector. The positiveness of this index indicates that the increase in the value of exports at FOB prices is greater than the increase in the value of imports at CIF prices. The positive change in the trade balance of the aquaculture sector in Iran was due to the increase in exports ($2,560,000) and the increase in imports ($2,160,000).

Table 4: Economic effects (trade balance) of tariff reduction in the Peruvian aquaculture sector (thousand dollars) Source: Research results (based on GTAP database version 10)

DTBALi	DVXW	DVIW	Economic activity	Regions
400	2560	2160	Aquaculture and fishing	Iran
0	0	0	Sea transportation	
0	0	0	Extraction of oil and gas from the seabed	
-760	490	1250	Aquaculture and fishing	Other countries in the world
365	420	55	Sea transportation	
5331	37894	32563	Extraction of oil and gas from the seabed	

Table (5) shows the effect of reducing the tariff on the aquaculture sector on changes in production. In Iran, by reducing the tariff on the aquaculture sector, the volume of aquaculture production will decrease by $120,000. Given Iran's access to open waters, this figure can be increased with proper planning.

Table 5: Economic effects (production changes) of tariff reduction in the Peruvian aquaculture sector (thousands of dollars) Source: Research results (based on GTAP database version 10)

Volume of changes	Percentage of changes	Post-impulse production	Pre-impulse production	Economic activity	Regions
-120	-0/01	1380260	1380380	Aquaculture and fishing	Iran
0/00	0/00	4156610	4156610	Sea transportation	
0/00	0/00	9562579	9562579	Extraction of oil and gas from the seabed	
-500	-0/03	390336810	390337310	Aquaculture and fishing	Other countries in the world
380	0/00	848295500	848295130	Sea transportation	
-142868	-0/02	1835693257	1978562143	Extraction of oil and gas from the seabed	

Second scenario: Increasing the productivity of the workforce employed in the three sectors of fishing and aquaculture, maritime transportation, and oil and gas extraction from the seabed.

Achieving sustainable economic growth requires investment in infrastructure to increase production capacities. Such investments include not only physical investments, but also investments in human resources, education, and health (Miqdad Moeini, 2021).

Improving the quality of the workforce can increase labour productivity, thereby having a favourable impact on future investment and economic returns. Accumulation of human capital through education plays an important role in the process of economic development. In this section, the policy impetus for increasing labour productivity in the three sectors of aquaculture, maritime transportation, and oil and gas extraction from the Iranian seabed has been analysed. In Iran, a 15 percent increase in labour productivity in the two sectors of aquaculture and maritime transportation will create a positive change in the trade balance of both sectors. Table (6) presents the change in the trade balance (DTBALi) by dividing the change in the value of exported goods DVXW(i,r) and the change in the value of imported goods DVIW(i,r) in thousands of dollars. The positive change in the trade balance of the aquaculture sector in Iran was due to an increase in exports ($130,000) and a decrease in imports ($60,000), and the positive change in the trade balance of the maritime transport sector in Iran was due to an increase in exports ($4,190,000) and a decrease in imports ($1,850,000). Table (7) shows the effect of a 15 percent

Table 6: Economic effects (trade balance) of increasing the productivity of the workforce employed in the three sectors of aquaculture, maritime transportation, and oil and gas extraction from the seabed (thousand dollars) Source: Research results (based on GTAP database version 10)

Volume of changes	Percentage of changes	Post-impulse production	Pre-impulse production	Economic activity	Regions
1450	0/11	1491850	1490560	Aquaculture and fishing	Iran
12740	0/43	4188450	4124610	Sea transportation	
748512	0/97	9983264	9234752	Extraction of oil and gas from the seabed	
-180	-0/00	385337130	385337310	Aquaculture and fishing	Other countries in the world
-14990	-0/36	848280445	848295695	Sea transportation	
-36594139	-0/32	1163578924	1126984785	Extraction of oil and gas from the seabed	

increase in the productivity of the workforce employed in the aquaculture and maritime transport sectors on the changes in the production of these two sectors. In Iran, the volume of production in the aquaculture sector increases by $1,450,000 and the volume of

production in the maritime transport sector increases by $12,740,000. Productivity leads to an increase in the production of these two sectors.

Table 7: Economic effects (production changes) of increasing the productivity of the labor force employed in the three sectors of aquaculture, maritime transportation, and oil and gas extraction from the seabed (thousand dollars) Source: Research results (based on GTAP database version 10)

DTBALi	DVXW	DVIW	Economic activity	Regions
70	130	-60	Aquaculture and fishing	Iran
2340	4190	-1850	Sea transportation	
5290	8540	-3250	Extraction of oil and gas from the seabed	
130	140	-10	Aquaculture and fishing	Other countries in the world
11500	12030	-530	Sea transportation	
17785	18745	-960	Extraction of oil and gas from the seabed	

The results of this part of the research can help the country's planners and policymakers in adopting appropriate policies in the field of investment and training of the workforce employed in the maritime-based sectors, which will ultimately lead to increased economic growth and increased exports of this sector. As stated in Table (7), training and productivity of the workforce employed in the maritime-based sectors can lead to increased production.

Third scenario: Increasing the productivity of intermediate inputs in the three sectors of fishing and aquaculture, maritime transportation, and oil and gas extraction from the seabed.

Intermediate goods can be considered as one of the factors of economic growth and development, like capital, human resources, etc. The main implication of the effect of intermediate goods on economic growth and development is from the perspective of capital that exists towards intermediate goods, in other words, in the growth process, intermediate goods are as important as capital. The first recognition obtained from intermediate goods is that they are very similar to capital. In fact, the difference between intermediate goods and capital is related to the time used. Intermediate goods are installed earlier than capital and are completely depreciated in the production process; however, capital is not completely depreciated during production. In the long run, capital and intermediate goods are completely the same and more importantly, both are factors of production. (Esfandyar Jahangard, 2011). Scientific recognition of the sources of production growth is one of the

requirements for achieving sustainable and endogenous economic growth. According to the Solow growth model, economic growth is achieved from two sources, namely the growth of production factors and the growth of productivity of production factors.

In the early literature on growth in economic growth patterns, emphasis was mainly placed on the role of production factors such as labor, capital, and even energy and land. While in the new literature in this field, emphasis is placed on other aspects and factors affecting economic growth, including productivity of production factors, accumulation of knowledge and research and development (R&D), human and social capital (Futros *et al.*, 2012). Productivity has a special place due to the scarcity of production factors such as specialized human resources, capital, and intermediate factors. Productivity of production factors can be explained as a change in the rate of production with fixed production factors, in which case it can be considered as a residual or a measure of the effect of unknown factors. Given the importance of the productivity impulses mentioned above, in this section, the policy impulse to increase productivity in intermediate inputs in three sectors of aquaculture, maritime transportation, and oil and gas extraction from the Iranian seabed is analyzed. The desired impulse was a 15 percent increase in the productivity of intermediate inputs in the three sectors of aquaculture, maritime transport, and oil and gas extraction from the seabed in Iran. Table (8) presents the change in the trade balance (DTBALi) by separating the change in the value of exported goods DVXW(i,r) and the change in the value of imported goods DVIW(i,r) in terms of thousand dollars.

In Iran, a 15 percent increase in the productivity of intermediate inputs in the two sectors of aquaculture and maritime transport creates a positive change in the trade balance of both sectors. For example, the positive change in the trade balance of the aquaculture sector in Iran was due to an increase in exports ($710,000) and a decrease in imports ($420,000), and the positive change in the trade balance of the maritime transport sector in Iran was due to an increase in exports ($92,340,000) and a decrease in imports ($35,220,000). Increasing the trade balance of the maritime transport sector is significant and can be considered as a policy option.

Table 8: Economic effects (trade balance) of increasing productivity in intermediate inputs in the three sectors of aquaculture, maritime transport, and oil and gas extraction from the seabed (thousand dollars) Source: Research results (based on GTAP database version 10).

DTBALi	DVXW	DVIW	Economic activity	Regions
290	710	-420	Aquaculture and fishing	Iran
57120	92340	-35220	Sea transportation	

40681	136895	-96214	Extraction of oil and gas from the seabed	
590	750	-160	Aquaculture and fishing	Other countries in the world
11022	22596	-11574	Sea transportation	
14211	99874	-85663	Extraction of oil and gas from the seabed	

Table (9) shows the effect of a 15 percent increase in productivity in intermediate inputs in the aquaculture and maritime transport sectors on changes in production in these two sectors. For example, in Iran, the volume of production in the aquaculture sector increases by $7,900,000 and the volume of production in the maritime transport sector increases by $265,590,000. Productivity leads to an increase in the production of these two sectors.

Table 9: Economic effects (production changes) of increasing productivity in intermediate inputs in the three sectors of aquaculture, maritime transport, and oil and gas extraction from the seabed (thousands of dollars) Source: Research results (based on GTAP database version 10).

Volume of changes	Percentage of changes	Post-impulse production	Pre-impulse production	Economic activity	Regions
7900	0/61	1498220	1481370	Aquaculture and fishing	Iran
265590	6/06	4422700	4171110	Sea transportation	
1154933	7/09	125369478	9875533	Extraction of oil and gas from the seabed	
-790	-0/00	390333240	390389310	Aquaculture and fishing	Other countries in the world
-268590	-0/03	848028652	846295140	Sea transportation	
-5694783	-0/11	1256912457	1302568423	Extraction of oil and gas from the seabed	

4-1. Welfare effects of different scenarios

In the first scenario: a policy impulse to reduce tariffs has been applied, with a reduction in tariffs for maritime sectors (a 90% reduction in bilateral tariff rates between Iran and other countries in the maritime sectors), the change in Iran's welfare is equal to $1,420,000 and for other countries in the world is equal to $132,000.

In the second scenario: a policy impulse to train the workforce employed in maritime sectors (increasing the productivity of the workforce employed in the three sectors of aquaculture, maritime transport and oil and gas extraction from the seabed) has been applied, with the application of the desired impulse (a 15% increase in the productivity of

those employed in maritime sectors in Iran), the change in Iran's welfare is equal to $9,026,000 and for other countries in the world is equal to $70,200,000.

In the third scenario: The policy impulse to use advanced intermediate inputs in sea-based sectors (increasing the productivity of intermediate inputs in the two sectors of aquaculture and maritime transport) has been applied. By applying the desired impulse (15% increase in the productivity of intermediate inputs in the three sectors of aquaculture, maritime transport and oil and gas extraction from the seabed in Iran), the change in welfare in Iran is equal to $16,120,000 and for the rest of the world it is equal to $128,600,000. The lowest welfare is related to the first scenario and the highest welfare is related to the third scenario. In this study, welfare changes are measured by equivalent changes (EV).

Table 10: Welfare impacts of different scenarios (USD) Source: Research results (based on GTAP database version 10).

Third scenario	Second scenario	First scenario	Regions
16120	9026	1420	Iran
128600	70200	132000	Other countries in the world

5. Conclusions

One of the pending development opportunities in the country is the maritime economy. Maritime development and the maritime economy, which have recently received more attention than ever before, are a very general issue and it is necessary to draw a clear picture of it. In this study, an attempt has been made to express some of the realities of the maritime economy in the country. Accordingly, in this study, the economic effects of focusing on these two sectors, based on the Multi-Regional Computable General Equilibrium Model (GTAP) and version 10 of its database, have been analysed through 3 scenarios (1. 90% reduction in tripartite tariff rates for maritime sectors, 2. Increasing the productivity of the workforce employed in the three sectors of fishing and aquaculture, maritime transportation, and oil and gas extraction from the seabed, 3. Increasing the productivity of intermediate inputs in the three sectors of fishing and aquaculture, maritime transportation, and oil and gas extraction from the seabed) with the GEMPACK software package.

The results show that with a 15 percent increase in the productivity of intermediate inputs in the three sectors of fishing and aquaculture, maritime transport, and oil and gas extraction from the seabed, a positive change is created in the trade balance of all three sectors. The positive change in the trade balance of the sea-based sectors is due to an increase in exports and a decrease in imports. The increase in the trade balance of the maritime transport sector is significant and can be considered as a policy option. The effect of a 15 percent increase in productivity in intermediate inputs in the two sectors of

aquaculture and maritime transport on production changes shows that, in Iran, the volume of production in the aquaculture and maritime transport sectors increases. Productivity leads to an increase in the production of these two sectors. With a 15% increase in the productivity of intermediate inputs in the two sectors of aquaculture and maritime transport, the change in Iran's welfare is equal to $16,120,000 and for the rest of the world it is equal to $128,600,000. The increase in the trade balance of the maritime transport sector resulting from a 15% increase in the productivity of the workforce employed in the two sectors of aquaculture and maritime transport is significant and can be considered as a policy option. The most important policy recommendation for the country, according to the research results and based on the GTAP model, is that focusing on the sea-based economy, especially paying attention to the maritime transport sector, can be considered as an appropriate policy option.

The results of this study can help the country's planners and policymakers adopt appropriate policies in the field of investment and training of the workforce employed in maritime sectors, which will ultimately lead to increased economic growth and increased exports of this sector. As stated, training and productivity of the workforce employed in maritime sectors can lead to increased production. One of the variables that can affect productivity is investment in maritime sectors. Iran's maritime advantage is unparalleled, and economic activities cannot be advanced solely by using government investment, and the capacity of the private sector should be best utilized in the maritime and port areas by domestic investment and by creating attractiveness for foreign investors. Foreign investment is an integral part of an open and effective system in the international economy and is a factor for the development and sustainable profitability of countries. Today, developing societies have taken steps to attract foreign investors in order to participate in the global economy and trade, transfer capital, expertise, and technology.

In this study, in order to focus on the maritime economy, only the reduction of tariffs and the productivity of the workforce employed in these sectors, as well as the productivity of intermediate inputs, have been used. Focusing on the maritime economy includes other measures such as the development of islands, coasts, maritime capacities, ports, maritime businesses, logistics infrastructure and transportation infrastructure, the development of ports, fisheries, shipping, shipbuilding complexes and their related industries, as well as the establishment of mother industries and a stable population on the coasts and seas. Therefore, by considering other policies, more accurate results can be achieved on the effects of focusing on the maritime economy on the welfare of society and other macroeconomic variables. Given the sensitivity of the subject, in terms of research

methodology, it is recommended to use the dynamic multi-regional computable general equilibrium model in future studies to measure the effects of focusing on the maritime economy on economic variables and indicators over time.

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Also, with a heart filled with sadness, I dedicate this article to the 168 students of Shajare Tayyiba School in Minab County, Hormozgan Province, who were martyred during the cowardly attacks by the United States and Israel on Iran. Students whose only "crime" was being in the classroom, trying to learn, grow, and dream. May their souls rest in peace and their memory be cherished.

Conflicts of Interest

This article is based on “Professional Conflict and Intellectual Property: Organizational Development and My Personal Expertise as the Responsible Author”. or “No Conflict of Interests are Declared by the Authors”.

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تحلیل و بررسی تأثیرات اقتصاد آبی بر ساختار اقتصادی جمهوری اسلامی ایران

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چکیده

اقتصاد آبی، اقتصادی مبتنی‌بر اقیانوس است که هدف آن بهبود رفاه انسانی و عدالت اجتماعی، هم‌زمان با کاهش مخاطرات زیست‌محیطی می‌باشد. این مفهوم به بهره‌برداری پایدار از منابع اقیانوسی برای رشد اقتصادی و بهبود معیشت و اشتغال اشاره دارد، به‌گونه‌ای که سلامت اکوسیستم‌های اقیانوسی نیز تضمین گردد. ایران می‌تواند با دسترسی به دریا و بهره‌گیری از فرصت‌ها و پتانسیل‌های آن، گام‌هایی در مسیر رشد و توسعهٔ اقتصادی بردارد. پژوهش حاضر به‌دنبال شناسایی منافع اقتصادیِ تمرکز بر اقتصاد دریامحور است و پرسش اصلی آن این است؛ تمرکز بر اقتصاد آبی چه تأثیر کلی بر رفاه و اقتصاد ایران دارد؟ در این مطالعه، آثار اقتصادیِ تمرکز بر اقتصاد آبی (شامل: بخش‌های شیلات و آبزی‌پروری، حمل‌ونقل دریایی، و استخراج نفت و گاز از بستر دریا) با استفاده از «مدل تعادل عمومی قابل‌محاسبه چندمنطقه‌ای» (GTAP) و نسخهٔ ۱۰ پایگاه دادهٔ آن، در قالب سه سناریو تحلیل شده است: ۱) کاهش ۹۰ درصدی نرخ تعرفه‌ها در این سه بخش؛ ۲) افزایش بهره‌وری نیروی کار در این سه بخش؛ و ۳) افزایش بهره‌وری نهاده‌های تولید واسطه‌ای در این سه بخش (با استفاده از بستهٔ نرم‌افزاری GEMPACK). نتایج این مطالعه نشان می‌دهد که کاهش تعرفه‌ها در بخش آبزی‌پروری منجر به کاهش حجم تولید در این بخش خواهد شد؛ افزایش بهره‌وری نهاده‌های واسطه‌ای در سه بخشِ شیلات و آبزی‌پروری، حمل‌ونقل دریایی، و استخراج نفت و گاز از بستر دریا، موجب ارتقائ رفاه در ایران می‌شود؛ و افزایش بهره‌وری نیروی کار و نهاده‌های واسطه‌ای در این سه بخش، تراز تجاری آن‌ها را مثبت خواهد کرد.

کلیدواژگان: اقتصاد آبی، حمل‌ونقل دریایی، پروژهٔ تحلیل تجارت جهانی (GTAP).
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Monetary-Fiscal Policy Regimes and Policy Dominance in the Iranian Economy

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Abstract

This study identifies monetary and fiscal policy regimes in Iran, and the resulting policy mix, over 1975–2024, the longest period with jointly available data. Monetary policy is a base-money growth rule responding to the inflation gap; fiscal policy is an operating budget balance rule responding to lagged government debt to the central bank, controlling for oil revenue, the output gap and COVID-19. Each rule is a Markov-switching regression with switching intercept, policy coefficient and error variance, estimated by penalized maximum likelihood to exclude degenerate regimes. The number of regimes is selected by sequential parametric-bootstrap likelihood-ratio tests, and time-varying transition probabilities driven by sanctions, war, oil shocks, exchange-rate depreciation and financial repression are tested against constant ones. The data select two monetary and three fiscal regimes. Monetary policy is passive throughout: base-money growth either ignores inflation (coefficient −0.09, in oil-boom years) or accommodates it (0.64). Fiscal policy cycles from a strongly passive regime (debt coefficient 0.11) to a weakly passive regime (0.04) and then an active regime in which deficits widen as debt rises (−0.03). The policy mix is therefore indeterminate in 35 of 50 years and fiscally dominant in 15 (1975–1977, 1986–1988, 2015–2023), when inflation averaged 28.6 percent versus 19.3 percent under indeterminacy; monetary dominance never occurs. Sanctions, war, oil shocks and exchange-rate depreciation do not affect transition probabilities. The active fiscal regime coincides with deep financial repression, but the real deposit rate's effect on transitions is insignificant under a parametric bootstrap ($p = 0.15$). The passive monetary stance and active fiscal regime are robust across 21 alternative specifications, and the regime-switching rules forecast 2019–2024 as accurately as linear rules. Price stability requires an enforceable fiscal rule, removal of financial repression and a monetary instrument that can lean against inflation.

Keywords: Monetary-Fiscal Policy Regimes, Monetary Dominance, Fiscal Dominance, Markov-Switching Model, Iranian Economy.
JEL Classification: C24, E52, E58, E62, E63.

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1. Introduction

The global financial crisis and the Great Recession generated growing interest in the interactions between monetary and fiscal policies and their joint effects on the macroeconomy. The theoretical analysis of policy interactions focuses on how monetary and fiscal authorities can jointly determine the price level and stabilise public debt. The literature points to two distinct, but equally viable, policy combinations. Under the conventional combination, a central bank stabilises inflation by raising nominal interest rates more than one-for-one with inflation, while the fiscal authority adjusts taxes or expenditures to ensure solvency. Under the alternative combination, the roles are reversed: fiscal policy determines the price level and monetary policy stabilises debt. Because these combinations imply substantially different transmission channels for policy shocks, understanding monetary-fiscal interactions is essential (Chang *et al.*, 2021).

Macroeconomic equilibrium depends heavily on the prevailing monetary-fiscal policy regime (Leeper *et al.*, 2017). The 2008 financial crisis and the COVID-19 pandemic further increased attention to these interactions, as many economies combined unconventional monetary measures with large fiscal packages (Liu *et al.*, 2021). Failure to account for how the two policies interact may prevent policymakers from achieving their objectives (Gilak Hakimabadi *et al.*, 2022).

Iran offers a particularly informative case. Government budgets depend heavily on oil revenue, which is exposed to large price swings and to sanctions; government borrowing from the central bank has repeatedly been monetised; nominal interest rates on bank deposits and loans have been set administratively and, in most years, below inflation; and the period since 1975 includes a revolution, an eight-year war, two waves of comprehensive sanctions and a pandemic. Each of these features can change the behaviour of monetary or fiscal authorities, which makes a regime-switching description of policy natural.

This paper revises and extends earlier work on Iranian policy regimes in six directions. First, the sample is extended to 1975–2024, the longest period over which all variables are jointly available, so that it covers the war years, the sanctions episodes and the inflationary episode of 2018–2024. Second, fiscal policy is measured by the operating budget balance relative to GDP, the instrument most directly controlled by the government, while government debt to the central bank, also relative to GDP, is the state variable to which a passive fiscal authority responds. Third, the number of regimes is selected by sequential parametric-bootstrap likelihood-ratio tests combined with explicit identification checks rather than assumed. Fourth, the estimator uses a penalised exact

likelihood that excludes degenerate regimes and a parsimonious switching structure suited to 50 annual observations. Fifth, transition probabilities are allowed to depend on sanctions, war, oil shocks, exchange-rate depreciation and financial repression; to make this feasible in a short sample, we propose a restricted time-varying specification with one slope for the exits from each extreme policy regime. Sixth, the monetary rule is classified with a criterion appropriate for a base-money instrument under administered interest rates, which we document directly, and the classification is reported under three conventions so that the results can be compared with the existing evidence for Iran.

The data select two monetary and three fiscal regimes. Monetary policy is passive throughout the sample. Fiscal policy cycles through a strongly passive, a weakly passive and an active regime, so that the policy mix alternates between indeterminacy (35 years) and fiscal dominance (15 years) and is never one of monetary dominance. Fiscal dominance coincides with the high-inflation episodes of 1975–1977, 1986–1988 and 2015–2023, and with deep financial repression. None of the candidate drivers, including sanctions and oil shocks, significantly shifts the transition probabilities; the real deposit rate comes closest, and once the economy was in the active fiscal regime, it remained there in every year in which the real deposit rate was below about −12 percent, but with 50 observations this association is suggestive rather than statistically established.

The remainder of the paper is organised as follows. Section 2 reviews the theoretical background and previous studies. Section 3 presents the policy rules, the econometric model and the inference procedures. Section 4 describes the data, their time-series properties and the evidence on administered interest rates. Section 5 reports the results, Section 6 the robustness and out-of-sample evidence, and Section 7 discusses the findings and their policy implications. Section 8 concludes.

2. Theoretical Background and Literature Review

2-1. Active and passive policies

According to Leeper (1991), a policy authority is active when it is not constrained by current budgetary conditions and is free to set its instrument and passive when it is constrained by consumer optimisation and the actions of the other authority. Monetary policy is active when it responds strongly to inflation (the Taylor principle) and passive otherwise. Fiscal policy is passive when taxes or primary surpluses respond sufficiently to government debt to keep it on a sustainable path, and active otherwise.

Four combinations follow. Under active monetary and passive fiscal policy (AM/PF), monetary policy anchors the price level and fiscal policy guarantees solvency: this is

monetary dominance and the conventional New Keynesian benchmark, with a unique equilibrium. Under passive monetary and active fiscal policy (PM/AF), the price level adjusts to make the real value of government debt consistent with the present value of surpluses: this is fiscal dominance, associated with the fiscal theory of the price level, and it also yields a unique equilibrium. Under PM/PF neither authority anchors nominal variables and the equilibrium is indeterminate. Under AM/AF both authorities try to anchor nominal variables and no stable equilibrium exists (Leeper, 1991; Liu *et al.*, 2021; Hinterlang & Hollmayr, 2022).

The distinction between fiscal and monetary dominance therefore refers to which authority determines the price level, not to which instrument is more volatile or more frequently used. Fiscal dominance requires both a passive central bank and an active fiscal authority; a passive central bank combined with a passive fiscal authority is not fiscal dominance but indeterminacy. Section 5.6 applies exactly this joint classification.

2-2. Policy rules with a base-money instrument

The thresholds above are defined for interest-rate and tax rules. Alexeeva *et al.* (2022), for example, specify a continuous-time New Keynesian model with government debt in which the central bank sets the real interest rate, $r_t = r + f_M(\pi_t - \pi^*)$, so that $f_M > 0$ (active) is equivalent to a nominal response greater than one, and taxes respond to debt, $\tau_t = \tau + f_F(b_t - b^*)$, with $f_F > r$ for passive fiscal policy.

In Iran the operational instrument of the central bank is the quantity of base money, and nominal interest rates have been set administratively (Komijani *et al.*, 2013; Zorriyeh Mohammadali *et al.*, 2021). Two implications follow. First, with an administered nominal rate, the real rate falls when inflation rises, so the interest-rate instrument is passive in the sense of Leeper (1991) and Alexeeva *et al.* (2022). Section 4.4 confirms this: over 1975–2024 the ceiling on the one-year deposit rate responds to inflation with a coefficient of only 0.14, far below one, and the real deposit rate falls by 0.60 points for each point of inflation ($f_M \approx -0.6 < 0$). The only margin along which monetary policy can lean against inflation is therefore the growth of base money. Second, in a base-money rule $\mu_t = \alpha + \phi(\pi_t - \pi^*)$, a contractionary response to inflation corresponds to $\phi < 0$, as in the base-money rule of McCallum (1988). A positive ϕ means that the central bank accommodates inflation by expanding base money. We therefore classify monetary policy as active when ϕ is significantly negative and passive otherwise, which is also the criterion of Erfani and Talebbeydokhti (2025a).

This criterion differs from the one that applied the interest-rate threshold $\phi > 1$ to base-money growth. For a money-growth instrument that threshold is inappropriate: a response of base-money growth greater than one-for-one to inflation is the most accommodative stance possible, not an active one. To make the role of the criterion transparent, Section 5.2 reports the classification under the sign criterion, under the threshold $\phi < 1$ implied by mapping base-money growth into an interest-rate response through money demand ($\Delta i_t \approx (1-\phi)\pi_t/\eta$ when $m_t - p_t = y_t - \eta i_t$), and under the Taylor-type threshold $\phi > 1$.

2-3. Price determination under indeterminacy

Under PM/PF neither policy pins down the price level. The fiscal authority stabilises debt for any path of prices, and the central bank validates whatever inflation occurs. Equilibrium inflation is then not determined by fundamentals alone: self-fulfilling revisions of expectations (sunspots) and fundamental shocks can move inflation persistently, and the propagation of fundamental shocks itself depends on expectations (Clarida, Galí & Gertler, 2000; Benhabib, Schmitt-Grohé & Uribe, 2001; Lubik & Schorfheide, 2004).

In the Iranian institutional setting the transmission runs as follows. A shock that raises expected inflation, typically an exchange-rate depreciation driven by oil-revenue or sanctions news, raises prices; with administered deposit rates, real rates fall and the demand for money and bank deposits declines; the central bank, whose base-money growth accommodates inflation, supplies the additional liquidity; and because fiscal policy is passive, no fiscal adjustment acts as a nominal anchor either. Inflation therefore becomes persistent and dependent on expectations rather than on a policy target. Financial repression completes the mechanism: because deposit rates are capped, the inflation generated in this way transfers resources from depositors to the government and to the borrowers of the banking system, which lowers the fiscal cost of inflation and weakens the incentive to restore a nominal anchor. Section 5.6 shows that inflation averaged 19 percent in the years of indeterminacy and 29 percent in the years of fiscal dominance.

2-4. Previous studies

Harada and Suzuki (2026) examine the interaction between monetary policy and fiscal conditions in advanced economies over 1980–2025 and find that moderate monetary expansion tends to stabilise budget deficits by raising nominal GDP. Giuli *et al.* (2025)

use a Markov-switching framework to study dominance and conflicts during crises: the United States alternated between monetary and fiscal dominance, the euro area was mainly under monetary dominance, and crisis periods triggered regime shifts. Serem *et al.* (2025) find for Kenya that monetary-fiscal coordination partially mediates the effect of policy on public debt. Liu *et al.* (2021) estimate regimes for China over 1993–2017 and find strong support for passive monetary and active fiscal policy. Hinterlang and Hollmayr (2022) classify monetary and fiscal dominance with machine-learning methods.

For Iran, Tavakolian *et al.* (2019) and Jaafari-Lylab *et al.* (2018) use DSGE models and find fiscal dominance and gains from coordination; Nazari (2018) estimates regime-switching rules over 1971–2016. The studies closest to ours are Erfani and Talebbeydokhti (2025a, 2025b). In the monetary study, base-money growth responds to the deviation of inflation from its Hodrick-Prescott trend in a three-regime MSIA model over 1975–2023; a negative response is classified as active. They find one short active regime (1978, 1993, and 2005), a "highly passive" regime with a response of 0.64 (1983–1992, 1997–2004, and 2009–2015) and a "relatively passive" regime with a response of 0.56. In the fiscal study, tax-revenue growth responds to the gap between government debt to the central bank and its HP trend and to the budget deficit in a three-regime MSIAH model over 1975–2022, and all three regimes are active. Both studies conclude that Iranian policy has been predominantly passive (monetary) and active (fiscal).

This study differs from these papers in five respects that matter for the results. (i) The two rules are analysed jointly, so that the policy mix and its equilibrium properties can be identified year by year. (ii) The fiscal rule uses the operating balance relative to GDP and is shown to form a cointegrating relation with debt once a regime shift is allowed. (iii) The number of regimes is tested rather than chosen by information criteria, which can be unreliable in small samples. (iv) The inflation target is explicit and constant, so that the policy coefficient does not depend on the level of the target; the HP-trend target is examined as a robustness check. (v) Financial repression is measured directly and tested both as a control in the fiscal rule and as a driver of regime transitions.

3. Methodology

3-1. Policy rules

The monetary rule is

$$MBGR_t = \alpha_0(S_t^M) + \phi(S_t^M)\,(\pi_t - \pi^*) + \alpha_y\,\tilde{y}_t + \rho_m\,MBGR_{t-1} + \alpha_c\,COVID_t + \sigma_m(S_t^M)\,\varepsilon_t^m \quad (1)$$

where $MBGR_t$ is the growth rate of the monetary base (percent), π_t is CPI inflation (percent), π^* is the inflation target, $\tilde{y}_t$ is the output gap, $COVID_t$ is a dummy for 2020–2021 and $S_t^M \in \{1, \dots, k_M\}$ is the monetary regime. The target π^* is set to the sample mean of inflation (22.07 percent). Because the target is constant, it shifts only the intercept and leaves ϕ unchanged.

The fiscal rule follows Bohn (1998) and Davig and Leeper (2006):

$$OB_t = \gamma_0(S_t^F) + \gamma_b(S_t^F)\, b_{t-1} + \gamma_y\, \tilde{y}_t + \gamma_o\, oil_t + \rho_1\, OB_{t-1} + \rho_2\, OB_{t-2} + \gamma_c\, COVID_t + \sigma_f(S_t^F)\, \varepsilon_t^f \quad (2)$$

where OB_t is the operating balance (general revenues minus current payments) as a percent of GDP, b_{t-1} is lagged government debt to the central bank as a percent of GDP, oil_t is oil revenue as a percent of GDP and $S_t^F \in \{1, \dots, k_F\}$ is the fiscal regime. Fiscal policy is passive when the operating balance improves significantly in response to debt ($\gamma_b > 0$) and active otherwise. The threshold of zero is the sustainability condition of Bohn (1998); because the real interest rate on government debt net of output growth has been negative for most of the sample, owing to administered rates and high inflation, it is a conservative version of the Leeper (1991) threshold $\gamma_b > r - g$. Because the rule is dynamic, the long-run response of the operating balance to debt in regime j is $\gamma_b(j)/(1 - \rho_1 - \rho_2)$. Two lags of the operating balance are included because with a single lag the residuals of the fiscal rule remain autocorrelated, whereas with two lags they are white noise (Sections 5.7 and 6.2).

In both rules the intercept, the policy coefficient and the error variance switch, while the coefficients on the controls and the autoregressive terms are common across regimes. This partial switching keeps the number of parameters compatible with 50 annual observations and isolates changes in the policy response from changes in the sensitivity to oil, the cycle or past deficits; Section 6.1 compares it with full switching of all coefficients.

3-2. Regime dynamics and time-varying transition probabilities

Each regime variable follows a first-order Markov chain with transition probabilities

$$p_{ij,t} = \Pr(S_t = j \mid S_{t-1} = i) = \frac{\exp(\eta_{ij,t})}{\sum_l \exp(\eta_{il,t})}, \quad \eta_{ii,t} = 0, \quad \eta_{ij,t} = a_{ij} + z_t' c_{ij} \quad (3)$$

With z_t empty the probabilities are constant; otherwise they vary with observed covariates (Diebold, Lee & Weinbach, 1994; Filardo, 1994). With k regimes the unrestricted specification has $k(k-1)$ slope coefficients per covariate. With three fiscal regimes and only a handful of regime changes in 50 years, these slopes are not identified:

the likelihood increases without bound as they diverge, so that transition probabilities become exactly zero or one, a quasi-complete separation analogous to that of logit models. For $k \geq 3$ we therefore estimate a restricted specification in which the covariate affects only the probability of leaving the two extreme regimes, with one common slope for each:

$$\eta_{1j,t} = a_{1j} + c_1 z_t, \quad \eta_{kj,t} = a_{kj} + c_k z_t, \quad \eta_{ij,t} = a_{ij} \quad (1 < i < k) \qquad (4)$$

where regime 1 has the largest and regime k the smallest policy coefficient. The restriction tests the economically relevant hypothesis, namely whether the covariate makes the most passive and the most active regime more or less persistent, with two slopes per covariate, as in the two-regime case. It is estimated starting from the constant-probability estimate with zero slopes, so that the likelihood-ratio statistic is non-negative by construction.

For the monetary rule we consider a sanctions dummy, a sanctions-intensity index, a war dummy (1980–1988), the change in oil revenue relative to GDP and the depreciation of the free-market exchange rate. For the fiscal rule we consider the same sanctions, war and oil covariates and two measures of financial repression: the real deposit rate and the public sector's share of bank credit. We also considered the lagged filtered probability that monetary policy is active, which would link the two chains, but it is constant because no monetary regime is active (Section 5.2). Covariates are standardised. Each candidate is estimated on a common sample; the preferred specification minimises BIC among estimates with a positive-definite Hessian and no parameter on a boundary, and each candidate is tested against constant probabilities by a likelihood-ratio test with two degrees of freedom. When a slope lies on its boundary, the χ^2 approximation is unreliable, so we also compute a parametric-bootstrap p-value: data are simulated from the constant-probability model with the regressors held fixed, both models are re-estimated on each simulated sample with the same procedure, and the p-value is the share of simulated statistics at least as large as the observed one.

3-3. Estimation

The likelihood is evaluated with the filter of Hamilton (1989), and smoothed regime probabilities are obtained with the smoother of Kim (1994). Normal mixture likelihoods are unbounded when a regime variance collapses to zero around a single observation, and in small samples maximum likelihood often converges to such degenerate solutions. We therefore maximise the penalised log-likelihood of Chen, Tan and Zhang (2008),

$$\ell_p(\theta) = \ell(\theta) - a_n \sum_{j=1}^{k} \left(\frac{s^2}{\sigma_j^2} + \log\sigma_j^2 \right), \quad a_n = n^{-1/2} \tag{5}$$

where s^2 is the residual variance of the linear rule. The penalty vanishes asymptotically and leaves non-degenerate solutions essentially unchanged. Reported log-likelihoods and information criteria are unpenalised. Models with constant transition probabilities are estimated from 50 random starting values, and restricted time-varying models from 20 starting values around the constant-probability estimate. Standard errors come from the inverse Hessian, and those of transition probabilities, expected durations $1/(1-p_{ii})$ and long-run responses from the delta method. Regimes are labelled ex post by their policy coefficient, which removes label switching.

3-4. Number of regimes

The number of regimes is selected by a sequential procedure. Models with $k = 1,2,3$ regimes are estimated. A model is considered identified if its Hessian is positive definite, no parameter lies on a boundary and every regime accounts for at least four expected years ($\sum_t \Pr(S_t = j \mid \text{data}) \geq 4$). Starting from $k = 1$, the current k is tested against each larger identified k; the procedure moves to the first alternative that is significant at 5 percent and stops when none is. Because the regime-specific parameters are not identified under the null, the likelihood-ratio statistic does not have a χ^2 distribution (Hansen, 1992; Garcia, 1998); its null distribution is obtained by a parametric bootstrap from the estimated null model with 99 replications (McLachlan, 1987), holding regressors fixed (Hansen, 2000). Testing the current model against every larger identified model, not only against $k+1$, matters: if the true model has $k+2$ regimes, the $(k+1)$-regime model is misspecified and the k versus $k+1$ test may have little power. AIC, BIC and HQ are reported for comparison; in small samples their performance in Markov-switching models depends strongly on sample size and regime separation (Psaradakis & Spagnolo, 2003).

The model with $k = 4$ was not considered: with partial switching it has 27 (monetary) and 29 (fiscal) parameters for 50 observations, and the three-regime monetary model already fails the identification criterion.

3-5. Regime classification and the policy mix

Each regime is labelled with a one-sided test at the 5 percent level: fiscal regimes are passive if γ_b is significantly positive, and monetary regimes are active if ϕ is significantly negative. Regimes that fail the test receive the other label, so a coefficient indistinguishable from zero is classified as active (fiscal) or passive (monetary). The

smoothed probability of each label is the sum of the probabilities of the regimes that carry it. Treating the two chains as conditionally independent, the probability of each policy mix in year t is the product of the corresponding label probabilities, and each year is assigned to the most likely mix.

3-6. Diagnostics

Residual diagnostics use probability-integral-transform residuals, $u_t = \Phi^{-1}\big(\sum_j \Pr(S_t = j \mid \mathcal{F}_{t-1})\, F_j(y_t)\big)$, which are i.i.d. standard normal under correct specification. We report Jarque-Bera, Ljung-Box, McLeod-Li and ARCH-LM tests. Regime separation is measured by the regime classification measure (RCM) of Ang and Bekaert (2002), which equals zero under perfect classification and 100 under none.

4. Data

4-1. Sources and construction

All series are annual and taken from the Economic Time Series Database of the Central Bank of Iran, except where noted. The sample is 1975–2024 (1354–1403 SH), the longest period over which all variables are jointly available; it is bounded by the monetary base, which starts in 1973. Gregorian years refer to the Iranian year that begins in March of that year.

Nominal and real GDP at basic prices are available for four base years (1383, 1390, 1395 and 1400). Each older vintage is rescaled to the newest one at their first common year, which preserves the growth rates of the older vintage. Government finance data are reported under GFS1986 until 1391 and GFS2001 from 1380; the two coincide exactly in the overlap for tax revenue, oil revenue, current payments and development payments. The operating balance is reported directly from 1380; for earlier years it is computed as revenues minus oil revenue minus current payments, which differs from the reported series by about one percent in the overlap. From 1400 the reported operating balance also nets other payments and statutory obligations. Inflation is the annual change in the consumer price index. The output gap is the deviation of log real GDP from its Hodrick-Prescott trend (Hodrick & Prescott, 1997; $\lambda = 100$), computed over 1959–2024 to reduce end-point effects.

Interest-rate, credit and exchange-rate data come from the same database. The deposit rate is the ceiling on the provisional profit rate of one-year investment deposits set by the Central Bank; the lending rate is the average of the expected profit rates on bank facilities in five sectors (trade, industry and mining, agriculture, housing and construction, and

exports). Where the Central Bank reports a range of rates, for example for different types of banks, we use its midpoint; where it reports a one-sided ceiling, we use the ceiling. The public sector's share of bank credit is the ratio of the banking system's claims on the public sector to its claims on the public and non-public sectors. Government debt to the central bank excludes public enterprises; a broader measure that includes them is used as a robustness check. The free-market exchange rate (rials per U.S. dollar) is spliced from the two series that the Central Bank reports under its earlier and its current classification of foreign-exchange markets, which coincide exactly in their overlap; its annual percentage change measures depreciation.

All fiscal variables are expressed as percentages of nominal GDP. Section 6.3 shows that this transformation removes the heteroscedasticity present in the data.

4-2. Sanctions

Sanctions are coded from the legal record compiled by the U.S. Office of Foreign Assets Control (Executive Orders and UN Security Council resolutions), supplemented by the EU oil embargo of 2012, the Joint Comprehensive Plan of Action (UN Security Council Resolution 2231) and the 2018 U.S. withdrawal (Executive Order 13846). A measure is assigned to a year if it was in force for at least half of that Iranian year. Table 1 reports the resulting intensity index. The sanctions dummy equals one in years of intensity 4 (2012–2015 and 2018–2024).

Table 1: Sanctions intensity index

Years	Intensity	Measures
1980	2	Asset freeze and trade embargo (EO 12170, 12205, 12211); lifted January 1981
1988–1994	1	U.S. import ban (EO 12613)
1995–2006	2	U.S. trade and investment embargo (EO 12957, 12959, 13059); Iran Sanctions Act (1996)
2007–2011	3	Plus UN Security Council Resolutions 1737, 1747, 1803 and 1929; CISADA (2010)
2012–2015	4	Plus EU oil embargo and SWIFT disconnection; sanctions on the central bank (EO 13599, NDAA §1245); IFCA
2016–2017	2	JCPOA: UN, EU and U.S. secondary sanctions lifted; U.S. primary embargo remains
2018–2024	4	Re-imposition and "maximum pressure" (EO 13846, 13871, 13876, 13902)

Other years: 0. Source: authors' coding from OFAC, EU Council Decision 2012/35/CFSP and UNSC Resolution 2231.

4-3. Descriptive statistics and time-series properties

Table 2 reports descriptive statistics for the variables used in the analysis.

Table 2: Descriptive statistics, 1975–2024 (N = 50)

Variable	Mean	SD	Min	Max
Operating balance (% of GDP)	−6.93	3.99	−18.46	−2.77
Government debt to the central bank (% of GDP)	12.52	12.58	1.31	43.79
Oil revenue (% of GDP)	8.44	5.90	0.91	30.76
Tax revenue (% of GDP)	5.23	1.04	3.13	7.45
Monetary-base growth (%)	24.36	11.85	3.89	63.80
CPI inflation (%)	22.07	12.03	6.90	53.10
Output gap, HP (%)	0.00	8.09	−26.54	22.51
Nominal deposit rate (%)	12.94	3.90	8.00	23.00
Real deposit rate (%)	−6.77	7.93	−23.69	6.40
Public sector's share of bank credit (%)	37.74	16.89	14.54	63.92
Free-market exchange-rate depreciation (%)	22.87	29.46	−5.83	167.87

Source: authors' calculations.

Table 3 reports unit-root tests. Monetary-base growth, inflation, the output gap, the change in oil revenue, the real deposit rate and exchange-rate depreciation are stationary. The operating balance and the debt ratio appear non-stationary according to ADF, KPSS and Zivot-Andrews (1992) tests, and so does the public sector's share of bank credit. The evidence for oil revenue relative to GDP is mixed: the ADF test rejects a unit root, but the KPSS test rejects stationarity. Unit-root tests have low power when the series switch between regimes (Nelson, Piger & Zivot, 2001), so we test directly whether the fiscal rule is a valid levels relation.

Table 3: Unit-root tests, 1975–2024

Variable	ADF	p	KPSS	p	Zivot-Andrews	Break
Operating balance / GDP	−2.14	0.52	0.87	0.01	−4.63	1981
Debt to central bank / GDP	−3.12	0.13	0.75	0.01	−4.32	1988
Oil revenue / GDP	−3.85	0.02	0.75	0.01	−4.32	1988
Change in oil revenue / GDP	−4.57	<0.01	0.37	0.09	−6.31*	1995
Monetary-base growth	−3.80	0.03	0.11	0.10	−4.79	1978
CPI inflation	−3.77	0.03	0.37	0.09	−5.19*	2013
Output gap (HP)	−6.28	<0.01	0.05	0.10	−6.89*	1981
Real deposit rate	−3.84	0.02	0.12	0.10	−5.47*	2013
Public share of bank credit	−2.44	0.40	0.97	0.01	−3.70	2002
Exchange-rate depreciation	−3.98	0.02	0.22	0.10	−6.50*	2017

*ADF with constant and trend (Said & Dickey, 1984); KPSS null of level stationarity (Kwiatkowski et al., 1992), p-values truncated at 0.01 and 0.10; Zivot-Andrews with a break in intercept and trend, 5% critical value −5.08, * rejection of the unit root.*

Phillips-Ouliaris (1990) tests do not reject the null of no cointegration between the operating balance and lagged debt over the full sample ($p \geq 0.15$), but they are biased against cointegration when the relation shifts. The Gregory-Hansen (1996) tests allowing for a shift in the intercept, and for a shift in both intercept and slope, reject the null at the 5 percent level, with breaks in 1983 and 1992 (Table 4). When oil revenue is added to the cointegrating regression, the Gregory-Hansen statistics fall short of the larger critical values for two regressors, whereas over 1989–2024 the Phillips-Ouliaris test rejects no cointegration for this relation ($p = 0.04$). We therefore treat the operating balance and debt as cointegrated subject to regime shifts, which is precisely the feature that the Markov-switching rule models, and oil revenue as a control. A further check supports the levels specification: a spurious regression would leave strongly autocorrelated residuals (Granger & Newbold, 1974), whereas the residuals of the estimated fiscal rule are white noise (Section 5.7).

Table 4: Cointegration with a regime shift (Gregory-Hansen), operating balance on lagged debt

Regressors	Model	ADF*	Break	5% CV	Reject
Lagged debt	Level shift (C)	−4.92	1983	−4.61	Yes
Lagged debt	Regime shift (C/S)	−5.33	1992	−4.95	Yes
Lagged debt, oil revenue	Level shift (C)	−4.42	1983	−4.92	No
Lagged debt, oil revenue	Regime shift (C/S)	−4.58	1987	−5.50	No

Sample 1975–2024. Critical values from Gregory and Hansen (1996, Table 1), Phillips-Ouliaris tests over 1989–2024: $p = 0.07$ for the relation with lagged debt only and $p = 0.04$ with oil revenue added.

4-4. Administered interest rates and financial repression

We measure financial repression with two indicators. The first is the real one-year deposit rate, computed from the ceiling on the deposit rate and CPI inflation, $r_t = 100\,[(1 + i_t/100)/(1 + \pi_t/100) - 1]$. The second is the public sector's share of banking-system credit.

Table 5 summarises the evidence. The nominal deposit rate responds to inflation with a coefficient of only 0.14, so an interest-rate rule would have a Taylor coefficient far below one. As a result, the real deposit rate falls by 0.60 points for each point of inflation, corresponding to $f_M \approx -0.6$ in the notation of Alexeeva *et al.* (2022). The real deposit rate was negative in 38 of the 50 years, averaging −6.8 percent, and the public sector absorbed on average 38 percent of banking-system credit, between 50 and 64 percent in the 1980s and between 15 and 23 percent since 2005. Both indicators are used in Sections 5 and 6 as drivers of fiscal regime switching and as controls in the fiscal rule.

Table 5: Response of administered interest rates to inflation, 1975–2024

Dependent variable	Coefficient on inflation	Newey-West SE	t (H0: 1)
Nominal deposit rate	0.135	0.049	−17.8
Real deposit rate	−0.604	0.047	—
Nominal lending rate	0.122	0.049	−17.8
Real lending rate	−0.623	0.050	—

Newey-West (1987) standard errors with two lags. Real deposit rate negative in 38 of 50 years (mean −6.77 percent). Source: authors' calculations from Central Bank of Iran data.

5. Results

5-1. Number of regimes

Table 6 reports the selection of the number of regimes. For the monetary rule, the bootstrap rejects the linear rule against two regimes (LR = 29.85, p < 0.01), and the three-regime model is not identified because one regime accounts for only 3.8 expected years; AIC, BIC and HQ also select two regimes. For the fiscal rule, two regimes do not improve significantly on the linear rule (LR = 16.15, p = 0.23), but three regimes do (LR = 43.88, p < 0.01). The three-regime model is identified, its smallest regime spans 9.7 expected years, and AIC and HQ also select it. BIC, which penalises the twelve additional parameters heavily in a sample of 50, prefers the linear rule, but its values for one, two and three regimes lie within 3.4 points of each other. The fiscal case illustrates why the test sequence matters: the two-regime model is misspecified when the data contain three regimes, so a procedure that only tested k against $k + 1$ would have stopped at the linear rule. We therefore use two monetary and three fiscal regimes. The three fiscal regimes agree with the number found by Erfani and Talebbeydokhti (2025b); for monetary policy, the third regime found by Erfani and Talebbeydokhti (2025a), which covers three isolated years, is not supported by our identification criterion.

Table 6: Selection of the number of regimes

Rule	k	Parameters	Log-lik.	AIC	BIC	HQ	Min. regime (years)	Identified
Monetary	1	6	−186.33	384.7	396.1	389.0	50.0	Yes
Monetary	2	11	−171.40	**364.8**	**385.8**	**372.8**	14.6	Yes
Monetary	3	18	−165.40	366.8	401.2	379.9	3.8	No
Fiscal	1	8	−74.40	164.8	**180.1**	170.6	50.0	Yes
Fiscal	2	13	−66.33	158.7	183.5	168.1	16.3	Yes
Fiscal	3	20	−52.46	**144.9**	183.2	**159.5**	9.7	Yes

Bootstrap LR test	LR	p (B = 99)	Decision
Monetary: 1 vs 2	29.85	0.000	Reject; k = 2
Fiscal: 1 vs 2	16.15	0.232	Do not reject

Rule	k	Parameters	Log-lik.	AIC	BIC	HQ	Min. regime (years)	Identified
Fiscal: 1 vs 3			43.88		0.000		Reject; k = 3	

Bold: minimum of each criterion within each rule. Source: authors' estimations.

5.2. Monetary policy regimes

None of the time-varying specifications improves significantly on constant transition probabilities (Section 5.4), so the results below use constant probabilities.

Table 7: Monetary-policy rule, two regimes

Parameter	Regime 1	Regime 2
Intercept	41.74 (4.13)	22.29 (1.92)
Inflation gap, ϕ	−0.095 (0.277)	0.637 (0.086)
σ	9.69 (1.95)	4.58 (0.58)
Probability of staying, p_{ii}	0.823 (0.103)	0.918 (0.047)
Expected duration (years)	5.7	12.3
Classification (sign criterion)	Passive	Passive
Common: output gap	−0.038 (0.135)	
Common: lagged base-money growth	−0.154 (0.086)	
Common: COVID-19	−3.20 (3.95)	
Log-likelihood / BIC / RCM	−171.40 / 385.8 / 7.2	

Standard errors in parentheses. Wald test of equal ϕ across regimes: $\chi^2 = 5.84$, $p = 0.016$. Source: authors' estimations.

Both monetary regimes are passive (Table 7 and Fig. 1). In regime 1, which prevails in 1975–1982, 1995–1996 and 2005–2008, base-money growth is high (an intercept of about 42 percent) and does not respond to inflation. These are periods of oil booms or of their immediate aftermath: in regime-1 years base-money growth averaged 36.8 percent and oil revenue 14.1 percent of GDP, against 19.5 and 6.2 percent in regime-2 years, consistent with the conversion of oil revenue into base money when the central bank purchases the government's foreign-exchange receipts. In regime 2, which prevails in 1983–1994, 1997–2004 and 2009–2024, base-money growth accommodates inflation with a coefficient of 0.64. This regime is persistent, with an expected duration of 12 years, and is the long-run (ergodic) regime with probability 0.69.

The results match those of Erfani and Talebbeydokhti (2025a), whose "highly passive" regime has a coefficient of 0.64 and covers 1983–1992, 1997–2004 and 2009–2015, and whose "relatively passive" regime includes 1979–1982, 1994–1996 and 2006–2008. Table 8 shows that the classification depends on the convention, which explains the apparently contradictory findings in the literature: under the sign criterion both regimes

are passive; under the money-demand mapping ($\phi < 1$) both would be classified as active; and under the Taylor convention ($\phi > 1$) both are passive. With administered interest rates, however, the money-demand mapping does not translate base-money growth into a market interest rate, and the real interest rate falls with inflation (Section 4.4), so we adopt the sign criterion.

Table 8: Monetary classification under alternative conventions

Convention	Regime 1 ($\phi = -0.095$)	Regime 2 ($\phi = 0.637$)
Sign: active if $\phi < 0$ (baseline)	Passive (p = 0.37)	Passive (p = 1.00)
Money demand: active if $\phi < 1$	Active (p < 0.001)	Active (p < 0.001)
Taylor convention: active if $\phi > 1$	Passive (p = 1.00)	Passive (p = 1.00)

One-sided p-values for the hypothesis that defines the active label. Source: authors' estimations.

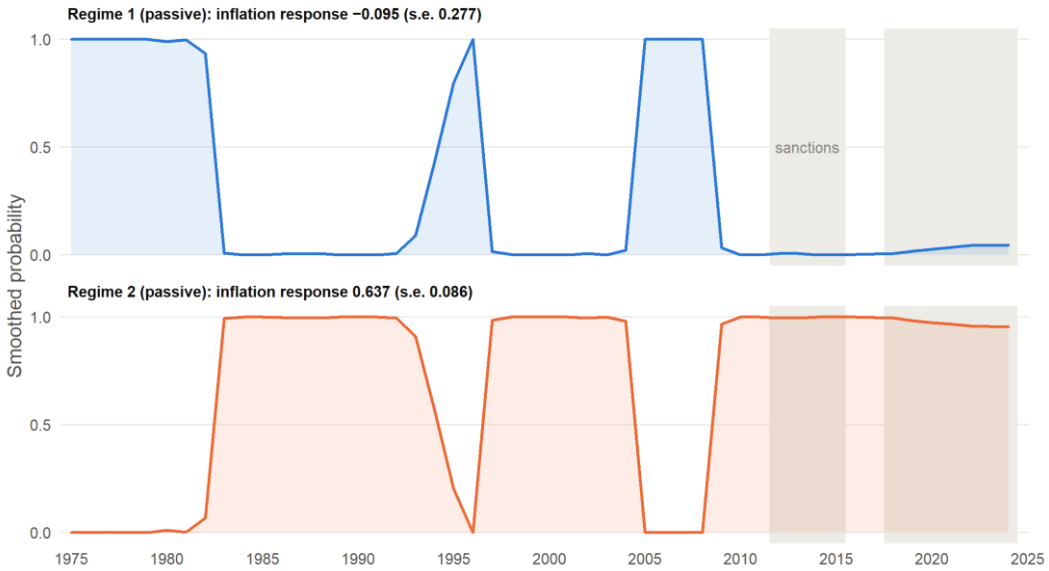

Fig. 1: Smoothed probabilities of the monetary-policy regimes, 1975–2024.

Shaded: sanctions intensity 4. Source: authors' estimations.

5-3. Fiscal policy regimes

Table 9: Fiscal-policy rule, three regimes

Parameter	Regime 1	Regime 2	Regime 3
Intercept	−3.318 (0.236)	−0.454 (0.272)	−0.665 (0.153)
Lagged debt, γ_b	0.109 (0.008)	0.038 (0.019)	−0.031 (0.006)
Long-run debt response, $\gamma_b/(1-\rho_1-\rho_2)$	0.242 (0.028)	0.084 (0.045)	−0.070 (0.015)
σ	0.330 (0.084)	0.865 (0.125)	0.268 (0.053)
Probability of staying, p_{ii}	0.753 (0.142)	0.905 (0.055)	0.822 (0.106)
Expected duration (years)	4.0	10.6	5.6
Classification (one-sided p for $\gamma_b > 0$)	Passive (< 0.001)	Passive (0.027)	Active (1.000)

Parameter	Regime 1	Regime 2	Regime 3
Common: output gap	0.119 (0.014)		
Common: oil revenue / GDP	−0.281 (0.035)		
Common: OB_{t-1}	0.312 (0.058)		
Common: OB_{t-2}	0.239 (0.029)		
Common: COVID-19	−0.309 (0.226)		
Log-likelihood / BIC / RCM	−52.46 / 183.2 / 0.0005		

Standard errors in parentheses. Wald tests of equal γ_b: regimes 1 and 2, $\chi^2 = 11.12$; regimes 2 and 3, $\chi^2 = 12.06$; regimes 1 and 3, $\chi^2 = 199.10$; all $p < 0.001$. Long-run effects of oil revenue and the output gap: −0.625 (0.030) and 0.265 (0.023). Source: authors' estimations.

The three fiscal regimes differ significantly in their response to debt (Table 9 and Fig. 2). Regime 1 is strongly passive: a one-point increase in the debt ratio raises the operating balance by 0.11 points of GDP in the same year and by 0.24 points in the long run. It prevails in 1978–1980, 1989–1994 and 2024. The 1989–1994 episode coincides with post-war reconstruction under the First Development Plan, when the operating deficit fell from 8.5 to 3.6 percent of GDP between 1988 and 1991 and debt to the central bank fell from 44 percent of GDP in 1988 to 18 percent in 1992. The 2024 observation lies at the end of the sample and reflects a sharp increase in the operating deficit (from 3.9 to 6.1 percent of GDP) that is matched by the regime's low intercept rather than by a debt response, so it should not be read as a return to fiscal discipline. Regime 2 is weakly passive: the debt response is 0.04 (0.08 in the long run) and significant only at the 5 percent level in a one-sided test. It is the most volatile regime and prevails in 1981–1985 and 1995–2014. Regime 3 is active: higher debt is associated with a larger operating deficit (−0.03, or −0.07 in the long run), so the fiscal authority finances deficits by borrowing from the central bank rather than stabilising debt. It prevails in 1975–1977, 1986–1988 and 2015–2023.

The active episodes are not explained by oil alone. Two of them coincide with oil-revenue collapses, the 1986 oil-price collapse during the war and the decline of oil revenue after 2014 that deepened with the 2018 sanctions, but the first (1975–1977) occurred at the peak of the oil boom, when oil revenue exceeded 20 percent of GDP and current spending expanded rapidly. What the three episodes share, on average, is high inflation and deep financial repression: in regime-3 years inflation averaged 28.6 percent and the real deposit rate −10.5 percent, against 21.0 and −8.2 percent in regime 1 and 18.6 and −4.0 percent in regime 2. Section 5.4 tests whether this link extends to the transition probabilities. Oil revenue also enters the rule directly: a one-point increase in oil revenue relative to GDP lowers the operating balance by 0.28 points on impact and by

0.62 points in the long run, consistent with the pro-cyclical expansion of current spending during oil booms. The output gap has the expected positive sign, reflecting automatic stabilisers.

The estimated transition matrix has a distinctive structure. The only transitions with non-negligible probability are from regime 1 to regime 2 ($p_{12} = 0.25$), from regime 2 to regime 3 ($p_{23} = 0.09$) and from regime 3 back to regime 1 ($p_{31} = 0.18$); all other transitions have probabilities below 0.001 and were never observed. The chronology follows this cycle two and a half times: active (1975–1977), passive (1978–1980), weakly passive (1981–1985), active (1986–1988), passive (1989–1994), weakly passive (1995–2014), active (2015–2023) and passive (2024). Fiscal consolidation follows active episodes, discipline then erodes gradually, and the economy tends to slide into the active regime when inflation and financial repression deepen.

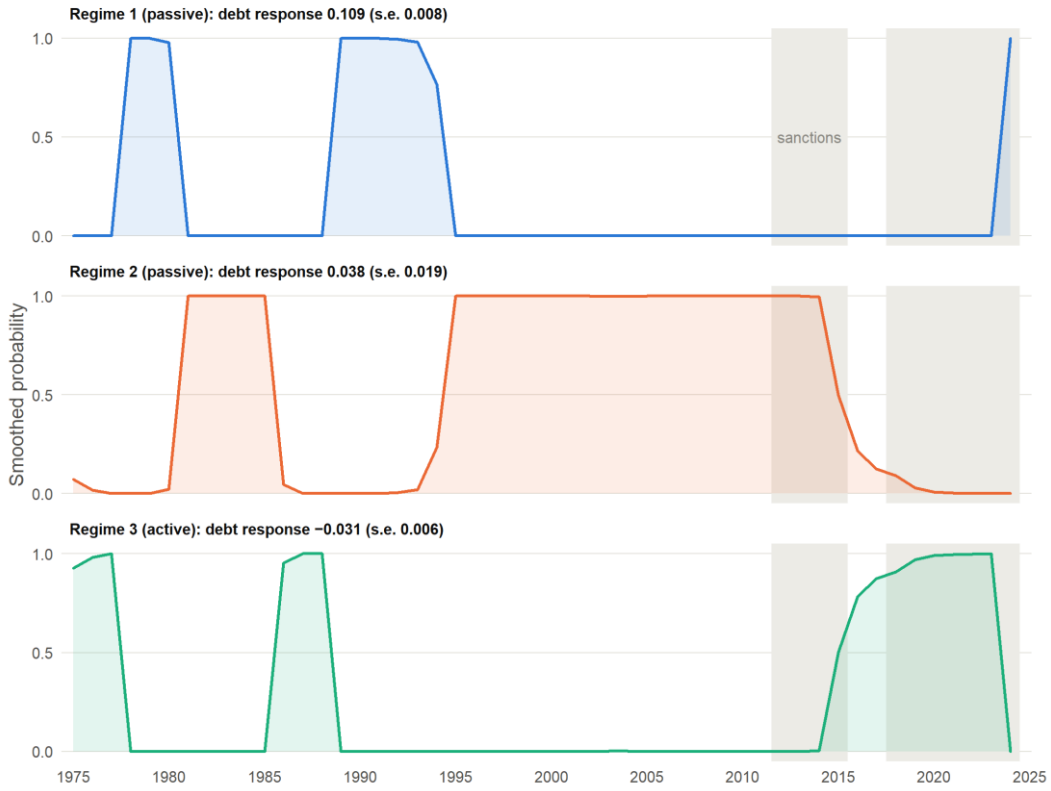

Fig. 2: Smoothed probabilities of the fiscal-policy regimes, 1975–2024.

Shaded: sanctions intensity 4. Source: authors' estimations.

5-4. What drives regime changes? Sanctions, oil, the exchange rate and financial repression

Table 10 reports the tests of time-varying transition probabilities. For the monetary rule, none of the covariates improves significantly on constant probabilities: the smallest p-value is 0.16, for the war dummy, and the depreciation of the free-market exchange rate gives p = 0.65. For the fiscal rule, the sanctions dummy (p = 0.96), the sanctions-intensity index (p = 0.90), the war dummy (p = 0.44), oil shocks (p = 0.91) and the public sector's share of bank credit (p = 0.56) are not significant either.

The real deposit rate gives the largest improvement in fit. It raises the log-likelihood of the fiscal rule by 4.70 (LR = 9.39, p = 0.009 under $\chi^2(2)$) and attains the lowest BIC of all fiscal specifications (181.6 against 183.2 with constant probabilities). Its slope on exits from the active regime, however, lies on the boundary of the parameter space: in every year in which the economy was in the active regime and the real deposit rate was below about −12 percent, the active regime continued, and every exit from it occurred when the rate was higher. This quasi-separation makes the χ^2 approximation unreliable, so we computed a parametric-bootstrap p-value with 99 replications. It is 0.15: when the data are generated by the constant-probability model, a likelihood-ratio statistic as large as 9.39 arises in 15 percent of samples, because with three regimes and 50 observations the active regime is observed in only 15 years and a covariate that happens to separate its few exits can produce a large statistic by chance. The real deposit rate therefore does not significantly affect the fiscal transition probabilities, and the estimates below describe the association in the sample rather than an established effect. In the estimated specification, the probability of remaining in the active regime equals one half when the real deposit rate is −11.7 percent and approaches one below −15 percent (Fig. 3). The slope on exits from the passive regime is negative but imprecise (−1.40 per standard deviation of the real deposit rate, SE 1.18): deep repression also tends to shorten the passive regime, as in 1994–1995, when the real deposit rate reached −24 percent and the passive regime of the reconstruction years ended. The regimes estimated with the real deposit rate coincide with the baseline regimes in 44 of the 50 years. The differences are that 1975 and 2015–2018 move from the active to the weakly passive regime, so that the most recent active episode starts in 2019 rather than 2015 (the real deposit rate was positive in 2015–2017), and that 1994 moves from the passive to the weakly passive regime.

Table 10: Tests of time-varying transition probabilities

Rule	Covariate	Log-lik.	BIC	LR vs constant	df	p	Reliable
Monetary	Constant probabilities	−171.40	**385.8**	—	—	—	Yes
Monetary	Sanctions dummy	−170.45	391.8	1.91	2	0.39	No
Monetary	Sanctions intensity	−169.77	390.4	3.26	2	0.20	Yes
Monetary	War	−169.59	390.0	3.63	2	0.16	Yes
Monetary	Δ oil revenue / GDP	−171.32	393.5	0.17	2	0.92	Yes
Monetary	Exchange-rate depreciation	−170.97	392.8	0.87	2	0.65	Yes
Fiscal	Constant probabilities	−52.46	183.2	—	—	—	Yes
Fiscal	Sanctions dummy	−52.42	190.9	0.08	2	0.96	No
Fiscal	Sanctions intensity	−52.36	190.8	0.21	2	0.90	Yes
Fiscal	War	−51.63	189.3	1.66	2	0.44	Yes
Fiscal	Δ oil revenue / GDP	−52.36	190.8	0.20	2	0.91	Yes
Fiscal	Real deposit rate	−47.77	**181.6**	9.39	2	0.009 (0.15)	No
Fiscal	Public share of bank credit	−51.87	189.8	1.18	2	0.56	Yes

Monetary: two regimes, one slope per origin regime. Fiscal: three regimes, restricted specification (4) with one slope for the exits from regime 1 and one for the exits from regime 3. p: $\chi^2(2)$; in parentheses, parametric-bootstrap p-value (99 replications). "Reliable": positive-definite Hessian and no parameter on a boundary. Bold: minimum BIC within each rule. The lagged probability of active monetary policy is constant because no monetary regime is active and is therefore excluded. Source: authors' estimations.

Two further qualifications apply. First, because the estimate lies on a boundary and is not significant under the bootstrap, we keep constant transition probabilities in the baseline (our selection rule also requires an interior estimate) and treat the financial-repression specification as descriptive evidence on the drivers of fiscal regime changes. Second, the association is contemporaneous. When the real deposit rate is lagged one year, the estimate is interior but the improvement in fit is smaller (LR = 6.04, p = 0.049 under $\chi^2(2)$), BIC rises to 185.0, above the 183.2 of constant probabilities, and neither slope is individually significant (−3.55, SE 2.34, for exits from the passive regime and −1.25, SE 1.05, for exits from the active regime); the latter even has the opposite sign to the contemporaneous estimate, so the lagged real deposit rate does not predict when the active regime ends. The evidence is therefore consistent with active fiscal policy and deep financial repression occurring together, as parts of a financing strategy that relies on the inflation tax, but it does not show that repression drives or predicts the change of regime.

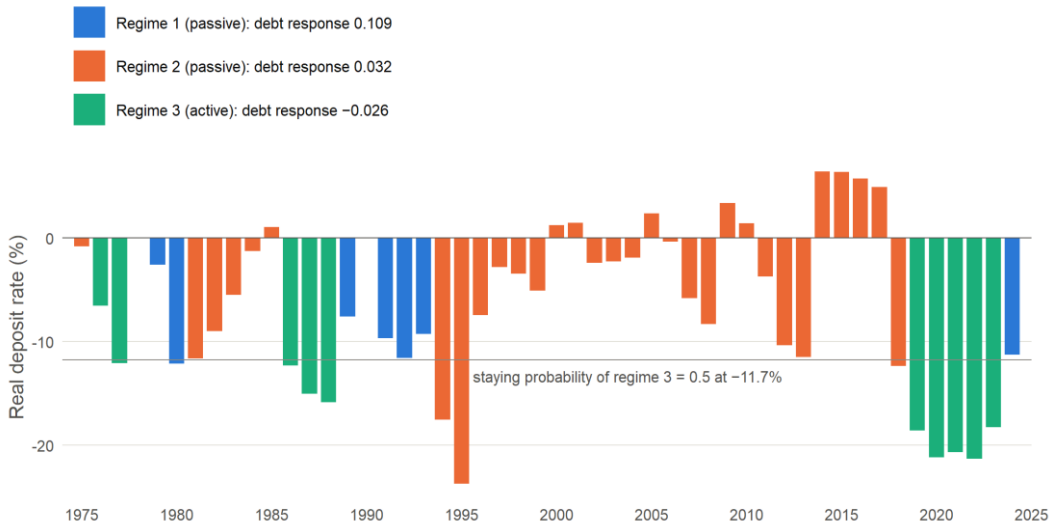

Fig. 3: Real deposit rate and the most likely fiscal regime in the specification with time-varying transition probabilities driven by the real deposit rate, 1975–2024.

The horizontal line marks the real deposit rate at which the probability of remaining in the active regime (regime 3) equals one half. Source: authors' estimations.

5-5. Regime chronology

Table 11 relates the estimated regimes to economic and political events. Sanctions do not affect the transition probabilities significantly (Table 10), but the timing of the regimes is informative. The active fiscal regime coincides with the end of the 1970s oil boom, with the oil-price collapse during the war and with the period of re-imposed sanctions and record inflation after 2018; the long weakly passive regime (1995–2014) spans the debt and exchange-rate crisis of the mid-1990s, the establishment of the Oil Stabilization Fund and the 2003–2008 oil boom; and the non-responsive, high-growth monetary regime coincides with oil booms (the late 1970s and 2005–2008) and with the aftermath of the 1994 exchange-rate crisis. The chronology is therefore consistent with oil and sanctions shocks shaping the timing of regime changes mainly through inflation and financial repression, but the sample of 50 annual observations is too short to estimate the effect of these shocks, or of financial repression, on the transition probabilities precisely.

Table 11: Regime chronology and events

Period	Monetary regime	Fiscal regime	Policy mix	Main events
1975–1977	Non-responsive	Active	PM/AF	Peak and end of the oil boom; inflation rises to 25 percent
1978–1980	Non-responsive	Passive	PM/PF	Revolution (1979); asset freeze (1980); war begins (1980)
1981–1982	Non-responsive	Weakly passive	PM/PF	War; war financing
1983–1985	Accommodative	Weakly passive	PM/PF	War; rationing and multiple

Period	Monetary regime	Fiscal regime	Policy mix	Main events
				exchange rates
1986–1988	Accommodative	Active	PM/AF	Oil-price collapse (1986); last years of the war; U.S. import ban (1987)
1989–1994	Accommodative	Passive	PM/PF	Post-war reconstruction; First Development Plan; external-debt and exchange-rate crisis (1993–1994)
1995–1996	Non-responsive	Weakly passive	PM/PF	Inflation peak (49 percent in 1995); U.S. embargo (1995); ILSA (1996)
1997–2004	Accommodative	Weakly passive	PM/PF	Oil Stabilization Fund (2000); exchange-rate unification (2002)
2005–2008	Non-responsive	Weakly passive	PM/PF	Oil boom; expansionary credit policy; UN sanctions (2007)
2009–2014	Accommodative	Weakly passive	PM/PF	Subsidy reform (2010); oil and banking sanctions (2012); currency crisis (2012–2013)
2015–2023	Accommodative	Active	PM/AF	Oil-price collapse; JCPOA (2016–2017); re-imposed sanctions (2018); COVID-19; inflation above 40 percent (2019–2023)
2024	Accommodative	Passive	PM/PF	End of sample

Regime with the highest smoothed probability. Monetary: non-responsive = regime 1, accommodative = regime 2. Fiscal: passive = regime 1, weakly passive = regime 2, active = regime 3. Source: authors' estimations.

5-6. Policy mix and dominance

Because no monetary regime is active, the policy mix alternates only between indeterminacy (PM/PF) and fiscal dominance (PM/AF) (Table 12 and Fig. 4). Indeterminacy prevails in 35 of the 50 years: 1978–1985, 1989–2014 and 2024, the years in which fiscal policy responded to debt. Fiscal dominance prevails in the 15 years of the active fiscal regime: 1975–1977, 1986–1988 and 2015–2023. Monetary dominance (AM/PF) and the unstable combination (AM/AF) are never observed. The policy mix changes only five times in 50 years.

The two configurations differ markedly. Under fiscal dominance inflation averaged 28.6 percent, the real deposit rate −10.5 percent and the depreciation of the free-market exchange rate 29.2 percent a year; under indeterminacy the corresponding Fig. s were 19.3, −5.2 and 20.2 percent. Inflation was high under both, as expected when no authority anchors the price level, but it was highest when the fiscal authority was active and the price level had to adjust to fiscal needs.

Table 12: Policy mix, 1975–2024

Policy mix	Equilibrium	Years	Count	Mean inflation (%)	Mean real deposit rate (%)
PM/AF	Fiscal dominance (unique)	1975–1977, 1986–1988, 2015–2023	15	28.6	−10.5
PM/PF	Indeterminacy	1978–1985, 1989–2014, 2024	35	19.3	−5.2
AM/PF	Monetary dominance (unique)	—	0	—	—
AM/AF	No stable equilibrium	—	0	—	—

Source: authors' estimations.

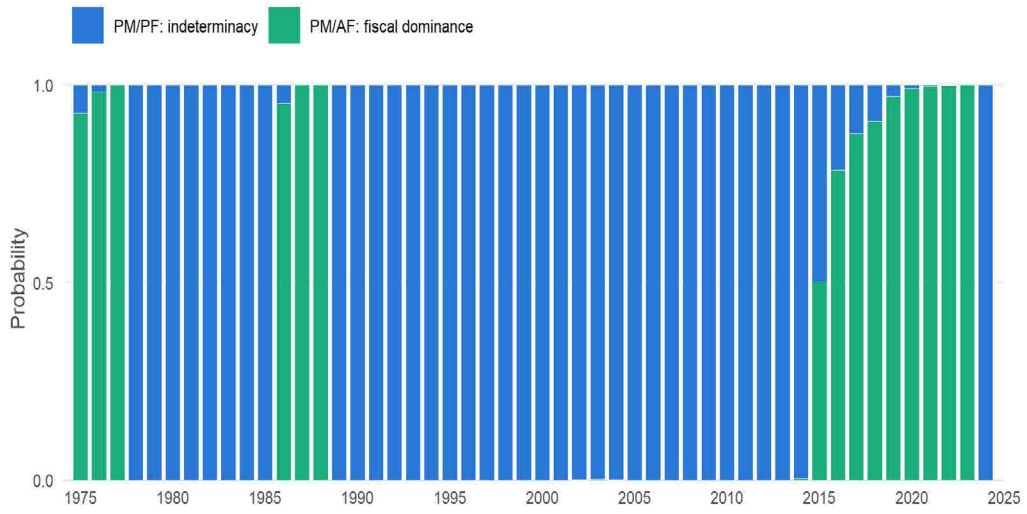

Fig. 4: Probability of each monetary-fiscal policy mix, 1975–2024.

The probabilities of monetary dominance (AM/PF) and of the unstable combination (AM/AF) are zero in every year. Source: authors' estimations.

Fig. 4 shows that the policy mix is driven entirely by the fiscal chain: because both monetary regimes are passive, the probabilities of monetary dominance (AM/PF) and of the unstable combination (AM/AF) are zero in every year, and the probability mass alternates between indeterminacy (PM/PF) and fiscal dominance (PM/AF). The probabilities are close to zero or one in almost all years, consistent with the sharp separation of the fiscal regimes (RCM = 0.0005, Section 5.7), so the classification of each year is clear-cut rather than sensitive to a probability threshold.

5-7. Diagnostics

The probability-integral-transform residuals of both rules pass all diagnostic tests. For the monetary rule, the Jarque-Bera, Ljung-Box Q(2), McLeod-Li and ARCH-LM tests give p = 0.81, 0.58, 0.50 and 0.49; for the fiscal rule, p = 0.60, 0.32, 0.69 and 0.62. With a single lag of the operating balance, the Ljung-Box test rejected the absence of residual autocorrelation in the fiscal rule (p = 0.02), which motivated the second lag. The regime classification measures (7.2 for the monetary and 0.0005 for the fiscal rule) indicate sharp separation of the regimes.

6. Robustness and Out-of-Sample Evaluation

6-1. Switching structure and the standard MSIAH benchmark

Table 13 compares the baseline partial-switching rules with linear rules, with rules in which all coefficients switch and with the standard two-regime MSIAH model estimated with the MSwM package. Full switching raises the likelihood but not enough to justify the additional parameters: BIC rises from 385.8 to 391.2 for the monetary rule and from 183.2 to 207.1 for the fiscal rule.

The MSIAH benchmark illustrates the risk of overfitting. Its monetary model contains a regime in which base-money growth contracts strongly with inflation ($\phi = -1.40$), but that regime lasts 1.2 years on average and has an autoregressive coefficient of 1.34, that is, explosive dynamics within the regime. Its fiscal model attains a lower BIC than the baseline (176.4, on 49 observations) only through a regime with a residual standard deviation of 0.15, an expected duration of 2.0 years and autoregressive coefficients that sum to 1.15. Combined, the two benchmark models imply 27 switches of the policy mix in 49 years and all four combinations, including six years of monetary dominance and two of the unstable combination, against five switches and two combinations in the baseline.

Table 13: Switching structure and the standard MSIAH benchmark

Rule	Specification	Parameters	n	Log-lik.	BIC	Remarks
Monetary	Linear	6	50	−186.33	396.1	
Monetary	Partial switching, k = 2 (baseline)	11	50	−171.40	385.8	RCM 7.2
Monetary	Full switching, k = 2	14	50	−168.20	391.2	RCM 12.2
Monetary	MSIAH(2)-AR(1), MSwM	13	50	−168.47	387.8	Regime 2: $\phi = -1.40$, duration 1.2 years, AR coefficient 1.34
Fiscal	Linear	8	50	−74.40	180.1	

Rule	Specification	Parameters	n	Log-lik.	BIC	Remarks
Fiscal	Partial switching, k = 3 (baseline)	20	50	−52.46	183.2	RCM 0.0005
Fiscal	Full switching, k = 3	30	50	−44.89	207.1	RCM 0.20
Fiscal	MSIAH(2)-AR(2), MSwM	17	49	−55.13	176.4	Regime 2: σ = 0.15, duration 2.0 years, AR coefficients sum to 1.15

Source: authors' estimations.

6-2. Alternative specifications

Table 14 reports 21 alternative specifications: nine for the monetary rule and twelve for the fiscal rule. For each, it reports the policy coefficient in each regime, the regime labels and the share of years in which the most likely label coincides with the baseline.

The monetary results are robust. Both regimes are passive in seven of the nine variants, including the alternative output-gap filters (HP with λ = 6.25 and Hamilton, 2018), the lagged inflation gap, the sub-samples ending in 2018 and starting in 1989, the exclusion of the COVID-19 control and the inclusion of sanctions as a control; the accommodative coefficient ranges from 0.56 to 0.70 in six of these variants and rises to 2.09 with the lagged inflation gap. Two variants, GDP-deflator inflation and the HP-trend inflation target of Erfani and Talebbeydokhti (2025a), produce a short "active" regime that covers about three years, as in that study; in both cases the estimate has a parameter on the boundary of the parameter space, so the active regime is not reliably identified, and the classification of the other 47 years is unchanged (agreement 0.94).

For the fiscal rule, the most responsive regime is passive and the least responsive regime is active in all twelve variants, including a two-regime specification, the post-war sample, controls for sanctions and financial repression, a broader debt measure that includes public enterprises, and a rule for tax revenue. The intermediate regime is the fragile one: its debt response is small in every variant (between −0.02 and 0.09) and is significantly positive in six of the eleven three-regime variants. When the weak debt response of regime 2 is not significant, the years 1981–1985 and 1995–2014 are classified as active, and the agreement with the baseline falls to between 0.24 and 0.54. Among the three-regime variants, the second lag of the operating balance is decisive for this regime: without it the debt response of regime 2 falls to 0.007, but BIC deteriorates from 183.2 to 194.5 and the residuals are autocorrelated. The two-regime fiscal model, which the bootstrap rejects in favour of three regimes, separates a passive regime (0.051) from an active regime (−0.039) and agrees with the baseline labels in 92 percent of the years.

The robust conclusions are therefore that monetary policy was passive in every specification in which the regimes are reliably identified, and that every fiscal specification contains a regime whose debt response is negative or insignificant. In the baseline estimates, monetary dominance never occurs and fiscal dominance prevails in 1975–1977, 1986–1988 and 2015–2023 whatever the label of the intermediate regime; whether the remaining years are best described as indeterminacy or as fiscal dominance depends on whether the weak debt response of 1981–1985 and 1995–2014 is regarded as sufficient to stabilise debt.

Table 14: Alternative specifications

Rule	Variant	n	Policy coefficient by regime	Labels	Agreement
Monetary	Output gap: HP, λ = 6.25	50	−0.097 / 0.635	P / P	1.00
Monetary	Output gap: Hamilton filter	50	−0.069 / 0.564	P / P	1.00
Monetary	Inflation: GDP deflator	50	−1.524 / 0.374	A / P	0.94
Monetary	Lagged inflation gap	50	0.453 / 2.091	P / P	1.00
Monetary	Inflation target: HP trend	50	−9.216 / 0.696	A / P	0.94
Monetary	Sample 1975–2018	44	−1.030 / 0.590	P / P	1.00
Monetary	Sample 1989–2024	36	0.190 / 0.646	P / P	1.00
Monetary	Without COVID-19 control	50	−0.086 / 0.606	P / P	1.00
Monetary	Sanctions as control	50	−0.087 / 0.693	P / P	1.00
Fiscal	Output gap: HP, λ = 6.25	50	0.108 / −0.000 / −0.041	P / A / A	0.54
Fiscal	Output gap: Hamilton filter	50	0.022 / 0.022 / 0.003	P / P / A	0.58
Fiscal	Tax rule: tax revenue / GDP	50	0.105 / 0.004 / −0.017	P / A / A	0.24
Fiscal	Sample 1975–2018	44	0.101 / −0.023 / −0.045	P / A / A	0.43
Fiscal	Sample 1989–2024	36	0.349 / 0.036 / −0.004	P / P / A	0.69
Fiscal	Without COVID-19 control	50	0.109 / 0.038 / −0.028	P / P / A	0.98
Fiscal	Sanctions as control	50	0.134 / 0.094 / −0.129	P / P / A	0.66
Fiscal	Two regimes	50	0.051 / −0.039	P / A	0.92
Fiscal	Control: real deposit rate	50	0.108 / 0.039 / −0.030	P / P / A	1.00
Fiscal	Control: public share of bank credit	50	0.101 / 0.021 / −0.044	P / A / A	0.50
Fiscal	Debt: public sector incl. public enterprises	50	0.115 / 0.038 / −0.019	P / P / A	0.84
Fiscal	One lag of the operating balance	50	0.119 / 0.007 / −0.029	P / A / A	0.44

P: passive; A: active (one-sided tests at 5 percent, Section 3.5). Monetary policy coefficient: response to the inflation gap; fiscal: response to lagged debt. Agreement: share of years in which

the most likely label equals the baseline label. Tax rule: tax revenue / GDP on lagged debt, expenditure / GDP, oil revenue / GDP and the output gap. Source: authors' estimations.

6-3. Data transformation and heteroscedasticity

A fiscal rule estimated in nominal levels (billions of rials) is strongly heteroscedastic: a studentised Breusch-Pagan test (Breusch & Pagan, 1979; Koenker, 1981) rejects homoscedasticity (BP = 25.1, df = 4, $p < 0.001$). This is the reason for expressing all fiscal variables as ratios to GDP. For the fiscal rule in ratios to GDP the test does not reject (BP = 8.9, df = 6, $p = 0.18$). The remaining differences in volatility across periods are captured by the regime-specific variances, which differ by a factor of three across fiscal regimes (σ from 0.27 to 0.86) and by a factor of two across monetary regimes, and the probability-integral-transform residuals show no conditional heteroscedasticity (ARCH-LM $p = 0.49$ for the monetary and 0.62 for the fiscal rule).

6-4. Out-of-sample evaluation, 2019–2024

To assess the rules in the current economic environment, we re-estimate each rule with an expanding window and forecast the policy instrument one year ahead for 2019–2024, using only data available before the forecast year and the realised regressors of that year. Table 15 compares the forecasts of the Markov-switching rules with those of the corresponding linear rules, using the Diebold-Mariano (1995) test with the small-sample correction of Harvey, Leybourne and Newbold (1997).

Table 15: Out-of-sample forecasts of the policy instruments, 2019–2024

Rule	Forecasts	RMSE, Markov switching	RMSE, linear	MAE, Markov switching	MAE, linear	DM statistic	p
Monetary *(base-money growth, %)*	6	8.74	8.39	6.93	6.89	1.93	0.11
Fiscal *(operating balance, % of GDP)*	6	1.02	1.09	0.77	0.68	−0.38	0.72

One-step-ahead forecasts from expanding-window estimates. Source: authors' estimations.

The Markov-switching rules forecast as accurately as the linear rules: for the fiscal rule the root mean squared error is lower (1.02 against 1.09 points of GDP) and the mean absolute error higher, and for the monetary rule the linear rule is slightly more accurate; neither difference is significant. Both rules miss the sharp increase in the operating deficit in 2024 (actual −6.1 percent of GDP against forecasts of −4.0 and −3.6 percent). With six

forecasts the test has little power, so the evidence does not show that the regime-switching rules forecast better; it shows that their regime structure is not obtained at the expense of out-of-sample accuracy in the turbulent period 2019–2024, which is what one would expect if the regimes reflected overfitting.

7. Discussion and Policy Implications

7-1. Indeterminacy and fiscal dominance in Iran

The central finding is that Iranian monetary policy did not anchor the price level at any point in the past half-century. Base-money growth either ignored inflation, in oil-boom periods when oil revenue was converted into base money, or accommodated it. Which equilibrium prevailed therefore depended on fiscal behaviour. In most years (35 of 50), the fiscal authority responded to debt, strongly in 1978–1980 and 1989–1994 and weakly in 1981–1985 and 1995–2014, so that solvency was not in question but the price level had no nominal anchor: the equilibrium was indeterminate. In three episodes, 1975–1977, 1986–1988 and 2015–2023, the operating balance deteriorated as debt rose, so that the price level had to adjust to make the real value of government liabilities consistent with fiscal behaviour: fiscal dominance in the sense of the fiscal theory of the price level. These were the episodes with the highest inflation, the most negative real interest rates and the fastest depreciation of the rial.

Neither configuration delivers a policy-determined anchor for inflation, which is consistent with the persistently high inflation observed throughout the sample. The distinction nevertheless matters for policy. Under indeterminacy, fiscal discipline exists but is not matched by an active central bank, so an active monetary framework would move the economy to monetary dominance. Under fiscal dominance, by contrast, monetary tightening alone would produce the unstable AM/AF combination.

The fiscal regimes follow a recurring cycle: consolidation after each active episode, a gradual erosion of discipline and a slide into the active regime that tends to occur when inflation and financial repression deepen. Oil revenue affects this cycle in two ways. It lowers the operating balance in all regimes, as current spending expands in booms, and the oil-revenue collapses of 1986 and after 2014 preceded two of the three active episodes. Oil, however, does not significantly affect the transition probabilities, and the first active episode occurred during a boom.

These findings agree with Erfani and Talebbeydokhti (2025a, 2025b) on passive monetary policy and on the presence of active fiscal regimes. They differ on the frequency of active fiscal policy: Erfani and Talebbeydokhti (2025b) classify all three

fiscal regimes as active, whereas we find active policy in one regime covering 15 years. The difference stems largely from the fiscal instrument. When we replace the operating balance with tax revenue relative to GDP, two of our three regimes become active (Table 14), as in their study. The operating balance, which also reflects current spending, shows that the government did respond to debt in most years, although weakly in the long period 1995–2014. Our joint analysis adds that even episodes of fiscal discipline did not produce monetary dominance, because the central bank remained passive.

7-2. Unconventional instruments and financial repression

Throughout the sample, nominal deposit and lending rates were set administratively and, in most years, below inflation. This has three consequences for the interpretation of the results. First, the interest rate could not serve as the instrument of an active monetary policy, which is why the monetary rule is specified for base money. Second, because the administered nominal rate responded only weakly to inflation (coefficient 0.14), the real interest rate fell by about 0.6 points for each point of inflation, so in the interest-rate sense monetary policy was passive. Third, negative real rates, observed in 38 of the 50 years, reduced the real cost of government debt and of bank lending to the public sector. Financial repression thus could act as a substitute for fiscal adjustment: it lowered the debt-stabilising surplus required of the government and, together with central-bank financing, made it possible for active fiscal policy to persist.

The estimates are consistent with this interpretation, although they do not establish it. First, the active fiscal regime is the regime of deep financial repression: the real deposit rate averaged −10.5 percent in its years, against −8.2 and −4.0 percent in the two passive regimes. Second, among the candidate drivers of fiscal regime transitions, the real deposit rate improves the fit most: in the sample, once the economy was in the active regime, it remained there in every year in which the real deposit rate was below about −12 percent, and every exit from it coincided with a rise in the real rate above this level (Section 5.4 and Fig. 3). This effect is not statistically significant, however, once the boundary estimate is taken into account (bootstrap $p = 0.15$), and the association is contemporaneous; the lagged real deposit rate does not predict the end of the active regime. The evidence therefore suggests that active fiscal policy and deep repression occur together, as parts of a financing strategy that relies on the inflation tax, rather than that repression causes the change of regime. Third, controlling for the real deposit rate in the fiscal rule leaves the regimes unchanged (agreement 1.00), whereas controlling for the public sector's share of bank credit makes the weak debt response of regime 2

insignificant (Table 14): once the public sector's command over bank credit is taken into account, the weakly passive regime can no longer be distinguished from an active one.

7-3. Policy implications

The results point to a sequence of reforms rather than to a single measure.

1. Since monetary policy has not anchored inflation, the first requirement is that the operating balance respond systematically to debt. In the passive regime, a one-point rise in the debt ratio improves the operating balance by 0.11 points of GDP within the year and by 0.24 points in the long run; the weakly passive regime that prevailed in 1995–2014 delivered only 0.08 points in the long run and eventually gave way to the active regime. A rule that ties a ceiling on the operating deficit to the debt ratio should therefore target a long-run response of at least the size observed in the passive regime.

2. The active fiscal regime is financed by borrowing from the central bank. Statutory limits on direct and indirect lending to the government, such as those introduced by the 2023 Central Bank Act, need to be enforced so that deficits cannot be monetised during oil-revenue shortfalls.

3. The active fiscal regime coincides with deep financial repression, and in every episode it has persisted while the real deposit rate was below about −12 percent; although this association is not statistically significant in a sample of 50 years, it points to the same financing channel as the theory in Section 7.2. Allowing deposit and lending rates to follow inflation and reducing the public sector's command over bank credit would remove a source of deficit financing that operates through the inflation tax on depositors.

4. A one-point increase in oil revenue relative to GDP lowers the operating balance by 0.62 points in the long run, and oil-revenue collapses preceded two of the three active episodes. A binding rule that saves oil revenue above a reference price in the National Development Fund and finances shortfalls from it, rather than from the central bank, would reduce both the pro-cyclicality of current spending and the risk that oil shocks push fiscal policy into the active regime.

5. Fiscal discipline alone yields indeterminacy, as in 1978–1985 and 1989–2014, unless the central bank becomes active. This requires either replacing administered interest rates with a market-based policy rate that can rise more than one-for-one with inflation, or committing base-money growth to contract when inflation exceeds an announced target.

6. An active central bank combined with active fiscal policy has no stable equilibrium. Monetary activism should therefore follow, not precede, the establishment of fiscal

discipline and the removal of financial repression, so that the economy moves from indeterminacy or fiscal dominance to monetary dominance rather than to instability.

7-4. Limitations

The sample contains 50 annual observations, which limits the number of regimes and covariates that can be estimated; quarterly fiscal data with consistent definitions are not available for the full period. Four further limitations deserve emphasis. First, the classification of the weakly passive fiscal regime (1981–1985 and 1995–2014) is sensitive to the specification: its debt response is significantly positive in the baseline and in six of the eleven alternative three-regime specifications. If it is regarded as active, the policy mix in these 25 years is fiscal dominance rather than indeterminacy; the conclusions that monetary dominance never occurred and that fiscal dominance prevailed at least in 1975–1977, 1986–1988 and 2015–2023 do not depend on this choice. Second, since 2008 government debt to the central bank has remained around 2 percent of GDP (3–4 percent including public enterprises), so the debt response in the most recent episodes is identified mainly from earlier episodes of the same regime; the classification of recent years rests on the Markov assumption that a regime's parameters are the same in each episode, and the classification of 2024 reflects a sharp rise in the operating deficit rather than a debt response. Third, the effect of the real deposit rate on the transition probabilities is estimated at a boundary, is not significant under the parametric bootstrap ($p = 0.15$) and is contemporaneous; it describes an association between financial repression and active fiscal policy, not a causal effect, and with only 15 years in the active regime none of the candidate drivers can be estimated precisely. Fourth, the sanctions index is coded from legal records and does not measure enforcement intensity, and the two rules are estimated separately and combined under conditional independence; a joint model with a four-state chain would require considerably more observations.

8. Conclusion

This paper identifies monetary and fiscal policy regimes in Iran over 1975–2024 using Markov-switching policy rules with a bootstrap-selected number of regimes, a penalised exact-likelihood estimator and tests of time-varying transition probabilities, including a restricted specification suited to short samples. Monetary policy is passive throughout, either ignoring or accommodating inflation. Fiscal policy cycles through a strongly passive, a weakly passive and an active regime; the active regime prevails in 1975–1977, 1986–1988 and 2015–2023 and coincides with deep financial repression. The policy mix

is indeterminate in 35 of the 50 years and fiscally dominant in the remaining 15; monetary dominance never occurs. The passive monetary stance and the active fiscal regime are robust across 21 alternative specifications, whereas the classification of the weakly passive fiscal regime depends on the specification; the regime-switching rules forecast as accurately as linear rules over 2019–2024. Establishing price stability in Iran therefore requires, in order, an enforceable fiscal rule, limits on central-bank financing, the gradual removal of financial repression and an oil-revenue smoothing rule, followed by a monetary framework in which the central bank can lean against inflation.

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Author Contribution

This research is derived from the first author's doctoral dissertation. The primary data collection, encompassing all observational and analytical components, was conducted by the first author under the direct supervision and mentorship of the second and third authors.

Conflict of Interest

In adherence to ethical publication standards, the authors affirm that there are no conflicts of interest, either personal or financial, that could have influenced the content or conclusions presented in this research.

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رژیم‌های سیاست پولی-مالی و سلطه سیاستی در اقتصاد ایران

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چکیده

این پژوهش رژیم‌های سیاست پولی و مالی ایران و ترکیب سیاستی را طی ۱۹۷۵ تا ۲۰۲۴م. شناسایی می‌کند. سیاست پولی قاعدهٔ رشد پایهٔ پولی در واکنش به شکاف تورم و سیاست مالی قاعدهٔ تراز عملیاتی بودجه در واکنش به وقفهٔ بدهی دولت به بانک مرکزی است؛ اثر درآمد نفت، شکاف تولید و کووید-۱۹ کنترل می‌شود. هر قاعدهٔ رگرسیونی مارکوف-سوئیچینگ با عرض از مبدأ، ضریب سیاستی و واریانس خطای متغیر است که با حداکثر درست‌نمایی جریمه‌شده برآورد می‌شود. تعداد رژیم‌ها با آزمون‌های متوالی نسبت درست‌نمایی بوت‌استرپ پارامتریک تعیین و احتمالات انتقال متغیر در زمان آزمون شده‌اند. داده‌ها دو رژیم پولی و سه رژیم مالی را برمی‌گزینند. سیاست پولی همواره منفعل است: رشد پایهٔ پولی یا به تورم واکنشی ندارد (ضریب ۰٫۰۹-) یا آن را همراهی می‌کند (۰٫۶۴). سیاست مالی از رژیم منفعل قوی (۰٫۱۱) به منفعل ضعیف (۰٫۰۴) و سپس فعال (۰٫۰۳-) می‌رود. ترکیب سیاستی در ۳۵ سال از ۵۰ سال با عدم تعیین تعادل (تورم ۱۹٫۳ ٪) و در ۱۵ سال (۱۹۷۵ تا ۱۹۷۷، ۱۹۸۶ تا ۱۹۸۸ و ۲۰۱۵ تا ۲۰۲۳) با سلطهٔ مالی (تورم ۲۸٫۶ ٪) همراه است؛ سلطهٔ پولی هرگز رخ نداده است. تحریم، جنگ، تکانه‌های نفتی و کاهش ارزش پول ملی بر احتمالات انتقال اثر ندارند؛ رژیم مالی فعال با سرکوب مالی هم‌زمان است، اما اثر نرخ سود حقیقی سپرده بر انتقال‌ها معنادار نیست (۰٫۱۵). نتایج در ۲۱ تصریح جایگزین پایدارند و پیش‌بینی ۲۰۱۹ تا ۲۰۲۴ به دقت قواعد خطی است. ثبات قیمت‌ها مستلزم قاعدهٔ مالی الزام‌آور، حذف سرکوب مالی و ابزار پولی مقابله‌کننده با تورم است.

کلیدواژگان: رژیم‌های سیاست پولی-مالی، سلطهٔ پولی، سلطهٔ مالی، مدل مارکوف سوئیچینگ، اقتصاد ایران.
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Economic Sustainability in Iran's Agricultural Sector: An Empirical Assessment and Analysis of Long-Run Dynamics

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Abstract

Given the pivotal role of the agricultural sector in food security and economic development, maintaining production continuity and ensuring the economic viability of this sector are of particular importance for policymaking. Accordingly, many agricultural support policies are designed to promote economic sustainability and ensure the continuity of agricultural production. This study aims to assess the economic sustainability of Iran's agricultural sector, examine the macroeconomic factors influencing it, and analyze its long-run dynamics over the period 1993-2023. To this end, a composite economic sustainability index comprising three components - income, risk adaptability (income stability), and productivity - was initially constructed and estimated. Subsequently, the long-run determinants of this index were investigated using the autoregressive distributed lag (ARDL) model. The results indicate that economic sustainability in Iran's agricultural sector followed an upward trend over the study period. In the long run, energy consumption and per capita agricultural credit contributed positively to economic sustainability, whereas resource rents, the poverty proxy index, and technological innovation adversely affected the agricultural economic sustainability index. Furthermore, the existence of a nonlinear relationship between real GDP and economic sustainability was confirmed. Based on the empirical findings, it is recommended that policymakers adopt an integrated approach to improving economic sustainability in the agricultural sector, with simultaneous attention to enhancing the productivity of production factors, stabilizing farmers' incomes, and improving resource allocation efficiency.

Keywords: Economic Sustainability, Sustainable Agriculture, Economic Viability, Livelihood Constraints, Composite Sustainability Index.
JEL Classification: Q01, Q56, Q19.

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1. Introduction

Food production is essential to the continuity of human civilization, while the political independence and sustainability of countries across social, economic, and political dimensions depend on food security. Ensuring sustainable agricultural production in all its dimensions has consistently been a major concern for policymakers. Accordingly, income generation and employment creation throughout the food supply chain are supported as part of efforts to promote sustainability in the agricultural sector (Bathaei and Štreimikiene, 2023). The agricultural sector occupies a prominent position in Iran's food security and economy. In 2024, it accounted for 6.3% of Iran's gross domestic product (Statistical Center of Iran, 2025). Moreover, the sector's share of total employment in Iran was 14.5% in 2023[1]. Agriculture also plays a significant role in the global economy: approximately 1.3 billion people, equivalent to 16% of the world's total population, are employed in this sector, while agricultural and food products account for approximately 24% of global output (Elawama, 2016). Accordingly, agricultural development programmers in many developing countries, including Iran, have traditionally emphasized increasing food production. In Iran, successive five-year development plans and higher-level policy documents have also placed particular emphasis on food security and self-sufficiency in essential and strategic agricultural products (Bagherzadeh Azar & Motafakerazad, 2021; Akbari *et al.*, 2020).

An excessive emphasis on production growth without due consideration of certain underlying constraints may undermine the sustainability of agricultural production. One of the major threats to production sustainability is the excessive and unsustainable use of the natural resource base on which agriculture depends, which can lead to the degradation of these valuable resources. Furthermore, exposure to various natural risks and hazards, low levels of investment in the sector, and inadequate access to finance can pose significant challenges to the sustainability of agriculture. These considerations underscore the importance of sustainable agriculture, economic viability, and production sustainability.

It is important to emphasize that, despite its contribution to national output, employment, and food security, Iran's agricultural sector faces structural and economic constraints that threaten its long-term economic sustainability. These constraints extend beyond production-related challenges and reflect broader weaknesses in the economic and institutional environment within which agricultural activities take place. In particular, the

[1] As reported by: Hosseini, S. M. (2025*), Deputy for Entrepreneurship Development and Employment at the Ministry of Cooperatives.* Labour and Social Welfare. Available at: https://www.mehrnews.com/news/6653729/

sector is characterized by income instability arising from various climatic and economic risks, limited access to financial resources, fluctuations in production costs, and insufficient investment in productivity-enhancing technologies. Such conditions may undermine farmers' ability to sustain their agricultural activities, adapt to economic shocks, and generate stable returns over time.

Furthermore, the institutional and policy framework governing Iran's agricultural sector adds to the complexity of these challenges. Although support policies, such as the provision of subsidized agricultural inputs, guaranteed wheat purchase schemes, and food subsidies, have played an important role in supporting domestic production and promoting agricultural output, the World Bank (2022) reports that some of these policy interventions have also resulted in price distortions, inefficient resource allocation, and considerable fiscal pressures. In addition, weaknesses in resource governance, particularly in the management of agricultural water resources, have constrained the efficient allocation and productive use of resources (Nouri *et al.*, 2023). Evidence from the experiences of farmers and the perspectives of experts in Iran also highlights the importance of economic and institutional-infrastructural barriers, including financial constraints, high investment costs, and inadequate organizational coordination (Ataei *et al.*, 2021). Taken together, these challenges indicate that the economic sustainability of the agricultural sector is shaped not only by farm-level production conditions but also by broader macroeconomic and institutional factors.

From an economic perspective, the sustainability of the agricultural sector depends on its ability to generate adequate income, maintain income stability, and improve productivity over time. These dimensions are particularly important in Iran, where agricultural producers operate in an economic environment characterized by resource dependence, financial constraints, and macroeconomic instability. Changes in areas such as energy consumption, access to agricultural credit, economic development, household economic conditions, natural resource rents, and technological innovation may therefore influence the sector's capacity to sustain its economic performance over the long term. However, the nature and magnitude of these relationships are not necessarily uniform. For instance, economic growth and technological progress may create new opportunities for agricultural development, but the extent to which the sector benefits from these opportunities depends on how resources are allocated, whether producers have access to adequate financial resources, and how closely technological advances align with the needs of agricultural production.

Researchers and scholars in the field of sustainability have examined the concept of sustainable development from various perspectives. Agricultural economists, in particular, have investigated the different economic, social, and environmental dimensions of sustainability in the agricultural sector. One dimension whose conceptual frameworks and definitions have recently undergone reconsideration, and which has become a major concern among specialists in this field, is economic sustainability (Spicka *et al.*, 2019). One reason for the growing importance of economic sustainability in agriculture is that farmers predominantly operate small-scale farms and often have limited financial resources (Khanal *et al.*, 2019). Moreover, agriculture is exposed to climatic hazards and various economic risks to which other sectors of the economy are generally less vulnerable. Farmers' economic resilience is particularly important in regions exposed to extreme weather events (Thompson *et al.*, 2023). One of the main purposes of providing support payments to farmers is to maintain their economic viability and enable them to continue their agricultural activities. In other words, governments implement various support policies to compensate farmers for the constraints and disadvantages they face in agricultural production as a result of adverse natural conditions, different types of risks, or other location-specific limitations. Such policies reflect the importance that policymakers attach to the economic resilience of farming communities. These support measures are intended to encourage farmers to continue operating agricultural land, help preserve rural landscapes, and maintain and enhance sustainable agricultural systems.

Agricultural census data indicate that more than 76% of Iranian farmers operate farms of less than five hectares (Agricultural Census, 2024). The prevalence of small-scale farming in Iran, combined with farmers' limited financial resources, leaves them particularly vulnerable to a wide range of economic and climatic shocks. This raises a fundamental question: how can economic viability and sustainability be measured, and which macroeconomic factors can contribute to improving economic sustainability? This question is particularly important because the continuity of agricultural production and food security in Iran are closely linked to the sustainability of the agricultural sector. Accordingly, this study first seeks to assess economic sustainability using an index suited to the aggregate level of the agricultural sector and the broader agricultural economy. It then examines the macroeconomic factors that influence improvements in the economic sustainability of Iran's agricultural sector.

2. Literature Review

2-1. Sustainability

The concept of sustainability is rooted in the overarching and fundamental framework established by the United Nations World Commission on Environment and Development (WCED). Within this framework, sustainability is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). The central principle underlying this definition is intergenerational equity, which implies that the exploitation of natural resources in the present should not come at the expense of depleting the ecological capacities available to future generations (Smith, 2024). At the macro level and in the context of resource management, sustainability is not a static concept but rather a dynamic approach that requires effective natural resource management and the implementation of sustainable policies. Such an approach seeks to improve the quality of life of present generations while preserving and protecting ecosystems and biodiversity for future generations (Clark and Harley, 2020). Furthermore, a genuine understanding of long-term sustainability requires that the hidden costs and environmental degradation resulting from resource exploitation, such as externalities and pollutant emissions, which are often overlooked in conventional assessments, be incorporated into comprehensive economic valuations (Cho, 2023).

2-2. Dimensions of Sustainability

Achieving sustainable development requires establishing a sound and lasting balance between growing human needs and the carrying capacity of the Earth's ecosystems. This complex balance can only be achieved through simultaneous and integrated consideration of the three principal dimensions of sustainability: the environmental (ecological) dimension, the social dimension, and the economic dimension (Biermann *et al.*, 2008). At the macro level, sustainability serves as an analytical framework for assessing the alignment of socioeconomic development with ecosystem health, and standard sustainability indicators generally integrate these three dimensions (Zhang *et al.*, 2023). In the agricultural sector, these dimensions are closely interrelated and can also be examined through three types of capital: natural capital (the environmental dimension), human capital (the social dimension), and physical capital (the economic dimension). In this regard, agricultural innovation serves as an indispensable requirement and a driving force for sustainable development by helping to connect these dimensions (Padel *et al.*, 2015). Given global challenges such as climate change and rapid population growth, the adoption of new technologies and innovative management practices can help societies simultaneously

increase productivity, reduce adverse environmental impacts, and protect natural resources and food security (Faure *et al.*, 2018).

2-3. Sustainable Agriculture

Sustainable agriculture, derived from the concept of sustainable development as applied to the agricultural sector, encompasses three main dimensions: economic, environmental, and social. Achieving sustainability in agriculture requires maintaining a balance among these three dimensions (Ana *et al.*, 2021). The objectives of sustainable agriculture include reducing adverse impacts on the environment and human health, strengthening and making use of local ecosystem resources, and conserving biodiversity. In addition to environmental parameters, agricultural productivity and income are also considered components of economic sustainability in the agricultural sector (Bathaei and Štreimikiene, 2023). Figure 1 illustrates the different dimensions of sustainability in agriculture.

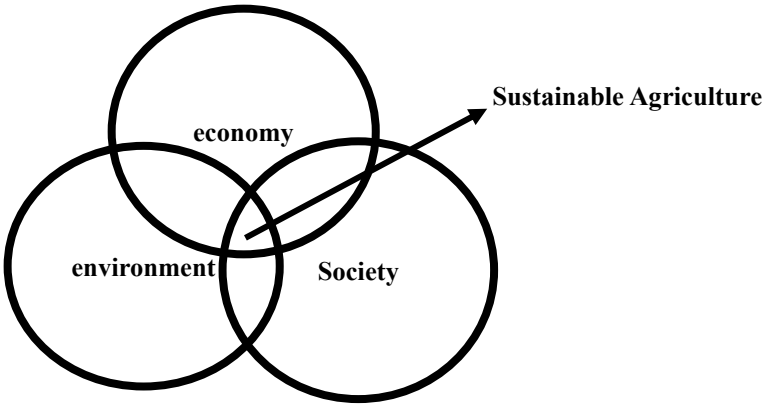

Fig. 1: Dimensions of Sustainable Agriculture

Understanding the concept of sustainable agriculture and interpreting its defining characteristics are of considerable importance. Numerous characteristics contribute to agricultural sustainability. These range from soil–plant interactions at the individual field level to markets, distribution networks, value chains, and global trade arrangements (Adam *et al.*, 2020). From an economic perspective, agriculture can be viewed both as a business activity at the farm level and as an economic sector at the regional or national level (Bathaei and Štreimikiene, 2023). Economic sustainability is assessed in terms of production costs and the prospects for maintaining economic viability under changing environmental, social, and economic conditions (Rachael *et al.*, 2021). From a macroeconomic perspective, agriculture is regarded as a productive sector capable of meeting food requirements and contributing to food security. At this level, sustainability concerns the capacity to meet

national and global demand for food and fiber, as well as the quality and safety of food supplies, technology transfer, and improvements in the efficiency and equity of food distribution systems (Kumar *et al.*, 2020).

Different perspectives on sustainability emerge depending on the scale of analysis. At the farm level, the condition of fundamental resources, particularly soil and its fertility, as well as access to water resources and plant growth, are among the main concerns associated with sustainability (De Corato, 2020). Farm-level agricultural activities encompass crop and livestock production, management practices, and the structure and economic viability of the farm. At the regional level, agriculture constitutes a major component of land-use patterns and natural resource exploitation, and therefore occupies a prominent position in environmental economics and sustainability. At the national and international levels, the agricultural sector is associated with issues such as food production and trade, equity, rural poverty, resource rents, and food security (Fanelli, 2019). Accordingly, different issues are examined depending on the scale of analysis and the dimension of sustainability under consideration. Given the emphasis placed on the economic dimension of sustainable agriculture in the present study, the following section focuses on the economic dimension of sustainability and sustainable agriculture.

2-4. Economic Sustainability

Economic sustainability is one of the three pillars of sustainable development (Biermann *et al.*, 2008). In agricultural systems, it is reflected in the formation and maintenance of physical capital and is intrinsically interconnected with the other two dimensions. From a functional perspective, economic sustainability does not simply mean generating profits; rather, it involves optimizing the economic use of nature while preserving the ecological integrity of ecosystems (Choy, 2017). This approach requires moving away from environmentally damaging patterns of unlimited growth towards more balanced approaches, such as carefully monitoring resource consumption and reducing waste. In this context, innovative technologies can create a win–win scenario in which economic growth and environmental improvement are achieved simultaneously (Lane *et al.*, 2024). In agricultural economics, economic sustainability can be influenced by various forms of rent. For example, economic sustainability is achieved at the green level, where the more efficient use of economic, intellectual, and technological capital enhances sustainability. By contrast, market monopolies at the orange level severely undermine economic and agricultural sustainability (Zaytsev, 2020). Furthermore, meeting the economic needs of local communities and creating sustainable employment opportunities are among the key

objectives of a sustainable economy (Wang *et al.*, 2024). Nevertheless, it should be emphasized that genuine economic sustainability can only be achieved when policymaking incorporates environmental costs, such as the high intensity of greenhouse gas emissions in agriculture, into economic calculations and the management of resource rents, thereby preventing distortions in the assessment of actual economic value (Cho, 2023).

At the farm level, economic sustainability can be regarded as a form of economic viability, or the ability of an agricultural system to maintain its operations over the long term under changing economic conditions. In other words, it concerns whether an agricultural system can remain economically viable over time despite changes in its economic environment (Latruffe *et al.*, 2016). Changes in the economic environment may be influenced by factors such as fluctuations in output and input prices, crop yields, markets and product marketing channels, public support, and government regulations. The long term may refer either to the entire professional career of a farmer or to several generations. The latter interpretation is associated with farm durability and the possibility of transferring the farm to a successor. Profitability, liquidity, stability, and productivity are considered the principal indicators of economic viability (Van Calker *et al.*, 2007).

This issue is particularly important for family farms, where economic sustainability is also associated with the concept of economic durability. Economic durability is defined as "the capacity of a farm to be transferred to the next generation or to a successor" (Latruffe *et al.*, 2016). Accordingly, family members' commitment to and emotional attachment to the continuation of the family business constitute important emotional drivers of the sustainability of agricultural holdings.

Economic sustainability is associated not so much with the farm business or agricultural activity in isolation as with the farming household. This concept is closely related to the notion of livability, which focuses on assessing whether agricultural activity enables farmers and their families to enjoy a decent professional and personal life (Zahm *et al.*, 2008). Some farms may not be economically viable when considered in isolation, yet their farming households may remain economically sustainable because their members earn income from off-farm sources (Hennessy *et al.*, 2008). Farm managers and operators consider income generated from both on-farm and off-farm activities as part of an overall income portfolio. Such an approach constitutes a strategy within the broader framework of farm risk management.

Some studies have also identified autonomy or freedom of action as an indicator of economic sustainability (Spicka *et al.*, 2019). Autonomy can be assessed in terms of the

degree to which a farm operates independently of external inputs, debt, subsidies, and the need to generate income from off-farm activities (Latruffe *et al.*, 2016).

As previously noted, profitability (the comparison of revenues and costs, expressed as a difference or ratio), liquidity (the ability to meet immediate and short-term financial obligations), financial stability, and productivity (the capacity of production factors to generate output) are important indicators used to assess economic sustainability. At the sectoral and national levels, the economic sustainability of agriculture can therefore be assessed by examining the sector's overall capacity to generate income, maintain income stability, and improve productivity over time, while accounting for the broader economic conditions that shape these outcomes.

The distinction between farm-level and sectoral economic sustainability is primarily a distinction in the scale of analysis rather than in the underlying economic principles. At the farm and household levels, economic sustainability concerns the ability of individual agricultural businesses and farming households to maintain adequate income, financial stability, productivity, and economic viability over time (Latruffe *et al.*, 2016; Spicka *et al.*, 2019). At the sectoral and national levels, these concerns are reflected in the overall economic performance of the agricultural sector, particularly its capacity to generate income, maintain income stability, and sustain productivity. Thus, national-level agricultural economic sustainability does not necessarily involve the direct aggregation of farm-level sustainability scores; rather, it represents an assessment of the sector's overall economic performance through indicators that capture these underlying dimensions. Moreover, macroeconomic conditions, including economic growth, credit availability, energy use, resource rents, and technological development, can shape the economic environment in which farms and agricultural households operate, thereby influencing the sector's overall economic sustainability. This multilevel perspective provides the conceptual basis for examining the macroeconomic determinants of agricultural economic sustainability at the national level in the present study.

2-5. Methods for Measuring Economic Sustainability

Various studies have sought to define and operationalize the concept of sustainability in order to make it measurable and facilitate comparisons across production systems and agricultural sustainability performance, thereby supporting agricultural policymaking. Differences in the proposed indicators and in the methods used for quantification and assessment have largely arisen from differing conceptual understandings of sustainability,

data characteristics, geographical settings, research objectives, and the specific context of each study (Chopin *et al.*, 2021; Coppola *et al.*, 2022).

Some studies have sought to establish common frameworks for selecting and developing a final set of indicators, primarily emphasizing the fundamental characteristics of sustainability (Zahm *et al.*, 2008; OECD, 2013; FAO, 2016). Although these frameworks may differ in terms of the proposed themes, subthemes, sub-indicators, and methods for integrating and aggregating individual indicators (Arulnathan *et al.*, 2020; Zahm *et al.*, 2008), they facilitate the comparison of impacts and outcomes across different dimensions of sustainability and help identify potential synergies among various groups of outcomes. Nevertheless, substantial differences in measurement and scoring approaches may limit their external comparability (Arulnathan *et al.*, 2020).

In other words, measurement tools designed for the same purpose sometimes employ different sub-indicators and aggregation methods. In their study, Nadaraja *et al.* (2021) reviewed 40 articles in which agricultural sustainability in commercial and large-scale cropping systems had been assessed. Their review revealed that these 40 articles employed 143 environmental, 90 social, and 60 economic sub-indicators to assess sustainability. This wide range of indicators is noteworthy because many of them refer to essentially the same underlying concept, yet different indicators have been proposed to measure that concept across individual studies (Nadaraja *et al.*, 2021).

The use of redundant and highly correlated indicators has also been observed in many studies (Coppola *et al.*, 2022). In some cases, state and pressure indicators are used interchangeably, resulting in the conflation of indicators describing the current state of a system with those measuring progress towards a desired state.

From an economic perspective, sustainability depends on income and profitability, financial autonomy, resource-use efficiency, competitiveness, the capacity to adapt to risk, and the ability to maintain economic activity over time (Spicka *et al.*, 2019; Coppola *et al.*, 2022). Various approaches used in previous studies to measure these concepts are presented in Table 1.

Table 1: Approaches to Measuring Economic Sustainability: Components and Definitions of Indicators

Study	Economic Components	Assessment Indicators
Frawley and Commines (1996)	Viability	Family farm income compared to the average agricultural wage, return on non-land assets
Zahm *et al.* (2008)	Economic viability	Available income per worker compared with the national legal minimum wage, economic specialization rate

	Independence	Financial autonomy, reliance on direct subsidies from CAP and indirect economic impact of milk and sugar quotas
	Transferability	Total assets minus lands value on non-salaried worker units
	Efficiency	Operating expenses as a proportion of total production value
Vrolijk *et al.* (2010)	Viability	Farm income, cash flow sign, rewards for the farmers input of labor and capital compared to the opportunity cost
Ryan *et al.* (2016)	Productivity	Gross output/utilized agricultural area
	Profitability	Income per unpaid labor unit, market-based gross margin (less subsidies) per hectare
	Markey orientation	Proportion of output derived from the market
	Viability	Capacity to remunerate family labor on the farm at the average agricultural wage and the capacity to provide an additional 5% return on non-land assets (Frawley and Commines 1996)
Gaviglio *et al.* (2017)	Economic viability	Value of production/utilized agricultural area, added value/agricultural working units
	Persistence	Farm ability to generate income given by EBITDA/value of production, ratio of (EBITDA + CAP subsidies) and family working units
	Independence	CAP independence given by public subsidies/farm income, autonomy measured by total amount of contracted loans
	Diversification	diversification of production given by the number and relative importance of products and services sold by the farm, business diversification
	Multi functionality	Economic weight of non-agricultural products and services
Fallah-Alipour *et al.* (2018)	Farm income	Agricultural value added per hectare: as a measure of the income-generating capacity and profitability of agricultural activities for producers, as well as the economic viability of farm households.
	Adaptation to economic risks - Stability	Percentage of agricultural land covered by insurance: as an indicator of risk reduction and income stabilization for farmers.
	Productivity	Physical yield of major crops per unit of land area
de Otálora *et al.* (2021)	Profitability	Net farm income, land productivity, animal productivity, feed efficiency
	Autonomy	Economic self-sufficiency, feed self-sufficiency
	Farm diversification	Food production, economic diversification, non-food earnings, added value products
	Durability	Succession and transferability
Coppola *et al.* (2022)	Efficiency	To estimate the Efficiency at the farm level, they used a data envelopment analysis (DEA) approach
	Factor profitability	Ability of the farm to remunerate the entrepreneur's production factors at their opportunity cost
	Comparable income	The CI was estimated by comparing the farm income to the average income reported by Eurostat for Italy for a family with two children

Thus, despite a degree of consensus regarding the concept of economic sustainability, considerable differences remain in the operational approaches used to measure it, and researchers have yet to reach agreement on a universally accepted measurement criterion.

The economic sustainability index adopted in the present study, following Fallah-Alipour *et al.* (2018), encompasses three main components at the macro level. In contrast, some of the indicators presented in other studies, including those reviewed in Table 1, assess economic sustainability at the farm (micro) level, relying on field observations and farm-specific data. Such indicators are often obtained through questionnaires or farm-level surveys conducted at a particular point in time, and therefore may not be available as consistent time-series data. By comparison, the sub-indicators employed in the framework of Fallah-Alipour *et al.* (2018) can be measured using annual data at the agricultural sector level and have also been incorporated into other studies on agricultural sustainability. Specifically, agricultural income or value added per unit of land has been used to represent the economic performance of agricultural activities (Sinisterra-Solís *et al.*, 2024; Tzouramani *et al.*, 2020; Vrolijk *et al.*, 2010), agricultural insurance coverage has been recognized as an indicator of risk mitigation, resilience and income stability (FAO, 2018), and agricultural productivity, measured by the yields of major crops (Ryan *et al.*, 2016; Haileslassie *et al.*, 2016; Talukder *et al.*, 2017), have been used in the literature to assess different aspects of agricultural economic sustainability. These indicators therefore provide a literature-based foundation for assessing the principal economic dimensions considered in this study. Another reason for selecting this framework and its underlying sub-indicators is their suitability for operationalizing an index in a national-level agricultural time-series study. All three selected sub-indicators can be measured using annual data.

Therefore, considering the evidence from previous studies and the specific requirements of the present research (including the geographical context (Iran), the need for time-series data, data availability throughout the study period, the coverage of key dimensions of economic sustainability, and the suitability of the indicators for the agricultural sector at the national level); the framework proposed by Fallah-Alipour *et al.* (2018) was adopted to assess the economic sustainability of Iran's agricultural sector. Under this approach, farm income was used as an indicator of income and the capacity to maintain economic activity; the yield per unit of land area of major crops was employed as an indicator of productivity; and agricultural crop insurance coverage was used as an indicator of farmers' capacity to cope with risk and maintain income stability. These indicators were therefore incorporated as sub-indicators for assessing economic sustainability.

2-6. Macroeconomic Determinants of Agricultural Economic Sustainability

The economic sustainability of agriculture is shaped not only by conditions at the farm level but also by the broader economic environment in which agricultural production takes place. From a capital-based perspective, the capacity of the agricultural sector to maintain income, ensure income stability, and improve productivity depends partly on the availability, allocation, and effective use of productive resources, including natural, physical, financial, and knowledge-based capital (Pretty, 2008). Macroeconomic conditions can influence these resources and, consequently, the economic performance of the agricultural sector through several channels. Real GDP per capita, for instance, reflects the broader level of economic development and may shape agricultural sustainability by influencing investment capacity, the provision of rural infrastructure, and the allocation of productive resources (Martin, 2019; Pender, 1998). Energy consumption represents an important production input that supports agricultural activities and can contribute to productivity growth. However, its economic implications also depend on energy costs and the efficiency with which energy is used (Pelletier *et al.*, 2011; OECD, 2017). Similarly, natural resource rents may influence agricultural performance through their effects on resource allocation and investment patterns across sectors. In resource-dependent economies, resource booms may divert productive resources and investment away from agriculture, potentially weakening its long-term economic performance. The implications of resource rents for agriculture therefore depend, in part, on how resource revenues are managed and allocated (Apergis *et al.*, 2014; Dorinet *et al.*, 2021). Agricultural credit can strengthen producers' financial capacity by easing liquidity constraints and enabling investment in productive inputs and improved technologies. It may also help farmers manage production-related risks and avoid underinvestment in agricultural activities (Regassa *et al.*, 2023; Magruder, 2018). Household economic conditions can further shape farmers' ability to maintain production and cope with financial pressures, as households with more limited financial resources and assets tend to have fewer options for responding to economic shocks (Börner *et al.*, 2015). Finally, technological innovation can contribute to productivity improvements and greater production efficiency. However, the extent to which these benefits materialize depends on the relevance and affordability of available technologies, as well as producers' capacity to adopt and effectively use them (OECD, 2022; Ruzzante *et al.*, 2021). These relationships provide the theoretical rationale for examining the selected macroeconomic variables as potential determinants of agricultural economic sustainability.

3. Methodology

In the present study, a composite economic sustainability index for the agricultural sector was constructed to assess economic sustainability, following the approach proposed by Fallah-Alipour *et al.* (2018). The sub-indicators used to construct this index, together with supplementary information, are described below:

1) **Farm income:** This sub-indicator was calculated as the agricultural value added per hectare of cultivated land in a given year. It was used as a measure of the income-generating capacity and profitability of agricultural activities for farmers, as well as the economic viability and livability of farm households. Based on the weighting scheme employed by Fallah-Alipour *et al.* (2018), this sub-indicator was assigned a weight of 0.445 in the calculation of the composite index. The data required to calculate this sub-indicator were obtained from the Central Bank of the Islamic Republic of Iran, the Ministry of Agriculture Jihad, and the World Bank.
2) **Risk adaptability and income stability:** This component was measured as the percentage of agricultural land covered by crop insurance relative to the total cultivated area. This sub-indicator reflects farmers' capacity to adapt to various economic and climatic risks. It can also serve as a proxy for farm income stability. Agricultural insurance can protect farmers against certain production-related risks, particularly losses resulting from adverse climatic events and other insured hazards, thereby helping to reduce income fluctuations and strengthen the financial resilience of agricultural producers. The relevance of insurance as a risk-mitigation mechanism is also recognized in the FAO framework for SDG indicator 2.4.1, which includes access to agricultural insurance among the mechanisms contributing to farm resilience (FAO, 2018). Nevertheless, insurance coverage does not capture all sources of agricultural income instability, particularly price volatility, market risks, and fluctuations in input costs. Accordingly, the insurance coverage ratio is interpreted in this study as a proxy for one important dimension of risk management and income protection, rather than a comprehensive measure of all risks affecting agricultural income. This sub-indicator was assigned a weight of 0.442 in the calculation of the final agricultural economic sustainability index. The data required to calculate this sub-indicator were obtained from the Agricultural Insurance Fund.
3) **Agricultural productivity:** This sub-indicator was calculated as the average physical yield of major crops, expressed in kilograms per hectare. It represents the efficiency of land use and can capture changes in production technology and the

sustainability of agricultural productivity over time. This sub-indicator was assigned a weight of 0.133 in the calculation of the final economic sustainability index. The data required to calculate this sub-indicator were obtained from the Ministry of Agriculture Jihad.

In the study by Fallah-Alipour *et al.* (2018), the data were collected cross-sectionally at the county level in Kerman Province. In the present study, however, annual time-series data for the country as a whole were obtained from reliable statistical sources for the period 1993–2023. Following the selection of indicators and data collection, the data needed to be converted into unit-free and dimensionless values to enable their aggregation and the subsequent calculation of the composite index. This process is commonly referred to as data normalization or standardization. Accordingly, the min–max normalization method was employed in this study (Haileslassie *et al.*, 2016). Under this method, all indicator values are transformed to a range between 0 and 1 (or 0 and 100). This transformation is performed using the following equation:

$$x^s = \frac{x - \min(x)}{\max(x) - \min(x)} \quad (1)$$

In Equation (1), x^s denotes the normalized value of indicator x, while $\min(x)$ and $\max(x)$ represent the minimum and maximum observed values, respectively, across the entire sample (Freudenberg, 2003). Finally, the agricultural economic sustainability index was calculated for each year of the study period using Equation (2):

$$EcoSus_t = \sum_{x=1}^{3} w_x . I_{x_t} \quad (2)$$

In the above equation, $EcoSus_t$ denotes the economic sustainability index of the agricultural sector in year t, w_x represents the weight assigned to each sub-indicator, and I_{x_t} is the normalized value of sub-indicator x in year t. To examine the macroeconomic factors influencing the agricultural economic sustainability index, the following general theoretical specification was employed:

$$EcoSus_t = f(EnerUse_t, PerCredit_t, PPPGDP_t, PPPGDP_t^2, Poverty_t, Rent_t, TI_t) \quad (3)$$

In the above specification, $EnerUse_t$ represents energy consumption in the agricultural sector, measured in million barrels of crude oil equivalent; $PerCredit_t$ denotes the per capita agricultural credit index, measured in million rials per farmer; $PPPGDP_t$ represents real gross domestic product based on purchasing power parity (PPP), measured in billion US dollars; and $PPPGDP_t^2$ is the squared term of $PPPGDP_t$. The variable $Poverty_t$ represents the share of food expenditure in total rural household expenditure and is used as a proxy

for poverty and household financial capacity. $Rent_t$ denotes the natural resource rents index, while TI_t represents the technological innovation index. The data used in this study were obtained from Iran's Energy Balance Sheet, Bank Keshavarzi, the World Bank, and the Statistical Center of Iran. In the main model, all variables were entered in logarithmic form to enable the interpretation of the estimated coefficients in terms of elasticities.

Furthermore, the autoregressive distributed lag (ARDL) approach was employed to examine and analyze the long-run dynamics of the macroeconomic factors affecting the economic sustainability of the agricultural sector. Pesaran and Shin (1995) demonstrate that when a cointegrating vector is obtained by applying the ordinary least squares method to an autoregressive distributed lag (ARDL) specification, the OLS estimator is asymptotically normally distributed and, even in small samples, can exhibit lower bias and greater efficiency. In the present study, this approach was selected because the variables under investigation were a mixture of I(0) and I(1) variables. Moreover, this method makes it possible to conduct economic analyses of both short-run and long-run relationships. Its application in small samples can also offer greater efficiency by accounting for short-run dynamics among the variables (Kripfganz and Schneider, 2023).

Under the ARDL approach, the short-run dynamic model is first estimated. The optimal lag length for each explanatory variable is determined using the Akaike information criterion (AIC), the Schwarz–Bayesian information criterion (SBC), the Hannan-Quinn criterion (HQ), or the coefficient of determination. In samples with fewer than 100 observations, the Schwarz-Bayesian criterion is generally preferred to avoid losing an excessive number of degrees of freedom. The general form of an autoregressive distributed lag model is expressed in Equation (4) (Tashkini, 2005):

$$\varphi(L,P)Y_t = \sum_{i=1}^{k} b_i(L,q_i)X_{it} + c'w_t + u_t \qquad (4)$$

In the above equation, L denotes the lag operator, while w is a vector of fixed variables, such as the intercept, dummy variables, a time trend, or exogenous variables with fixed lags. Furthermore, $\varphi(L,P)$ and $b_i(L,q_i)$ are defined as follows (Tashkini, 2005):

$$\varphi(L,P) = 1 - \varphi_1 L - \varphi_2 L^2 - \ldots . - \varphi_P L^P \qquad (5)$$

$$b_i(L,q_i) = b_{i0} + b_{i1}L + b_{i2}L^2 \ldots + b_{iq}L^q \,, \quad i = 1,2,\ldots,k \qquad (6)$$

The long-run coefficients are obtained from the above dynamic model. The long-run coefficients associated with the explanatory variables X are derived from Equation (7):

$$\theta_i = \frac{\hat{b}_i(1,q_i)}{1-\hat{\varphi}(1,p)} = \frac{\hat{b}_{i0}+\hat{b}_{i1}+\ldots+\hat{b}_{iq}}{1-\hat{\varphi}_1-\ldots-\hat{\varphi}_p} \quad (7)$$

To examine the existence of a long-run relationship (cointegration) among the model variables, the bounds testing approach proposed by Pesaran *et al.* (2001) within the autoregressive distributed lag (ARDL) framework is employed. In this test, the null hypothesis of no long-run relationship is tested against the alternative hypothesis of the existence of a long-run relationship using the F-statistic. The calculated F-statistic is compared with two sets of critical values: the lower bound, which assumes that the explanatory variables are integrated of order zero, I(0), and the upper bound, which assumes that they are integrated of order one, I(1). If the calculated F-statistic exceeds the upper-bound critical value, the null hypothesis of no long-run relationship is rejected, confirming the existence of a cointegrating relationship among the variables. Conversely, if the calculated F-statistic falls below the lower-bound critical value, the null hypothesis cannot be rejected. If the F-statistic lies between the two bounds, the test result is inconclusive. Once the existence of a long-run relationship has been established, the long-run coefficients and the error correction model (ECM) can be estimated to examine short-run dynamics and the speed of adjustment towards long-run equilibrium. The main advantage of error correction models is that they link short-run fluctuations in variables to their long-run equilibrium values. The error correction model is estimated using Equation (8):

$$\Delta Y_t = a + b\Delta X_t + cU_{t-1} + e_t \quad (8)$$

Here, c denotes the coefficient of the error correction term (ECT), which is expected to have a negative sign. It indicates the proportion of disequilibrium in the dependent variable that is corrected in each period, reflecting the speed at which the system adjusts towards its long-run equilibrium relationship.

4. Results and Discussion

The economic sustainability index of the agricultural sector constructed in this study comprises three sub-indicators: farm income (agricultural value added), agricultural crop insurance (the percentage of agricultural land insured to mitigate risks, enhance adaptability to shocks, and promote economic stability), and agricultural productivity (the physical yield of major agricultural crops in the country, measured in kilograms per hectare). Following the normalization and aggregation of these sub-indicators using the method described in the Methodology section, the overall economic sustainability index was assessed and measured over the 31-year period from 1993 to 2023. The time trends of

the overall index and its constituent sub-indicators are presented in Figure 2 and 3, respectively.

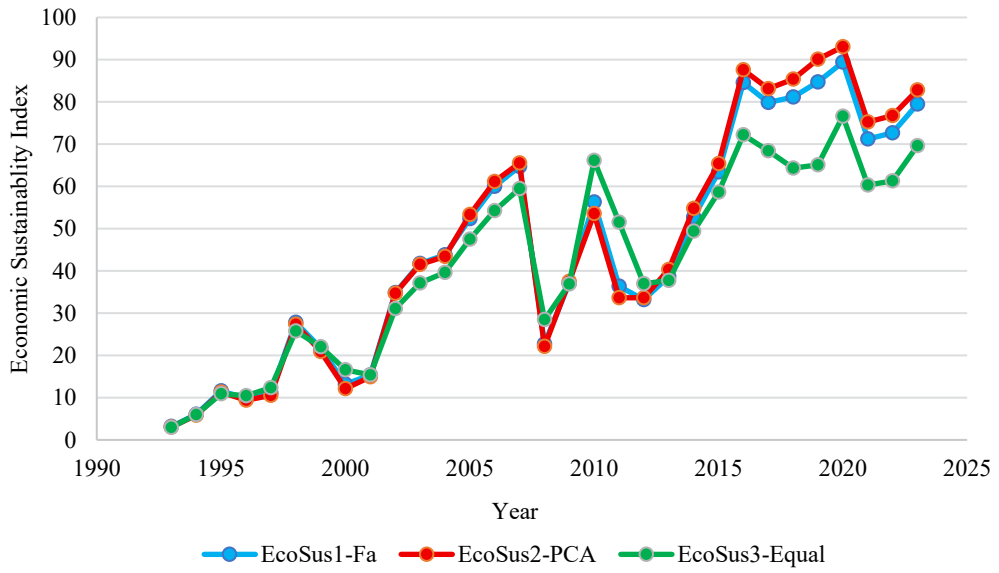

Fig. 2: Comparison of the Agricultural Economic Sustainability Index under Alternative Weighting Schemes during 1993-2023

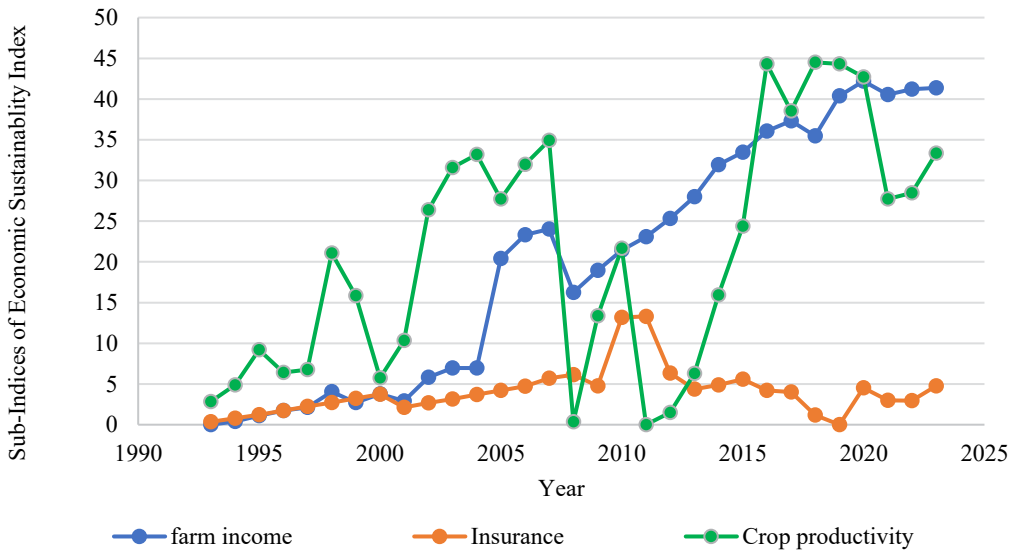

Fig. 3: The sub-indices trend of the agricultural sector's economic sustainability index during 1993-2023

Figure 2 illustrates the evolution of the agricultural economic sustainability index over the period 1993-2023, based on three alternative weighting schemes: the original weights proposed by Fallah-Alipour *et al.* (2018), equal weights, and PCA-derived weights. The figure shows that the overall temporal pattern of the index remains broadly consistent

across all three approaches. The index trajectories overlap in several years, while the differences in their numerical values toward the end of the study period remain relatively small, with broadly similar patterns of change. These findings suggest that the overall trend of the agricultural economic sustainability index is relatively robust to alternative weighting schemes. Accordingly, the index constructed using the original weights proposed by Fallah-Alipour *et al.* (2018) was retained as the baseline measure for the subsequent econometric analysis.

The time trend of the agricultural economic sustainability index indicates that economic sustainability in this sector followed an upward trajectory over the study period. A sharp shock and decline in agricultural sustainability can be observed in 2007. This substantial shock appears to have been caused by an unprecedented cold wave that affected the country, resulting in the destruction of and frost damage to numerous agricultural crops. The effects of this climatic shock became evident in the economic sustainability index for 2008, with a one-year lag. In 2008, all three sub-indicators - farm income, insurance coverage, and productivity - declined, although the decrease in the productivity sub-indicator (crop yield) was particularly pronounced. This finding illustrates the extent to which climatic events can affect the economic sustainability of the agricultural sector. From 2008 onward, the economic sustainability index generally followed an upward trend, with the exception of the 2010-2012 period and 2021. Among the agricultural sustainability sub-indicators, productivity exhibited considerable fluctuations over the years. Given the dependence of agricultural production on climatic conditions and the various weather-related risks facing Iran's agricultural sector, this pattern of productivity fluctuations is not unexpected. Farm income followed an upward trend throughout the 1993-2023 period. The insurance sub-indicator also increased until 2011, after which it declined before rising again. Before estimating the econometric model, it is necessary to examine the stationarity of the variables using unit root tests. The results of the unit root tests for the variables included in the empirical model are presented in Table 2.

Table 2: The results of unit root test

Variable	Symbol	Level				First Difference				Results
		ADF		PP		ADF		PP		
		Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	
Economic Sustainability index	*Ln_EcoSus*	-3.63	0.04	-3.64	0.04	-	-	-	-	I(0)
Energy Consumption in Agri-Sector	*Ln_EnerUse*	-1.01	0.92	-1.19	0.89	-2.28	0.42	-7.06	0.00	PP: I(1)
Per Capita Agricultural Credit	*Ln_PerCredit*	-1.54	0.50	-1.56	0.49	-4.90	0.00	-4.92	0.00	I(1)

Real GDP per capita based on purchasing power parity	Ln_PPPGDP	-0.85	0.78	-0.85	0.79	-4.69	0.00	-4.70	0.00	I(1)
The square of Ln PPPGDP	$(Ln_PPPGDP)2$	-0.71	0.83	-0.71	0.83	-4.72	0.00	-4.70	0.00	I(1)
Share of food expenditure in the household budget (as a proxy for poverty)	$Ln_Poverty$	-2.21	0.21	-1.86	0.35	-4.23	0.00	-4.23	0.00	I(1)
Natural Resource Rent	Ln_Rent	-3.16	0.03	-3.27	0.02	-	-	-	-	I(0)
Technological Innovation	Ln_TI	-2.21	0.21	-1.86	0.35	-4.22	0.00	-4.23	0.00	I(1)

As indicated by the stationarity test results reported in Table 2, the variables under investigation are a mixture of I(0) and I(1) variables. Accordingly, the ARDL approach can be employed to estimate the model. The bounds test was used to examine the existence of a long-run relationship among the model variables, and the results are presented in Table 3.

Table 3: The results of the long run relationship F-Bounds test

Test Statistic	**Value**	**Signif.**	**Critical Value (Null Hypothesis: No levels relationship)**	
			I(0)	**I(1)**
F-statistic	6.375	10%	2.27	3.50
		5%	2.73	4.16
K	7	1%	3.86	5.69

The results of the F-bounds test indicate that the null hypothesis of no long-run relationship is rejected at all significance levels. Therefore, the existence of a long-run relationship among the model variables is confirmed. The results of estimating the dynamic ARDL model are reported in Table 4.

Table 4: The Estimation Results of the Dynamic ARDL Model

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Ln_EcoSus_{t-1}	0.296	0.182	1.63	0.135
Ln_EcoSus_{t-2}	-0.282	0.167	-1.69	0.121
$Ln_EnerUse_t$	3.264	1.453	2.24	0.048
$Ln_PerCredit_t$	-0.712	0.299	-2.38	0.039
$Ln_PerCredit_{t-1}$	0.745	0.322	2.31	0.043
$Ln_PerCredit_{t-2}$	0.809	0.290	2.79	0.019
Ln_PPPGDP_t	-62.551	49.757	-1.26	0.237
Ln_PPPGDP_{t-1}	88.270	65.890	1.34	0.210
Ln_PPPGDP_{t-2}	108.85	46.891	2.32	0.043
$(Ln_PPPGDP)_t^2$	4.669	3.572	1.31	0.225
$(Ln_PPPGDP)_{t-1}^2$	-6.883	4.781	-1.43	0.180
$(Ln_PPPGDP)_{t-2}^2$	-7.828	3.408	-2.29	0.044

Variable	Coefficient	Std. Error	t-Statistic	Prob.
$Ln_Poverty_t$	-1.540	1.761	-0.87	0.402
$Ln_Poverty_{t-1}$	-3.842	1.532	-2.51	0.031
Ln_Rent_t	-0.513	0.233	-2.20	0.052
Ln_Rent_{t-1}	0.062	0.304	0.20	0.841
Ln_Rent_{t-2}	-0.763	0.300	-2.54	0.029
Ln_TI_t	-0.669	0.203	-3.29	0.008
$Intercept$	-463.98	151.61	-3.06	0.012
Selected model: ARDL(2,0,2,2,2,1,2,0) - Model selection method: Akaike info criterion				
$R^2 = 0.97$	$\bar{R}^2 = 0.92$	$F - stat = 19.93$	$Prob(F - statistic) = 0.000$	

The results of the dynamic ARDL model indicate that energy consumption has a positive and statistically significant effect on economic sustainability. The contemporaneous value of per capita agricultural credit has a negative effect on the agricultural economic sustainability index, whereas its first and second lags have positive and statistically significant effects. This finding suggests that the effects of agricultural credit on the agricultural sector and its sustainability materialize with a time lag. Real GDP based on the PPP index has a positive and statistically significant effect on economic sustainability at its second lag. The poverty variable, measured as the share of food expenditure in total household expenditure, has a negative effect on economic sustainability with a one-period lag. The resource rents variable also has a negative effect on the sustainability of the agricultural sector in the current period and at its second lag. To provide a more detailed interpretation of these findings and integrate them with the results concerning short-run and long-run relationships, the estimated short-run and long-run models, together with the error correction coefficient, are presented in Table 5.

Table 5: The Estimation Results of short-run and long-run models

ARDL Long run relationship				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
$Ln_EnerUse_t$	3.310	1.190	2.78	0.011
$Ln_PerCredit_{t-1}$	0.854	0.420	2.03	0.055
Ln_PPPGDP_{t-1}	136.48	36.449	3.74	0.001
$(Ln_PPPGDP)^2_{t-1}$	-10.185	2.722	-3.74	0.001
$Ln_Poverty_{t-1}$	-5.458	1.456	-3.75	0.001
Ln_Rent_{t-1}	-1.231	0.351	-3.51	0.002
Ln_TI_t	-0.679	0.294	-2.30	0.031
$Intercept$	-470.58	123.20	-3.819	0.001
ARDL short run relationship and error correction coefficient				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
ECM_{t-1}	-0.986	0.097	-10.16	0.000
ΔLn_EcoSus_{t-1}	0.282	0.091	3.09	0.006
$\Delta Ln_PerCredit_t$	-0.712	0.139	-5.12	0.000
$\Delta Ln_PerCredit_{t-1}$	-0.809	0.180	-4.49	0.000
ΔLn_PPPGDP_t	-62.551	24.458	-2.56	0.020
ΔLn_PPPGDP_{t-1}	-108.85	26.337	-4.13	0.001

$\Delta(Ln_PPPGDP)_t^2$	4.669	1.756	2.66	0.016
$\Delta(Ln_PPPGDP)_{t-1}^2$	7.828	1.920	4.08	0.001
$\Delta Ln_Poverty_t$	-1.540	0.894	-1.72	0.102
ΔLn_Rent_t	-0.513	0.116	-4.42	0.000
ΔLn_Rent_{t-1}	0.763	0.149	5.11	0.000
$R^2 = 0.91$	$\bar{R}^2 = 0.87$	$F - stat = 19.53$	$Prob(F - statistic) = 0.000$	

The long-run estimation results indicate that energy consumption in the agricultural sector has a positive and statistically significant effect on the agricultural economic sustainability index. Specifically, a 1% increase in energy consumption leads to a 3.3% improvement in the agricultural economic sustainability index. Given the role of energy in promoting mechanization, water extraction, the adoption of modern technologies, the transition towards smart agriculture, and the expansion of agricultural production capacity, higher energy consumption can enhance the value-creation capacity of agricultural production. In this way, it can positively affect economic sustainability, economic viability, and the continuity of production in the agricultural sector. The findings of Zou (2022) and Akyol (2020) also indicate that increased energy consumption contributes to agricultural sector growth and higher value added in this sector. Nevertheless, the positive economic effect of energy consumption should not lead to neglect of the fact that continued energy use without due consideration of energy efficiency, energy intensity, and environmental considerations may jeopardize environmental sustainability and ultimately affect agricultural sustainability through greenhouse gas emissions.

Per capita agricultural credit, used as an indicator of financial development, has a statistically significant coefficient with the expected sign. The estimated coefficient indicates that a 1% increase in per capita agricultural credit leads to a 0.8% improvement in the agricultural economic sustainability index. This finding is consistent with theoretical expectations, as financial development and improved access to agricultural credit can ease farmers' liquidity constraints, facilitate investment in the agricultural sector and production technologies, and strengthen the economic capacity of agricultural holdings. The findings of Seven and Tumen (2020) and Sabasi *et al.* (2021) also indicate that financial development and improved access to agricultural credit enhance total factor productivity in the agricultural sector, thereby contributing to economic sustainability. It is also noteworthy that, in the short-run model, changes and fluctuations in per capita agricultural credit have negative and statistically significant coefficients in explaining changes in the economic sustainability index. This finding reflects the difference between the short-run and long-run effects of this variable on agricultural sustainability. In the short run, financing costs, the inability to recover investments within a short period, and the way credit is

allocated may have adverse effects on economic sustainability. In the long run, however, capital accumulation and increased production capacity may generate positive effects. This interpretation is also consistent with the dynamic ARDL results, in which the effect of this variable on economic sustainability becomes positive at the second lag.

Real gross domestic product based on the purchasing power parity (PPP) index and its squared term have statistically significant positive and negative coefficients, respectively, indicating an inverted U-shaped nonlinear relationship between GDP (based on PPP) and the economic sustainability index. Given the statistical significance and signs of these two coefficients, the results indicate that as PPP-based GDP increases, the agricultural economic sustainability index initially rises. However, as GDP continues to grow, its positive effect gradually diminishes, reaches a maximum point, and eventually becomes negative beyond that threshold. In other words, during the initial stages of economic growth, particularly when measured using the purchasing power parity index, which reflects improvements in purchasing power and consumer welfare, rising GDP can strengthen the economic sustainability of the agricultural sector through increased demand for agricultural products, higher government expenditure on production infrastructure, and market development. However, beyond a certain level of GDP, continued economic growth may weaken the agricultural economic sustainability index through structural changes in the economy, shifts in consumption patterns, a decline in the relative share of agriculture, higher opportunity costs of resources, rural-to-urban migration, and the transfer of capital and labor from agriculture to other sectors. In the present study, the turning point of the agricultural economic sustainability index was estimated at a PPP-based GDP level of USD 812.7 billion. Various studies have established nonlinear relationships between agricultural value added, income, GDP, and per capita GDP and variables associated with the agricultural sector. For example, Cetin *et al.* (2022) found a long-run nonlinear, inverted U-shaped relationship between income and carbon dioxide emissions. Similarly, Trofimov (2023) demonstrated that the relationship between per capita output and agricultural land use is nonlinear and follows an inverted U-shaped pattern.

The share of food expenditure in total household expenditure, used as a proxy for poverty in rural and agricultural communities, has a statistically significant coefficient with the expected negative sign. The estimated coefficient indicates that a 1% increase in the poverty proxy is associated with a 5.4% decline in the agricultural economic sustainability index in the long run. A higher share of household expenditure allocated to food indicates that households face substantial constraints on their real purchasing power. This budgetary constraint may itself signal economic deprivation, limiting effective demand for high-

quality and diverse food products. By constraining market capacity, increasing fluctuations in producers' income, and heightening economic uncertainty, it may adversely affect the economic sustainability of the agricultural sector. In the short-run model, however, although the coefficient of this variable is negative, its changes do not have a statistically significant effect on agricultural economic sustainability. Various studies have examined the effects of poverty on natural resource conservation and other economic variables. For example, the findings of Mgomezulu *et al.* (2023) indicate that economic constraints and household characteristics influence the adoption of sustainable agricultural practices. This provides some support for the finding of the present study that poverty and household financial constraints may affect farmers' adoption of sustainable practices.

Natural resource rents have a negative and statistically significant effect on the agricultural economic sustainability index. Specifically, a 1% increase in natural resource rents leads to a 1.23% decline in the agricultural economic sustainability index in the long run. Dependence of the agricultural sector and the wider economy on revenues derived from natural resources - a phenomenon discussed in the economic literature in terms of the resource curse and Dutch disease - may alter resource allocation, weaken incentives for productive investment, change relative prices, increase dependence on natural resource revenues, and undermine competitiveness. These developments may, in turn, weaken the agricultural sector and ultimately reduce its economic sustainability. The findings of Dorinet *et al.* (2021) similarly indicate that increased revenues resulting from a boom in natural resource extraction reduce agricultural labor productivity. The short-run model shows that contemporaneous changes in natural resource rents initially have a negative effect on changes in agricultural economic sustainability, whereas the first lag has a positive effect. This suggests that the short-run effects of resource rents on economic sustainability may vary over time. However, the long-run results indicate a persistently negative relationship between resource rents and the economic sustainability of the agricultural sector.

The technological innovation variable also has a negative and statistically significant coefficient. The estimated coefficient indicates that a 1% improvement in the technological innovation index is associated with a 0.6% decline in the agricultural economic sustainability index in the long run. One possible explanation for the negative effect of TI on EcoSus is the mismatch between innovation and the actual needs of the agricultural sector. Another consideration is the high cost of technology adoption. In fact, the use of new technologies may increase investment, maintenance, and repair costs, as well as dependence on imported inputs, particularly in the short and medium term. Furthermore,

the unequal distribution of technology may explain why, despite advances in technological innovation, its estimated effect has the opposite sign to that expected. This may occur because such innovations are not widely adopted by smallholder farmers, who constitute a substantial proportion of Iran's agricultural community. This finding contrasts with many studies that have established positive effects of innovation and technology on agricultural sustainability. For example, Emerick *et al.* (2016) found that agricultural innovation has a positive effect on crop yields. Similarly, Läpple and Thorne (2019) showed that innovation enhances the economic sustainability of farms, although this relationship is nonlinear and the magnitude of the economic benefits depends on the level of innovation. Conversely, other studies have found that the effect of innovation on production performance is uncertain and may even be negative in some cases. For instance, Frick *et al.* (2024) examined the effects of different types of innovation on various economic, social, and environmental dimensions of sustainability. Their results showed that positive effects of innovation across all sustainability dimensions cannot be taken for granted. Moreover, unexpected negative relationships with farm performance were observed for certain types of innovation. Therefore, given the prevalence of smallholder farming and farmers' resistance to innovation in Iran, the findings of the present study are not entirely unexpected, and other studies have also reported similar results.

In the short-run model, the error correction term is negative and statistically significant. Its estimated coefficient indicates that, following a shock to any of the model variables, approximately 98% of the deviation from the long-run equilibrium is corrected in each period. In other words, when a shock affects the model variables, the deviation from the long-run equilibrium is adjusted within the same period, and the model returns towards its long-run equilibrium path. To assess the validity of the estimated model, the classical assumptions concerning the model's error term were tested. The results are presented in Table 6.

Table 6: Results of Tests for the Classical Assumptions of the Error Term

Breusch-Godfrey serial correlation LM test		**Heteroskedasticity test (Breusch-Pagan-Godfrey: $N*R^2$)**		**Normality test (Jarque-Bera test)**	
F-statistic	Prob.	Statistic	Prob.	JB Statistic	Prob.
1.234	0.295	11.983	0.848	1.827	0.401

The test results indicate that none of the classical assumptions has been violated. In particular, there is no evidence of autocorrelation among the error terms or heteroskedasticity, and the error terms are normally distributed. These findings therefore

support the validity of the estimated model. To examine model stability, the CUSUM and CUSUM of Squares (CUSUMSQ) tests were conducted, and the results are presented in Figures 4 and 5, respectively.

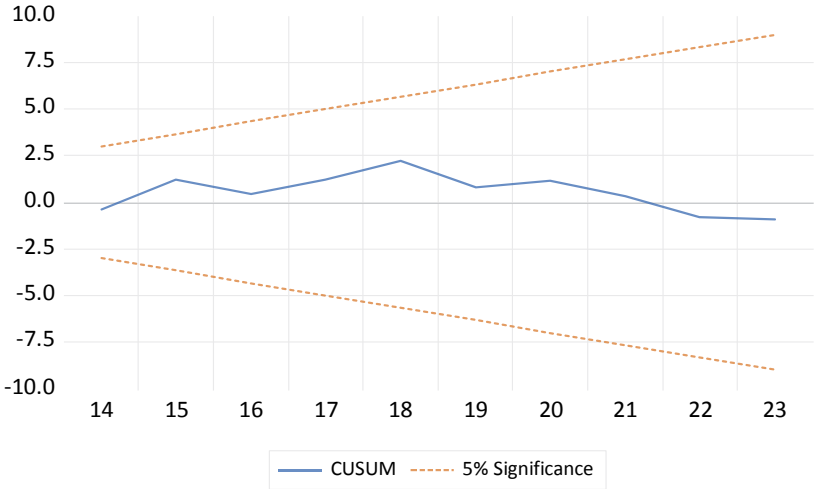

Fig. 4: Results of the CUSUM Test for Model Stability

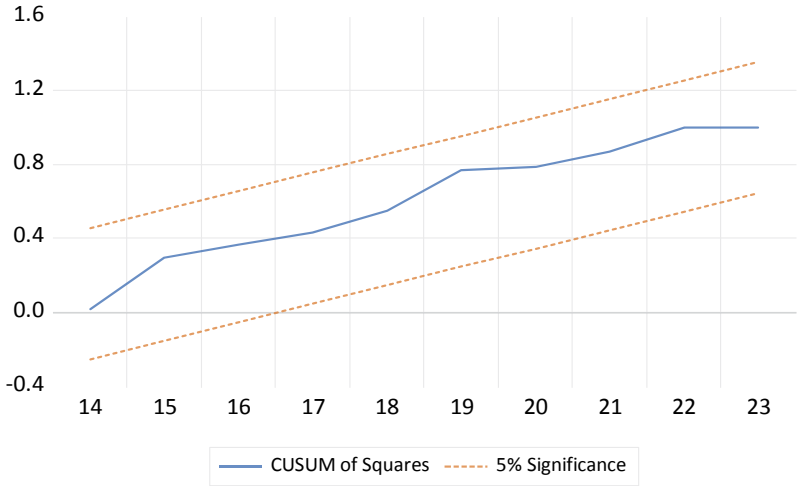

Fig. 4: Results of the CUSUM of Squares (CUSUMSQ) Test for Model Stability

The test results indicate that the calculated statistics remain within the specified critical bounds at the 5% significance level. Accordingly, the stability of the estimated model is confirmed.

5. Conclusion

The present study aimed to assess the economic sustainability of Iran's agricultural sector, examine the economic factors influencing it, and analyze its long-run dynamics. The findings indicate that the economic sustainability of Iran's agricultural sector is shaped by the interplay among economic development, the structure of financial provision, household welfare pressures, dependence on natural resource rents, and the ways in which energy and

technology are utilized. In particular, economic growth can strengthen agricultural economic sustainability during its initial stages; however, this relationship becomes negative beyond a certain threshold. Given the nonlinear relationship identified between real GDP and agricultural economic sustainability, it can be concluded that overall economic growth does not necessarily translate into improved economic performance in the agricultural sector. To strengthen the agricultural sector's responsiveness to broader economic development, it is recommended that agricultural development policies prioritize stronger economic linkages between agriculture and other sectors of the economy, alongside the expansion of agro-processing and downstream industries.

According to the results, energy consumption in the agricultural sector has a positive and statistically significant effect on economic sustainability in the long run, indicating that energy remains an important input in agricultural production. Nevertheless, excessive and inefficient energy consumption may undermine environmental sustainability through increased greenhouse gas emissions. To address this trade-off, energy policies should move beyond maintaining access to low-cost energy and focus on improving the efficiency of its use. Relevant measures include conducting energy audits on farms, replacing outdated and energy-intensive machinery with more efficient equipment, improving the efficiency of irrigation pumping systems, and providing targeted financial incentives for investments in energy-saving technologies. Agricultural credit programs could also prioritize machinery and equipment that reduce energy use per unit of output rather than simply increasing energy-consuming production capacity. Per capita agricultural credit, as an indicator of financial development, exhibited different effects in the short and long run. Accordingly, agricultural lending policies should distinguish between short-term liquidity support and long-term productive investment. In particular, credit allocation could prioritize investments in modern production equipment, irrigation infrastructure, post-harvest facilities, and technologies that demonstrably improve farm productivity and income-generating capacity.

The findings also revealed that the share of food expenditure in total rural household expenditure, used as a proxy for poverty-related economic pressures and financial deprivation, has a negative effect on agricultural economic sustainability. This finding highlights the importance of addressing the economic vulnerability of rural and farming households. Policy measures could include targeting credit and insurance support towards financially vulnerable agricultural producers, simplifying access to agricultural insurance, reducing administrative and transaction costs associated with financial services, and improving farmers' bargaining position through producer organizations and more effective

market linkages. These measures could help reduce financial pressures on farming households and strengthen their capacity to maintain productive activities in the face of economic shocks.

Another important finding is the negative effect of natural resource rents on the economic sustainability of the agricultural sector. Although the present study does not directly examine the channels through which resource rents affect agricultural performance, this finding raises concerns about the extent to which revenues generated from natural resources are translated into productive investment in agriculture. A more targeted allocation of a portion of these revenues could help address this concern. Specifically, such resources could be directed towards investments in agricultural infrastructure with clear productivity-enhancing objectives, including storage and cold-chain facilities, rural transport infrastructure, water-use efficiency improvements, and post-harvest processing capacity. In addition, competitive funding mechanisms could be established to support agricultural research and development projects that address clearly identified production constraints and have a credible pathway for practical application. Linking the allocation of these funds to measurable outcomes, such as reductions in post-harvest losses, improvements in water and energy productivity, and increased value added within agricultural value chains, could help ensure that resource-derived revenues contribute more directly to the productive capacity of agriculture.

Finally, the negative long-run coefficient of the technological innovation index suggests that improvements in aggregate innovation indicators do not necessarily translate into stronger economic sustainability in agriculture. Since the present study does not directly measure agricultural technology adoption or the channels through which innovation affects farm performance, this result should not be interpreted as evidence that technological innovation itself is detrimental to the sector. Rather, it points to the possible limitations of relying on aggregate innovation policies without sufficiently considering the technological requirements and adoption capacities of agricultural producers. To address this issue, agricultural innovation policies should be more demand-driven and closely connected to production-level needs. Practical measures include conducting periodic assessments of farmers' technological constraints, directing a greater share of agricultural research funding towards technologies that address locally relevant production problems, establishing demonstration farms to evaluate technologies under actual farming conditions, and strengthening extension services to support their adaptation and use. Moreover, public support for technology development and transfer could be linked to field-based assessments of usability, affordability, and potential productivity gains. Strengthening formal

cooperation among agricultural research institutions, extension organizations, technology providers, and farmers' organizations could also help reduce the gap between innovation development and its effective application in agricultural production.

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Contributions' Authors

This study is based on data from the MSc thesis of the second author. The second author was responsible for collecting the primary data and under the supervision of the first author. The first author selected the research topic, designed the study, and conducted the scientific analyses.

Interest of Conflicts

The authors declare no conflict of interest. This study received no financial support from an organization.

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پایداری اقتصادی بخش کشاورزی ایران: ارزیابی تجربی و تحلیل پویایی‌های بلندمدت

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چکیده

با توجه به جایگاه بخش کشاورزی در امنیت غذایی و توسعهٔ اقتصادی، تداوم تولید و قابلیت تداوم حیات اقتصادی بخش کشاورزی از اهمیت ویژه‌ای در سیاست‌گذاری برخوردار است. به‌همین جهت بسیاری از سیاست‌های حمایتی از بخش کشاورزی در راستای پایداری اقتصادی و تداوم تولید در این بخش صورت می‌گیرد. هدف از مطالعهٔ حاضر ارزیابی پایداری اقتصادی بخش کشاورزی ایران و سپس بررسی عوامل کلان اقتصادی تاثیرگذار بر آن و تحلیل پویایی‌های بلندمدت در طی دورهٔ ۲۰۲۳-۱۹۹۳م. است. برای این‌منظور ابتدا شاخص ترکیبی پایداری اقتصادی متشکل از سه مولفه درآمد، سازگاری با ریسک (ثبات درآمد) و بهره‌وری مورد ارزیابی و محاسبه قرار گرفت و سپس با استفاده از الگوی خودتوضیح برداری با وقفه‌های توزیعی (ARDL) عوامل تعیین‌کنندهٔ شاخص در بلندمدت مورد بررسی قرار گرفت. نتایج مطالعه نشان‌داد که وضعیت پایداری اقتصادی در بخش کشاورزی از یک روند افزایشی در دورهٔ مورد بررسی برخوردار بوده است. مصرف انرژی و سرانهٔ اعتبارات کشاورزی سبب بهبود پایداری اقتصادی و در مقابل رانت منابع، شاخص پروکسی فقر و نوآوری فناوری سبب تنزل شاخص پایداری اقتصادی بخش کشاورزی در بلندمدت در طی دورهٔ مورد بررسی در ایران شدند. همچنین وجود یک رابطهٔ غیرخطی بین GDP واقعی و پایداری اقتصادی به اثبات رسید. براساس نتایج به‌دست آمده از مدل تحقیق، پیشنهاد می‌شود جهت بهبود پایداری اقتصادی در بخش کشاورزی، با اتخاذ رویکردی یکپارچه، هم‌زمان بهبود بهره‌وری عوامل تولید، ایجاد ثبات درآمد کشاورزان و کارایی تخصیص منابع موردتوجه سیاست‌گذاران این بخش قرار گیرد.

کلیدواژگان: پایداری اقتصادی، کشاورزی پایدار، زیست‌پذیری اقتصادی، تنگناهای معیشتی، شاخص ترکیبی پایداری.
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Bu-Ali Sin University

A Systematic Review of Quantitative Methods for Estimating the Economic, Human, and Environmental Damages of War: Challenges, Applications, and Biases in Recent Crises

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Abstract

Abstract: Armed conflicts impose substantial physical, economic, human, and environmental costs. However, estimates of war-related damages vary considerably depending on the methodological approach, type of damage, data availability, and assessment objectives. This study aims to systematically review existing approaches for estimating the economic and broader consequences of armed conflicts and to develop an integrated framework for combining complementary methods while minimizing double counting. A systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Relevant studies and institutional reports published between 1988 and January 15, 2026, were identified through searches of international and domestic scientific databases and relevant institutional sources. After screening and eligibility assessment, 67 sources were included in the qualitative synthesis. The reviewed approaches were organized into four major methodological categories: direct cost-based methods for estimating physical asset damage; econometric and assessment methods, including the Synthetic Control Method (SCM) and Damage and Needs Assessment (DaNA); human valuation methods, including the Value of a Statistical Life (VSL) and Present Discounted Value (PDV); and remote sensing-based methods for identifying and measuring physical damage. The reviewed evidence indicates that no single method can comprehensively capture all dimensions of war-related damage. Direct cost-based approaches are useful for estimating physical asset damage, while SCM and DaNA provide complementary approaches for assessing economic losses and recovery requirements. VSL and PDV can be used to incorporate mortality, disability, and human-capital losses, whereas remote sensing and Earth observation techniques can provide spatially detailed evidence of physical destruction. The findings also indicate that differences in accounting boundaries, time horizons, and data sources may lead to overlapping estimates when multiple methods are combined.

Keywords: War Damage Estimation, Synthetic Control Method, Value of Statistical Life, Post-Crisis Needs Assessment, Systematic Review.
JEL Classification: D74, C18.

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1. Introduction

Accurate and transparent estimation of these damages is important for reconstruction planning, humanitarian assistance, compensation analysis, economic recovery assessment, and historical documentation. However, war-damage estimation is complicated by incomplete data, restricted access to affected areas, heterogeneous valuation methods, rapidly changing prices, and substantial differences between physical, economic, human, and environmental dimensions of damage. Recent conflicts in Ukraine, Gaza, Syria, Lebanon, Sudan, and other conflict-affected settings have highlighted the limitations of conventional damage-assessment approaches. These settings differ substantially in the availability of administrative data, accessibility of affected areas, physical patterns of destruction, duration of conflict, and the extent of environmental and human losses. Consequently, no single estimation method can adequately capture all dimensions of war-related damage.

2. Research Background and Literature Gap

The existing literature can be organized into four major methodological categories: direct cost-based methods, econometric and assessment methods, human valuation methods, and remote sensing-based methods.

Direct cost-based methods: estimation of physical damage to buildings, infrastructure, productive assets, and other tangible assets."

"Econometric and assessment methods: estimation of economic losses and reconstruction requirements using approaches such as the Synthetic Control Method (SCM) and Damage and Needs Assessment (DaNA)."

"Human valuation methods: estimation of mortality, disability, and human-capital losses using approaches such as the Value of a Statistical Life (VSL) and Present Discounted Value (PDV)."

"Remote sensing-based methods: identification and measurement of observable physical damage using satellite imagery, Earth observation, and related computational methods.

Despite this diversity, a fundamental gap is observed in the scientific literature of this field: Although previous studies have examined individual methods or specific conflict settings, relatively few studies have systematically compared these methodological approaches within a single analytical framework. Existing studies are either limited to a specific method, or have focused solely on one crisis (such as the World Bank, 2023), or have a descriptive aspect and do not address methodological critique. However, in Iran, the

authors' search in domestic scientific databases (such as Noormags, Magiran, Elmnet, and SID) shows that. The only available information relates to news reports about damage estimates from a hypothetical conflict, which lack scientific methodology and a peer-review process. It should be noted, however, that in the field of economic research related to international pressures (such as sanctions), some studies have been conducted in Iranian scientific journals. For instance, Adeli *et al.* (2022) employed the Synthetic Control Method (SCM) to examine the effect of sanctions on Iran's exports. Although this study did not directly address war damage estimation, it is closely related to the present research both methodologically (the application of SCM to assess the impact of an external shock on the macro economy) and thematically (the assessment of economic losses resulting from international pressures), and it can be cited as a domestic example of applying econometric methods to damage assessment.

The main objective of the present study is to provide a systematic review of existing methods for estimating war damages, analyze the strengths and weaknesses of each approach based on the experiences of recent crises, and propose a combined framework. Therefore, four main questions can be stated for this research as follows:

• What are the main methodological approaches for estimating physical, economic, human, and environmental dimensions of war damage, and how can they be categorized?

• What are the strengths, weaknesses, accuracy, speed, and vulnerability to bias of each method in the context of real crises (Ukraine, Gaza, Syria, Lebanon, Sudan)?

• What research and methodological gaps exist in the field of war damage estimation?
• Given the existing limitations, what combined framework can provide a more realistic and valid estimate of war damage?

To the best of the authors' knowledge, relatively few studies have systematically compared these methodological categories within a single analytical framework and examined their potential integration.

3. Research Methodology

This study is a systematic review based on the PRISMA guidelines. The systematic review approach was chosen over meta-analysis for the following reasons:

• Severe heterogeneity of methods and data: Existing studies have used completely different methods (cost-based, econometric, human valuation, remote sensing) that cannot be statistically combined.

• Diversity of damage dimensions: War damage includes physical, economic, human, and environmental dimensions, each of which requires its own specific methods.

Search strategy and date. A systematic search was conducted on January 15, 2026 (final search date) across the following databases: Web of Science, Scopus, and Google Scholar (international scientific databases), as well as the World Bank, United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), Organization for Economic Co-operation and Development (OECD), PAX, Humanity & Inclusion (HI), and Insecurity Insight (gray literature). The following Boolean search strings were used (adapted for each database):

- String 1: ("war damage" OR "conflict losses" OR "economic cost of war" OR "environmental impact of war") AND (estimation OR assessment OR valuation OR "earth observation" OR "remote sensing") AND (methodology OR model OR approach OR framework).
- String 2: (war OR conflict) AND (damage OR loss) AND (assessment OR measurement) AND (economic OR human OR environmental).

The search was limited to English and Persian languages, and studies published from 1988 up to the final search date of January 15, 2026, were considered. The inclusion and exclusion criteria for articles and studies were as follows:

Inclusion criteria

- Articles and reports that present an explicit quantitative method for estimating damage caused by armed conflict.
- Studies that have used remote sensing data for mapping or damage estimation.
- Research that has compared or critiqued damage estimation methods.
- Case studies on the crises in Ukraine, Gaza, Syria, Lebanon, Sudan, Iraq, Yemen, and Afghanistan.
- Publication within the time frame of 1988 to 2026.
- English language or having a valid English abstract (for Persian sources).

Exclusion criteria

- Purely qualitative articles without presenting a specific quantitative method.
- Purely theoretical studies without practical application in a real crisis.
- Articles that solely address countries' military budget expenditures (not damage to civilians, infrastructure, and the environment).
- Duplicate articles or those without primary data.

Quality appraisal and risk of bias assessment.

To ensure the scientific rigor of the review, each included source was appraised against three quality criteria: (1) *methodological validity*—whether the study employed an explicit, replicable quantitative method with clearly stated assumptions; (2) *data transparency*—

whether the source documented the origin, coverage, and limitations of its data; and (3) *institutional independence and transparency of mandate*—whether the assessment was conducted by an institution with a declared mandate that could influence the framing or scope of the estimate. Based on these criteria, sources were classified as high, moderate, or low quality. Particular attention was paid to two forms of bias that are especially relevant to war damage estimation: *political framing bias* (the influence of how a conflict is labeled and framed on the choice of assessment components and final figures) and *methodological bias* (systematic distortions arising from the structure of a method itself. These bias assessments were then incorporated into the thematic analysis and are reflected in the comparative discussion of methods in Section 4 and Section 5.

Table1 presents the quality appraisal of the 67 included sources based on the three criteria (methodological validity, data transparency, and institutional independence and transparency of mandate), indicating the distribution of sources across high, moderate, and low-quality levels.

Table 1. Quality Appraisal of the 67 Included Sources

Quality level	Methodological validity	Data transparency	Institutional independence and transparency of mandate	Number of sources (n=67)
High	Explicit and replicable method	Fully documented data origin/limitations	Independent academic or audit institution	28 (41.8%)
Moderate	Method stated but limited assumptions	Partial data documentation	Institutional report with stated mandate	25 (37.3%)
Low	Vague or non-replicable method	Poor data documentation	Strong political framing evident	14 (20.9%)

(Note: The classification of each specific source is available in Appendix 1, the detailed classification of the included sources is provided in Appendix 1)

Screening and selection process of articles:

- The screening process was conducted in four stages in accordance with the PRISMA guidelines:
- Identification: The initial search in the databases led to the identification of 387 sources (See figure 1).
- Initial screening: Removal of duplicates (89 items) and review of titles and abstracts to remove irrelevant sources (192 items). 106 sources remained.
- Eligibility assessment: Full-text review of 106 sources and application of inclusion and exclusion criteria. 39 additional sources were removed (due to lack of quantitative method, lack of primary data, or irrelevance to war damage).

- Final inclusion: 67 sources were selected for final analysis, including 42 scientific articles, 15 reports from international organizations, and 10 reports from non-governmental organizations and research groups.

Data extraction and analysis

- For data extraction, a structured coding form was designed that included the following:
  - Bibliographic information (author, year, title, journal/publisher)
  - Type of damage estimation method
  - Type of damage (economic, human, environmental, infrastructural)
  - Geographical context (country/region involved)
  - Time frame of conflict and assessment
  - Data used (source, quality, limitations)
  - Strengths noted by the authors
  - Weaknesses and limitations noted
  - Reference to political or methodological biases

For data analysis, thematic analysis was used. Accordingly, first, the methods were classified into four main categories based on the type of approach. Then, for each category, the main themes (strengths, weaknesses, applications, challenges) were extracted. Finally, a comparative analysis between methods was conducted based on key criteria (accuracy, speed, data requirements, transparency, vulnerability to bias).

The PRISMA flow diagram summarizing the identification, screening, eligibility, and inclusion stages is presented in Figure 1.

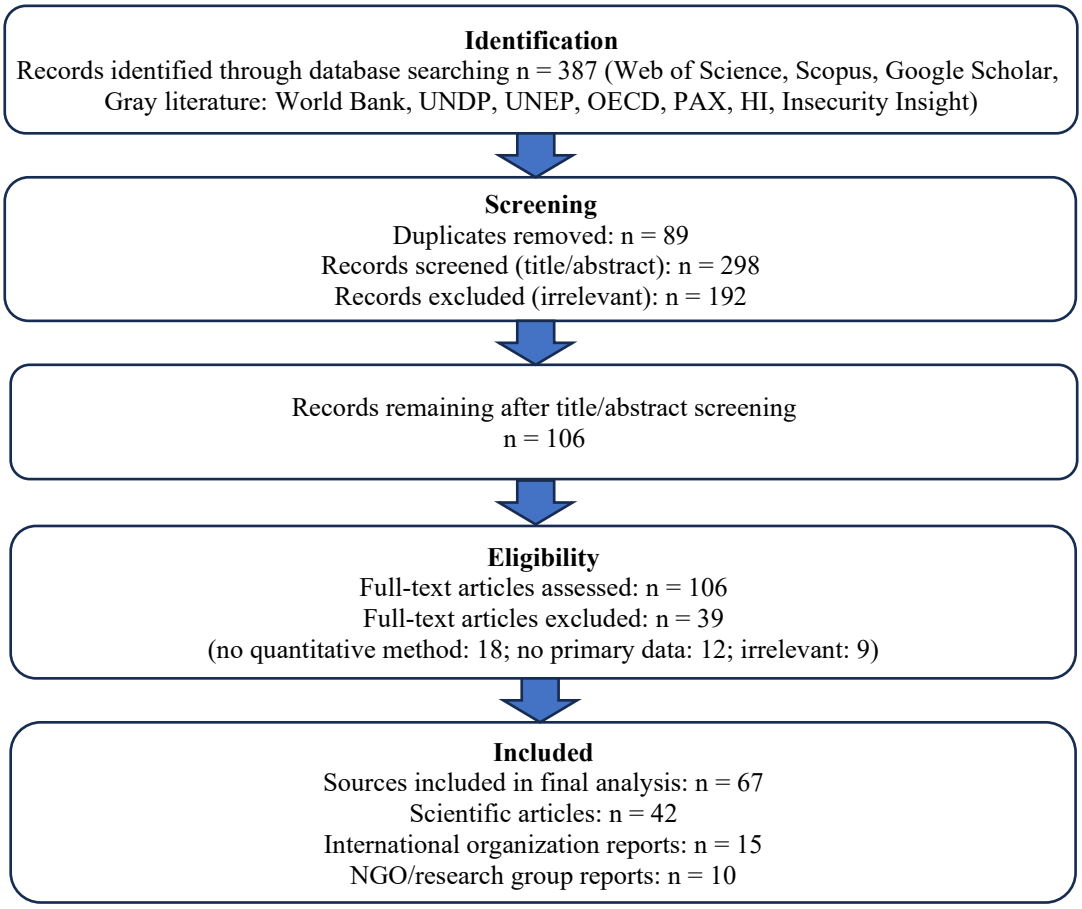

Fig. 1: PRISMA Flow Diagram of the Source Selection Process

4. Research Findings

Based on the analysis of the 67 selected sources, the methods for estimating war damage were classified into four main categories comprising five methodological approaches. The four categories are direct cost-based methods, econometric and assessment methods, human valuation methods, and remote sensing-based methods; within the second category, the Synthetic Control Method (SCM) and the Damage and Needs Assessment (DaNA) are treated as two distinct methodological approaches and are evaluated separately in Table 3. It should be emphasized that the four categories differ not only in their techniques but also in their fundamental methodological nature, and this distinction is essential for understanding their respective roles and limitations.

Table 2: Classification of War Damage Estimation Methods

Category	Subsets	Type and scope of damage covered
Direct cost-based methods	Partial estimation, replacement cost with upscaled unit values (UPVV)	**Physical and tangible** (housing, roads, schools, hospitals)

Econometric and assessment methods	Synthetic control method (SCM), damage and needs assessment (DaNA)	**Economic losses and recovery/reconstruction assessment**
Human valuation methods	Value of statistical life (VSL), present discounted value of lost income (PDV)	**Human** (loss of life, disabilities, human capital reduction)
Remote sensing-based methods	Satellite imagery (Sentinel, NASA), machine learning	**Observed physical** (mapping destruction, monitoring land use changes, water infrastructure)

4-1. Description of Methods and Case Studies

4-1-1 Direct Cost-Based Methods (CBDM)

Direct cost-based methods (CBDM) are the most widely used approach for estimating physical damage to infrastructure. These methods are based on calculating the cost of reconstruction or replacement of lost assets and are most widely used in estimating physical damage to infrastructure. One of these methods in the empirical literature is the UPVV method.

• Replacement Cost Method with Upscaled Unit Values (UPVV)

This method, which has its roots in the 1970s, provides a rapid estimate of damage by using fixed construction cost indices and indexing them based on inflation.

Case Study of Syria: In the joint damage assessment report by the World Bank and the United Nations for selected cities in Syria, the replacement cost method using pre-war prices (2010) was used as the basis for valuation. This report estimated the damage to various sectors (housing, health, education, energy, water and sanitation, agriculture, transportation) based on the number of damaged assets and the reconstruction cost of each unit. However, researchers have acknowledged that severe fluctuations in exchange rates and inflation in Syria have severely affected the accuracy of these estimates (World Bank and United Nations, 2022).

These figures are mainly calculated based on replacement-cost approaches. In Gaza, the extensive destruction of water and sanitation systems may substantially increase reconstruction costs, illustrating the importance of including sector-specific infrastructure needs in physical-damage assessments.

The main advantage of these approaches is their speed and operability in chaotic conditions, and their main limitation is ignoring non-physical economic losses (such as production stoppage, reduced tax revenues, and loss of human capital) and extreme sensitivity to price and inflation fluctuations.

4-1-2 Econometric and Assessment Methods

These methods, instead of calculating physical costs, estimate economic losses through statistical models and simulation. In the empirical literature, the following methods have generally been used to estimate economic losses.

4-1-3. Synthetic Control Method (SCM)

This method is a causal method that simulates potential economic growth in the absence of war by creating a synthetic unit from control regions (that have not experienced war). The difference between actual GDP and simulated GDP will be the estimate of war-induced loss. The validity of the estimates depends on the quality of the donor pool, pre-intervention data, and the plausibility of the counterfactual construction (Abadie & Gardeazabal, 2003). Case Study of Ukraine: Synthetic control studies have been used to estimate the economic effects of the Russia-Ukraine conflict by constructing a counterfactual based on comparable control units. The reliability of such estimates depends on the quality of pre-intervention data, the suitability of the donor pool, and the plausibility of the counterfactual assumptions.

4-1-4. Damage and Needs Assessment (DaNA) Method

DaNA is an established framework used by international organizations to assess physical damage, economic losses, and recovery and reconstruction needs. This method calculates damage using cost-based methods and loss through the difference in production levels before and after the war (United Nations Development Programme, 2022).

The main advantage of this method is its comprehensiveness and endorsement by credible international institutions, and its main limitation is its heavy dependence on field assessment teams (which is not possible in insecure conditions) and may be affected by institutional, contextual, and data-availability constraints.

4-1-5. Human Damage Valuation Methods (VHL)

The major part of war damage is non-market in nature and must be valued using specific methods. Amputation in war zones has revealed new dimensions of this challenge. In the empirical literature, the following methods have generally been used to value human damages.

• Value of Statistical Life (VSL): This is essentially a method for estimating individuals' willingness to pay to reduce the risk of death. This method is calculated based on revealed

preference studies (e.g., hazardous job wage premiums) or stated preferences (willingness-to-pay questionnaires).

• Present Discounted Value of Lost Income (PDV): To calculate the opportunity cost of lost labor force due to death or disability, the present value of the individual's future income stream is calculated using an appropriate discount rate.

Nevertheless, the main advantage of this method is that these methods can provide monetary estimates of selected human losses, but their interpretation requires careful consideration of ethical, distributional, and methodological assumptions.

4-1-6. Remote Sensing Data-Based Methods (EO)

Earth observation (EO) methods, which rely on satellite imagery and remote sensing data, play an important role in damage estimation, especially in conditions where field access is impossible or very dangerous. In this method, mapping is carried out using satellite imagery.

• Mapping Method through Satellite Imagery: Using multi-temporal satellite imagery (before and after the conflict) from Sentinel (European Space Agency), Landsat (NASA), and high-resolution commercial data, changes in land use, destruction of buildings, forests, agricultural land, and water infrastructure can be identified and mapped. Machine learning algorithms can accelerate the process of automatic detection of destruction patterns (Pax, 2025).

The main advantage of this method is providing spatially explicit evidence independent of field sources, the ability to cover vast and inaccessible areas, verifiability and reviewability, and reducing political biases, but it also faces limitations, including the method's need for high technical expertise, inability to estimate non-physical damages (such as economic and human losses), and the need for baseline data (before the conflict) for comparison.

4-2. Comparative Analysis of Methods

In this study, the war-damage estimation approaches were compared based on six key criteria, as summarized in Table 3.

Based on Table 3, no single approach can address all dimensions of war-damage estimation. The suitability of each approach depends on the research objective, the type of damage, data availability, and the assessment time frame. Direct cost-based methods are useful for rapid estimation of physical damage; SCM can provide causal estimates when the required data and identification assumptions are satisfied; DaNA provides a structured

assessment of damage, losses, and recovery needs; human valuation approaches address selected non-market human losses; and remote sensing provides spatially explicit evidence of observable physical destruction.

Criteria for comparison and basis of judgment. The six criteria used in Table 3 were selected to capture the dimensions most relevant to policymakers and researchers engaged in war-damage estimation: type and scope of damage covered, need for long-term data, speed of implementation, accuracy in crisis conditions, transparency and replicability, and vulnerability to political bias. To ensure that the comparative judgments in Table 3 are transparent and replicable, the basis for each rating is specified as follows.

To further clarify the basis of comparison, a three-level rating scale was used for each criterion: *high*, *moderate*, and *low*. A "high" rating indicates that the method performs strongly on that criterion relative to the alternatives reviewed (e.g., very fast implementation, high accuracy where reference data exist, or low vulnerability to bias); a "moderate" rating indicates partial or conditional performance that depends on data availability and context; and a "low" rating indicates a structural weakness inherent in the method (e.g., inability to capture non-observable damages, or high dependence on assumptions that are difficult to verify). Where a criterion is not applicable to a method (e.g., "need for long-term data" in the case of a purely physical replacement-cost estimate), this is indicated explicitly rather than assigned a rating. This scale is intended to facilitate comparison across methods, not to rank them in absolute terms, since the appropriateness of a method depends on the research question, the phase of the crisis, and the available data.

It should be noted that the comparative ratings in Table 3 reflect the synthesized evidence from the reviewed sources and are therefore subject to the limitations of those sources. In particular, ratings for accuracy in crisis conditions depend on the availability of reference data, while ratings for vulnerability to political bias depend on institutional context, methodological assumptions, and transparency of the assessment process.

Table 3: Comparison of Methods Based on Six Criteria

Criterion	Direct Method (CBDM/UP)	SCM	DaNA	Human Valuation (VSL/PDV)	Remote Sensing (EO)
Type and scope of damage covered	Physical only. Tangible assets (housing, infrastructure, roads, schools, hospitals).	Macroeconomic only. Production, exports, unemployment, investment.	Physical and economic. Combination of asset damage and income loss.	Human only. Loss of life, disabilities, human capital, long-term treatment costs.	Observable physical only. Buildings, agricultur, forests, water infrastructure.

Need for long-term data	Low. Requires initial maps, satellite imagery, and unit cost indices.	High. Requires sufficiently long pre-conflict time-series data and an appropriate donor pool	Moderate. Timing depends on data availability, field access, and assessment scope.	Moderate. Requires preference studies or demographic and wage data.	Moderate. Requires pre- and post-conflict satellite imagery.
Speed of implementation	Very high. Initial estimate within days.	Low. Requires data preparation and model specification before reliable estimation	Moderate. Timing depends on data availability, field access, and assessment scope.	Moderate to low. Requires adaptation to local conditions and discount rates.	High. A destruction map can be prepared quickly.
Accuracy in crisis conditions	Low. Due to price fluctuations, inflation, material shortages.	High, conditional. Reliability depends on identification assumptions and data quality.	Moderate to high, depending on data quality, field access, and assessment scope.	Moderate. Heavy dependence on assumptions (discount rate, income elasticity).	Moderate to high. Especially for vast and inaccessible areas.
Transparency and replicability	High. Clear formulas and indices.	High. Codifiable and reliant on mathematics/statistics.	Moderate. Physical part is transparent; loss part is less transparent.	Moderate. Depends on transparency of valuation assumptions and data sources.	High. Verifiable and reviewable data.
Vulnerability to political bias	Moderate. Choice of base index and scope of damage can change the result.	Moderate. Choice of base index and damage scope can affect results.	Moderate. Sensitive to model specification, donor-pool selection, and institutional context.	Moderate to high. Sensitive to valuation assumptions, income differences, and ethical choices.	Low to moderate. Provides spatially explicit evidence, but interpretation and classification choices may still introduce bias.

5. Discussion and Analysis of Findings

The findings of this systematic review showed that there is a deep gap between "what should be estimated" and "what is actually estimable" in the field of war damage. In the following, the most important challenges, biases, and opportunities identified are discussed.

5-1. Main Methodological Challenges

Heterogeneity of methods and incomparability of results. The most fundamental challenge revealed by this review is not simply that methods differ, but that they measure conceptually different quantities that cannot be aggregated or directly compared. Each method captures a distinct dimension of war damage: direct cost-based methods measure

the *stock of destroyed assets*, econometric methods measure the *flow of lost income*, human valuation methods measure the *monetary value of non-market human losses*, and remote sensing methods measure the *observable physical footprint* of destruction. A concrete illustration makes this clear: the derived from the replacement cost method, represents the accumulated loss of assets (housing, infrastructure, and capital stock), whereas the SCM-based estimate of a 30–35 percent reduction in Ukraine's GDP represents the loss of income flow (production, trade, and investment) relative to a counterfactual. These two figures are not two estimates of the same thing; they are estimates of different things. The first answers the question "how much would it cost to rebuild?", while the second answers "how much output has been foregone?". Treating them as comparable, or aggregating them, would constitute a category error. This conceptual heterogeneity prevents policymakers from obtaining a unified picture of total damage and creates serious ambiguity in reconstruction budgeting, because the two types of estimates imply different policy responses: asset losses call for reconstruction financing, while income losses call for economic stabilization and compensation (World Bank, 2023).

• The human capital challenge: Methods for valuing mortality and disability involve ethical and methodological assumptions. VSL and PDV estimates should therefore be interpreted cautiously, with attention to the assumptions used to transfer or adapt values across populations and contexts.

• The impact of institutional and methodological framing: The choice of assessment boundaries, indicators, data sources, and valuation assumptions can influence reported damage estimates. Transparent definitions and explicit accounting boundaries are therefore essential for comparing estimates across conflicts.

• Data and access limitations: In many war zones (such as Syria, Yemen, Sudan), reliable and long-term statistical data are not available, which makes the implementation of precise methods such as SCM impossible. Also, the access of field assessment teams to affected areas in insecure conditions is one of the biggest challenges of the DaNA method and causes estimates to be presented with significant delay and incomplete coverage (United Nations Environment Programme, 2022).

5-2. Opportunities and New Solutions

• The role of modern technologies and remote sensing data: Remote sensing and satellite imagery can support spatially explicit mapping of observable destruction, particularly where field access is restricted. Such data can complement field-based assessments and

provide an additional source for cross-checking physical-damage estimates. However, remote sensing alone cannot estimate non-observable human or macroeconomic losses.

• Artificial intelligence and machine learning: Machine-learning algorithms can support automated or semi-automated analysis of satellite imagery and may improve the speed and scalability of damage detection. Their reliability nevertheless depends on training data, image quality, and the transferability of models across conflict settings.

• International cooperation and standardization: International organizations such as the World Bank, the United Nations Development Programme, and the United Nations Environment Programme can help reduce the heterogeneity of methods and increase the comparability of results by creating standard frameworks and shared databases. Also, developing a global protocol for valuing human and environmental damages can reduce existing structural biases (United Nations Development Programme, 2022; United Nations Environment Programme, 2022).

5-3. The State of Research in Iran and Existing Gaps

Based on the search conducted in domestic scientific databases (Noormags, Magiran, Elmnet, and SID), the review identified limited directly relevant Iranian literature on quantitative methods for estimating war damage. The available evidence did not provide a sufficient basis for a separate methodological synthesis of Iranian studies. This finding should therefore be interpreted as a limitation of the search and evidence base rather than as evidence that no relevant Iranian research exists.

5-4. Limitations of the Review

This systematic review has several limitations that should be acknowledged. First, a quantitative meta-analysis was not possible due to the severe heterogeneity of methods and data across the included studies; the review therefore remains qualitative and comparative in nature. Second, although a comprehensive search strategy was employed, access to some gray literature sources—particularly reports from national institutions in conflict-affected countries—was limited, and some relevant sources may have been missed. Third, the review focused on studies published in English or with a valid English abstract, which may have excluded relevant Persian-language or Arabic-language sources. Fourth, the quality appraisal of sources relied on the authors' judgment against three criteria (methodological validity, data transparency, and institutional independence and transparency of mandate), and inter-rater reliability was not formally assessed. Fifth, the proposed three-phase framework is a synthesis of existing methods rather than an empirically validated model;

its operational effectiveness in future crises remains to be tested. Finally, the comparative ratings in Table 3 reflect the synthesized evidence from the reviewed sources and are therefore subject to the limitations of those sources, as discussed in Section 4.

6. Conclusion

Based on the findings of this systematic review, no single method can address all dimensions of war-damage estimation. Reliance on a single method may result in an incomplete estimate when important dimensions of damage fall outside its scope. The four main categories—direct cost-based, econometric and assessment, human valuation, and remote sensing-based—contain five methodological approaches that differ in their strengths, limitations, and data requirements:

• Direct cost-based methods are suitable for rapid estimation of physical damage but may be sensitive to price fluctuations, unit-cost assumptions, and the scope of physical damage captured.

• SCM can provide causal estimates when adequate pre-intervention data, a suitable donor pool, and credible identification assumptions are available.

• DaNA provides a structured framework for assessing damage, losses, and recovery or reconstruction needs, but its implementation may be constrained by data and field-access requirements.

• Human valuation methods can incorporate selected non-market human losses but require careful treatment of ethical, distributional, and methodological assumptions.

• Remote sensing methods provide spatially explicit evidence of observable physical destruction but cannot by themselves capture non-observable economic and human losses.

Based on the findings of this study and with the aim of more comprehensive coverage of damage dimensions, a three-phase combined model is proposed in which, depending on the time frame after the crisis, an appropriate combination of methods is used:

First phase (rapid response: 0 to 3 months after the conflict)

Objective: Attracting immediate international aid and initial decision-making. *Proposed method:* Using the replacement cost method with upscaled unit values (UPVV) for the initial estimation of physical damage to infrastructure. Complemented with remote sensing data to cover inaccessible areas and independently verify damage. *Output:* Initial estimate of physical damage (in dollars) for submission to international institutions.

Second phase (macro estimation: 3 to 12 months after the conflict):

Objective: Accurate estimation of macroeconomic losses and medium-term reconstruction planning. *Proposed method:* Implementing the synthetic control method

(SCM) to estimate GDP reduction and productivity loss. Complemented by using the standard DaNA (Damage and Needs Assessment) framework of the World Bank and the United Nations to create comparability with other crises. *Output:* Estimation of macroeconomic loss and sector-disaggregated reconstruction needs.

Third phase (full valuation: after 12 months)

Objective: covers all physical, human, economic, and environmental dimensions. Although the three phases are presented in chronological order, they are complementary rather than mutually exclusive. Updates may be incorporated as new data become available, while the accounting boundaries of each phase should remain distinct to prevent double counting. In other words, the second phase refines the estimates of the first phase, and the third phase complements the estimates of the second phase, without requiring the process to be restarted. Proposed method: Comprehensive valuation using a combination of the Value of Statistical Life (VSL) for fatalities, the Present Discounted Value of Lost Income (PDV) for disabilities and human capital reduction, and environmental cost-benefit methods, with careful separation of the components already estimated in the previous phases. Output: A final comprehensive estimate of total war damage, covering physical, economic, human, and environmental dimensions, for historical, legal, and compensation purposes.

Distinguishing damage, loss, and reconstruction needs. A crucial conceptual requirement for any combined framework is to clearly distinguish between three related but non-additive concepts: *damage* (physical asset loss), *loss* (economic flow loss), and *reconstruction needs* (future costs). Damage refers to the destruction of the **stock** of assets (e.g., a destroyed factory or a collapsed building). Loss refers to the reduction in the **flow** of income and production that results from the conflict (e.g., the factory's foregone output or the lost tax revenue). Reconstruction needs refer to the **future costs** required to rebuild and restore the damaged assets, which may exceed the pre-war replacement value due to inflation, improved standards, or the need for disaster-resilient infrastructure. These three concepts are not directly additive: adding the value of destroyed assets to the value of lost income would result in double counting, because the lost income is partly a consequence of the destroyed assets. Similarly, reconstruction needs are not simply equal to the assessed damage, as they include future costs that may not have been captured in the initial damage estimate. The proposed three-phase framework therefore explicitly separates these dimensions: Phase 1 estimates damage (stock), Phase 2 estimates loss (flow), and the reconstruction needs are derived from the damage estimate but adjusted for future costs and standards. This separation ensures that the final estimate does not conflate distinct

economic concepts and provides a clear basis for different policy responses: compensation for damage, stabilization for loss, and financing for reconstruction.

Rules for avoiding double counting. A critical operational requirement of any combined framework is the prevention of double counting, which arises when the same loss is estimated more than once across different phases. To address this, three rules are proposed. First, physical asset losses estimated in Phase 1 through the UPVV method should not be counted again in Phase 2 as reductions in GDP; the physical asset estimate and the GDP-based loss estimate should be defined using non-overlapping accounting boundaries. In other words, the loss of a residential building is an asset loss (Phase 1), whereas the loss of a factory's output is an income loss (Phase 2); only the latter should enter the GDP-based estimate. Second, the DaNA framework used in Phase 2 should explicitly separate damage (stock) from loss (flow), so that the physical component of DaNA does not duplicate the Phase 1 estimate. Third, human valuation in Phase 3 (VSL/PDV) must be conducted independently of physical damage estimates; care must also be taken not to count the same human loss twice. Adherence to these rules ensures that the three phases complement rather than duplicate one another.

Mathematical representation of non-duplication. To operationalize the rules above, the final comprehensive damage estimate can be represented as:

$$D_{total} = D_{physical} + L_{economic} + V_{human} + E_{environmental} - I_{overlap}$$

Where:

- $D_{physical}$ = Physical asset damage (Phase 1, UPVV).
- $L_{economic}$ = Economic flow loss (Phase 2, SCM/DaNA).
- V_{human} = Human valuation (Phase 3, VSL/PDV).
- $E_{environmental}$ = Environmental costs (Phase 3).
- $I_{overlap}$ = Intersection term representing only components demonstrably counted in more than one accounting component. It should be identified using explicit accounting boundaries rather than an arbitrary adjustment.

Figure 2 illustrates the operational logic of this framework, showing how the three phases are aggregated while subtracting the overlap term (I overlap) to prevent double counting.

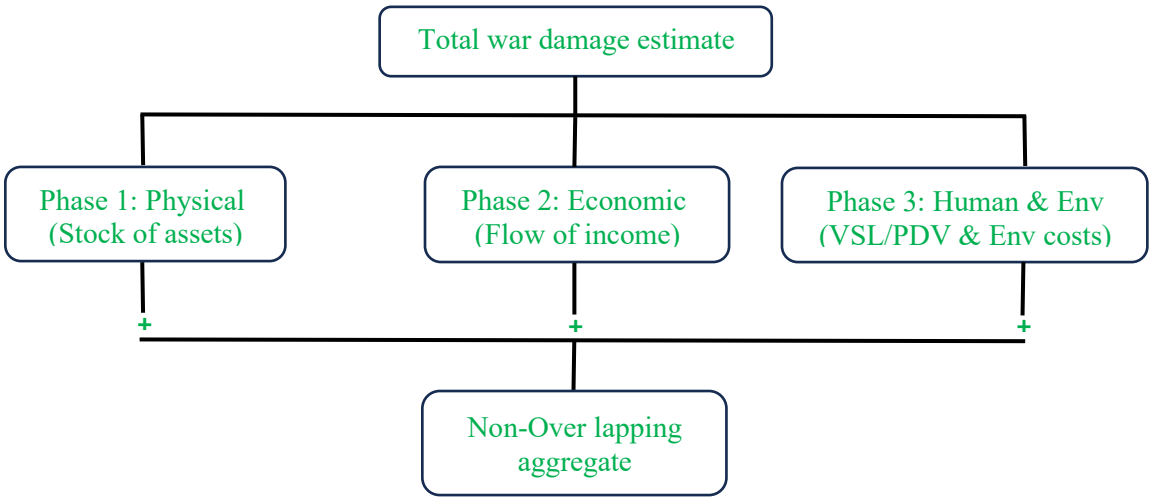

Fig. 2: Operational Logic of the Three-Phase Combined Framework for Avoiding Double Counting

Appendix 1. List of Sources Included in the Systematic Review

Editorial check required before final submission: reconcile this appendix with the eligibility window (1988–January 15, 2026). Sources published before 1988, a fter January 15, 2026, or containing unresolved bibliographic information should not be counted among the included studies.

	Tupe	References	Year	Vol.	No.	PP.	DOI
1	Journal Article	Abadie & Gardeazabal (2003). The economic costs of conflict: A case study of the Basque Country. *American Economic Review,* 93(1), 113–132	2003	93	1	113–132	https://doi.org/10.1257/00028803321455188
2	Journal Article	Collier (1999). On the economic consequences of civil war. *Oxford Economic Papers,* 51(1), 168–183	1999	51	1	168–183	https://doi.org/10.1093/oep/51.1.168
3	Journal Article	Miguel, Satyanath & Sergenti (2004). Economic shocks and civil conflict: An instrumental variables approach. *Journal of Political Economy,* 112(4), 725–753	2004	112	4	725–753	https://doi.org/10.1086/421174
4	Journal Article	Murdoch & Sandler (2002). Economic growth, civil wars, and spatial spillovers. Journal of Conflict Resolution, 46(1), 91–110	2002	46	1	91–110	https://doi.org/10.1177/022002702046001006
5	Journal Article	Koubi (2005). War and economic performance. *Journal of Peace Research,* 42(1), 67–82	2005	42	1	67–82	https://doi.org/10.1177/0022343305049667
6	Journal Article	Blattman & Miguel (2010). Civil War. *Journal of Economic Literature,* 48(1), 3–57	2010	48	1	3–57	https://doi.org/10.1257/jel.48.1.3
7	Journal Article	Smith (2013). The economic costs of military conflict. *Journal of Peace Research,* 51(2), 245–256	2013	51	2	245–256	https://doi.org/10.1177/0022343313496595
8	Journal Article	Dunne & Tian (2015). Military expenditure, economic growth and heterogeneity. *Defence and Peace Economics,* 26(1), 15–31	2015	26	1	15–31	https://doi.org/10.1080/10242694.2013.848575

9	Journal Article	Abadie, Diamond & Hainmueller (2010). Synthetic control methods for comparative case studies: Estimating the effect of California's tobacco control program. *Journal of the American Statistical Association,* 105(490), 493–505	2010	105	490	493–505	https://doi.org/10.1198/jasa.2009.ap08746
10	Journal Article	Abadie, Diamond & Hainmueller (2011). Synth: An R package for synthetic control methods in comparative case studies. *Journal of Statistical Software,* 42(13), 1–17	2011	42	13	1–17	https://doi.org/10.18637/jss.v042.i13
11	Journal Article	Abadie, Diamond & Hainmueller (2015). Comparative politics and the synthetic control method. *American Journal of Political Science,* 59(2), 495–510	2015	59	2	495–510	https://doi.org/10.1111/ajps.12116
12	Journal Article	Abadie (2021). Using synthetic controls: Feasibility, data requirements, and methodological aspects. *Journal of Economic Literature,* 59(2), 391–425	2021	59	2	391–425	https://doi.org/10.1257/jel.20191450
13	Journal Article	Bluszcz & Valente (2022). The economic costs of hybrid wars: The case of Ukraine. *Defence and Peace Economics,* 33(1), 1–25	2022	33	1	1–25	https://doi.org/10.1080/10242694.2020.1791616
14	Journal Article	Chupilkin & Koczan (2022). The economic consequences of war: Estimates using synthetic controls. *EBRD Working Paper* No. 271	2022	23	4	433–447	https://www.ebrd.com/home/news-and-events/publications/economics/working-papers/economic-consequences-of-war.html?utm_source=chatgpt.com
15	Journal Article	Audretsch, Momtaz, Motuzenko & Vismara (2023). War and entrepreneurship: A synthetic control study of the Russia-Ukraine conflict. *CESifo Working Paper* No. 10466	2023	30	1	3–33	https://www.ifo.de/en/cesifo/publications/2023/working-paper/war-and-entrepreneurship-synthetic-control-study-russia-ukraine?utm_source=chatgpt.com
16	Journal Article	McCannon (2022). The Economic Costs of Conflict: Ukraine, 2014–20. *SSRN working paper*	2022	125	—	103562	https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4118671&utm_source=chatgpt.com
17	Journal Article	Mancini, Conteduca & Borin (2024). The real-time impact of the war on Russian imports: A synthetic control method approach. *World Trade Review,* 23(4), 433–447	2024	11	9	nwae304	https://doi.org/10.1017/S1474745623000484
18	Journal Article	Jamsheed (2026). Causal impacts of the 2014 Russia-Ukraine conflict on machinery and pharmaceutical trade: A synthetic control analysis. *East Asian Economic Review,* 30(1), 3–33	2026	6	—	215	https://doi.org/10.11644/KIEP.EAER.2026.30.1.459
19	Journal Article	Kussul, Drozd, Yailymova, Shelestov, Lemoine & Deininger (2023). Assessing damage to agricultural fields from military actions in Ukraine: An integrated approach using statistical indicators and machine learning. *International Journal of Applied Earth Observation and Geoinformation,* 125, 103562	2023	XI-3-2026	—	539–548	https://doi.org/10.1016/j.jag.2023.103562
20	Journal Article	Holail *et al.* (2024). Time-series satellite remote sensing reveals gradually increasing war damage in the Gaza Strip. *National Science Review,* 11(9), nwae304	2024	16	—	12557	https://doi.org/10.1093/nsr/nwae304

21	Journal Article	Dietrich *et al.* (2025). An open-source tool for mapping war destruction at scale in Ukraine using Sentinel-1 time series. *Communications Earth & Environment,* 6, 215	2025	657	—	891–899	https://doi.org/10.1038/s43247-025-02183-7
22	Journal Article	Gapp *et al.* (2026). Efficient fine-tuning for building damage assessment with high-resolution optical satellite imagery: A case study for war damage in Ukraine. *ISPRS Annals* XI-3-2026, 539–548	2026	5	5	pgag124	https://doi.org/10.5194/isprs-annals-XI-3-2026-539-2026
23	Journal Article	Karwowska *et al.* (2026). Integrating optical and radar satellite data for conflict-related change detection in Ukraine. *Scientific Reports,* 16, 12557	2026	27	1	5–76	https://doi.org/10.1038/s41598-026-41424-3
24	Journal Article	Sticher, Bara, Kotajoki *et al.* (2026). Advancing conflict research and response through satellite-derived data. *Nature*, 657, 891–899	2026	1	3	285–304	https://doi.org/10.1038/s41586-026-11004-6
25	Journal Article	Van den Hoek *et al.* (2026). The destruction of Gaza: Satellite measurements of the economic cost of war. *PNAS Nexus,* 5(5), pgag124	2026	114	5	871–904	https://doi.org/10.1093/pnasnexus/pgag124
26	Journal Article	Viscusi & Aldy (2003). The value of a statistical life: A critical review of market estimates throughout the world. *Journal of Risk and Uncertainty,* 27(1), 5–76	2003	95	1	277–291	https://doi.org/10.1023/A:1023301308899
27	Journal Article	Rosen (1988). The value of changes in life expectancy. *Journal of Risk and Uncertainty,* 1(3), 285–304	1988	2	1	1–27	https://doi.org/10.1007/BF00055586
28	Journal Article	Murphy & Topel (2006). The value of health and longevity. *Journal of Political Economy,* 114(5), 871–904	2006	9	2	205–246	https://doi.org/10.1086/508033
29	Journal Article	Becker, Philipson & Soares (2005). The quantity and quality of life and the evolution of world inequality. *American Economic Review,* 95(1), 277–291	2005	16	2–3	247–274	https://doi.org/10.1257/0002828053828563
30	Journal Article	Hammitt & Robinson (2011). The income elasticity of the value per statistical life: Transferring estimates between high and low income populations. *Journal of Benefit-Cost Analysis,* 2(1), 213–226	2011	28	4	213–226	https://doi.org/10.2202/2152-2812.1009
31	Journal Article	Viscusi (2018). Best estimate selection bias in the value of a statistical life. *Journal of Benefit-Cost Analysis,* 9(2), 205–246	2018	13	1	111–118	https://doi.org/10.1017/bca.2017.13
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The contribution of all authors to the writing of the article has been equal.

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In adherence to ethical publication standards, the authors affirm that there are no conflicts of interest, either personal or financial, that could have influenced the content or conclusions presented in this research.

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امیرحسین منتظرحجت[۱]، محمد محبی[۲]

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چکیده

درگیری‌های مسلحانه، هزینه‌های فیزیکی، اقتصادی، انسانی و زیست‌محیطی قابل‌توجهی ایجاد می‌کنند. برآورد این خسارات بسته به روش‌شناسی، نوع خسارت، دسترسی به داده‌ها و اهداف ارزیابی متفاوت است. این مطالعه با مرور نظام‌مند روش‌های برآورد خسارات جنگ، چارچوبی یکپارچه برای ترکیب روش‌های مکمل و کاهش شمارش مضاعف ارائه می‌دهد. مرور نظام‌مند مطابق دستورالعمل PRISMA انجام شد. مطالعات و گزارش‌های نهادی منتشرشده از سال ۱۹۸۸ تا ۱۵ ژانویه ۲۰۲۶م. از پایگاه‌های علمی داخلی و بین‌المللی و منابع نهادی استخراج شدند. پس از غربالگری، ۶۷ منبع انتخاب شد. روش‌ها در چهار دسته طبقه‌بندی شدند: هزینهٔ مستقیم خسارت دارایی‌های فیزیکی؛ روش‌های اقتصادسنجی و ارزیابی، شامل روش کنترل مصنوعی (SCM) و ارزیابی خسارت و نیازها (DaNA)؛ ارزش‌گذاری انسانی، شامل ارزش یک زندگی آماری (VSL) و ارزش فعلی تنزیل‌شده (PDV)؛ و سنجش از دور برای اندازه‌گیری تخریب فیزیکی. هیچ روش واحدی تمامی ابعاد خسارات جنگ را پوشش نمی‌دهد. روش هزینهٔ مستقیم خسارات فیزیکی، SCM و DaNA زیان‌های اقتصادی و نیازهای بازسازی، VSL و PDV تلفات انسانی، معلولیت و زیان سرمایهٔ انسانی، و سنجش از دور تخریب مکانی را ارزیابی می‌کنند. تفاوت در مرزهای حسابداری، افق زمانی و منابع داده، می‌تواند موجب هم‌پوشانی برآوردها شود. چارچوب پیشنهادی سه مرحله دارد: خسارت دارایی‌های فیزیکی، زیان‌های اقتصادی و تولیدی، و هزینه‌های انسانی و زیست‌محیطی. تعریف مرزهای حسابداری و تعدیل اجزای هم‌پوشان برای کاهش شمارش مضاعف و افزایش دقت برآوردها ضروری است.

کلیدواژگان: برآورد خسارت جنگ، روش کنترل ترکیبی، ارزش آماری زندگی، ارزیابی نیاز پس از بحران، مرور نظام‌مند.
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