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System Dynamics Modeling to Forecast Economic and Financial Market Indicators Using Interrelationship of Shocks among Global Financial Markets

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Abstract:
Objective: In today's interconnected global economy, changes in one market can have ripple effects across related markets, making it essential for economic and financial policymakers and experts to accurately predict these mutual impacts. Various methods have been developed to forecast the impact and mutual impressions of financial markets. In this study, a generic framework is proposed for forecasting economic and financial market indicators using the interrelationship of shocks among global financial markets and a system dynamic approach.
Methods: To demonstrate the stages of the proposed generic framework and system dynamics modeling, as an example, the study forecasts the Iranian economic and the Tehran Stock Exchange indicators using their interactions with eleven major global financial markets, including London, Tokyo, Shanghai, Frankfurt, Paris, Milan, SIX Swiss, Istanbul, Korea, Bombay Stock Exchanges, and Dubai Financial Market. The New York Stock Exchange index return is used as a stimulant or driver for the other stock exchanges in the model.
Results: The results indicate that the proposed forecasting model successfully predicted Iranian economic and the Tehran Stock Exchange indicators. Furthermore, the study finds that while Iranian exports are sensitive to global financial markets, the sensitivity of imports and production returns to global financial markets is low.
Conclusions: The proposed generic framework and system dynamics modeling can provide valuable insights for predicting different economies using their interactions with the global economy and finances.

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1. Introduction

The world is evolving rapidly, leading to constant innovations and scientific advancements in various fields. However, the primary challenge of our modern era remains the ability to adapt to change. This includes financial markets, which have undergone significant transformations in recent years. Today, financial markets are no longer confined to specific geographic areas. They have become sophisticated information networks that send various types of data and transactions worldwide through advanced communication devices.

It is important to understand that financial markets, both financial and non-financial, are interconnected. Past events have shown that markets are not isolated and their trends are not confined to a single space. As markets interact with each other, their performance is systematically affected by the behavior and performance of other markets. For instance, Asian companies hold stocks in American or European companies and participate in their productions.

The interaction among stock markets is a critical issue that can help decision-makers forecast future trends. Due to the continuous interaction among financial markets, a system dynamic approach can be beneficial in predicting market behavior. It is crucial to note that the accuracy of predictions will be higher if the pattern of relations between variables is stronger.

Researchers in literature to model global financial markets have proposed various techniques. According to Murphy (2004; 1991), studying financial events from the 1980s reveals the importance of understanding the relationships between markets, whether financial or non-financial, domestic or international. Specifically, the stock market is strongly influenced by the bond market, which is in turn affected by the commodity market and is dependent on the United States dollar (USD). Moreover, international markets are impacted by USD as well. While it is widely acknowledged that financial markets interact and influence each other, as well as the real economy, a model that can systematically demonstrate the effects of financial markets on the real economy has yet to be identified.

The interaction between financial and real markets across the world means that changes in one market can affect related markets to varying degrees. Accurately predicting these mutual effects is of significant interest to financial and economic policymakers. Numerous methods have been developed for predicting the impact and mutual impressions of markets. This article proposes a generic framework for predicting the economic and financial indicators of a country based on its interactions with other related countries, using a dynamic system approach. The framework is applied to the case of Iran to explain its mechanism.

To formulate the forecasting dynamic model, regression models are estimated to predict the returns of twelve financial market indices (New York, London, Tokyo, Shanghai, Frankfurt, Paris, Milan, SIX Swiss, Istanbul, Korea, and Bombay and Dubai financial markets), as well as returns of commodities in the real economy sector (oil, gold, metals, and mineral price indices). The system dynamics approach is then applied using Excel, E-views, and Vensim software. Finally, using the regression equations and system dynamics, the returns of the Iranian stock market index, as well as exports, imports, and production, are simulated for the period of 2005-2011.

2. Literature review

Globalization of financial markets regards as the main reason of market's relations. The globalization of financial markets is internationalization of them and intensifying their relationships (Calabrò et al., 2011). Although financial globalization confers notable benefits, it also entails huge costs including financial crisis because irrational trades or crisis in one region can move to other markets or regions (Obadan, 2006)

Murphy (1991, 2004) states that one of the subjects to be learned from these events is the relationships between markets, whether financial or non-financial, whether domestic or international. The findings indicate that the stock market is strongly influenced by the bond market, the bond price in turn is affected by commodity market, and this market is dependent to the United States dollar (USD). Finally, international markets affected by USD.

Liow (2008) examines–the changes in long run and short term associations among the US, UK and eight Asian real estate securities markets before, during, and after Asian financial crisis. He found a rising trend in market interdependence in Asian real estate securities markets in the long and short term since the Asian financial crisis. Moreover. He concludes that the stronger market relationship between the Asian and US markets encourages a portfolio combination of these markets is less likely to provide diversification benefit in the form of minimum risk.

Awokuse et. al (2009), examined the structural changes and international markets dependency. They investigated the evolving pattern of the interdependence among selected Asian emerging markets and three major stock markets (Japan, UK and US). They found time-varying co-integration relationships among these stock markets. Their results showed that wave of financial liberalization policies in the early 1990s led to a significant growth in the market connections, which later, during the Asian financial crisis in 1997, weakened. Moreover, they indicated that japan and United States have more influence on the emerging markets while Singapore and Thailand's influences have increased since the Asian financial crisis.

Katsanos (2010), shows that an analyst can predict the future equity and index price movements by introducing custom indicators and inter-market-based systems by examining the relationship between these markets. He provided a total of 29 convention and 5 neural network-trading systems to trade gold, the

S&P ETF (SPY), S&P e-mini futures, DAX and FTSE futures, gold and oil stocks, commodities, sector and international ETF, and the Yen and the Euro.

Huyghebaert and Wang (2010), investigate the integration and causality of interdependencies between seven great East Asian stock exchanges before, during and after the Asian financial crisis in 1997-1998. For this aim, he used daily stock market data from July 1, 1992 to June 30, 2003 in local currency and USD. The data showed that the relationships between East Asian Stock markets vary through time.

Kenourgios et. al (2010), studied financial contagion in a multivariate time-varying asymmetric framework by focusing on two developed markets (U.S. and U.K.) and four emerging equity markets including Brazil, Russia, India, and China (BRIC). Their empirical evidence confirms a contagion effect from the crisis country to other countries. The results showed that emerging BRIC is more bowed to financial contagion while turmoil in the industry -specific has a larger impact than country-specific crises.

Samarakoon (2011), examined the transmission of shocks between the U.S. and foreign markets to specify interdependence from the contagion of the U.S financial crisis by constructing shock models for partially overlapping and non-overlapping markets. The results demonstrate that contagion is driven more by emerging market shocks and interdependence is driven more by U.S. shocks.

Filis et. al (2011), examined the time-varying correlation between stock market prices and oil prices for oil exporting and importing countries. They used a DCC-GARCH-GJR approach to test the above hypothesis in six countries, which included USA, Germany, Netherlands as the oil importing, and Brazil, Canada, and Mexico as the oil exporting countries. The results showed that in periods of significant economic turmoil, the oil market is not safe for offering protection versus stock market losses.

Sandoval and Franca (2012), demonstrated that the high volatility of markets is directly related to the strong correlation between them. They used the eigenvalues and eigenvectors of correlation matrices of the main financial market indices in the global financial markets and showed that fluctuation of markets is directly linked with strong correlations between them. For this purpose, they examined several financial market crises that had taken place in 1987 (Black Monday), 1989 (Russian Crisis), 2001 (Burst of the dot-com bubble and September 11) and 2008 (Subprime Mortgage Crisis).

Today, the correlation between financial markets, monetary markets and real economy has become a basic phenomenon in economics and trade. This correlation can be found both between domestic markets and between domestic markets with international and global markets. Kaur and Arora (2018) argue that very few studies conducted on the subject of mutual interdependence among domestic financial markets in developing countries like India. They examine the level of correlation and co-integration among the different financial markets in

India. They provide evidence of interdependence among the stock market, currency market, government bonds and commodity market.

Law (2019) indicates that how there is a correlation between a country's foreign exchange reserves and the exchange rate or values. He investigates the impact of foreign exchange reserves on the value of the Korean won relative to the US dollar using a comparison of linear and nonlinear autoregressive distributed lag estimation. Using nonlinear models, he found that only the reduction in the reserves would cause the Korean won to appreciate in the long term. In the short run, variations in the foreign exchange reserves are significant.

Apergis & Eleftherion (2019) investigate the roles of both the 2008 global financial crisis and the Greek sovereign crisis in the Greek banking system. They found that the actual determinants that drive the banking system that were responsible for driving the Greek economy into the austerity programs. They show evidence of effects of global financial markets’ situations on the national economy and its banking system.

Bhandari and Kamaiah (2020) argue that in the literature on global market integration, the strength of interdependence measured using different methods. Using novel time-frequency based wavelet techniques; they analyze the interdependence of global equity markets from a heterogeneous investor perspective, with a special focus on the Indian stock market.

There are many examples in literature to express the mutual effects and transmission of shocks between countries. For instance, Muhammad Zubair Chishti (2021) explore the effects of oscillations in the exchange rate on bilateral trade between Pakistan and its major trading partner Saudi Arabia. Gupta and Vershney study the impact of exchange rate volatility on the trade flow between India and U.S.

Umar Muhammad Dabachi, et al. (2021) examined the interaction effect of energy price on the relationship between financial instability, trade openness and non-OPEC countries economic growth. The results revealed a long run relationship among the variables in non-OPEC countries. They showed that financial instability have negative effect on economic growth, while, trade openness has positive effect on the economic growth. Additionally, the results confirmed that the interaction term of energy prices and financial instability is negatively affecting the economic growth, but interaction term of energy prices and trade openness is positively affecting the economic growth of non-OPEC countries (emerging ASEAN economies).

In Iran, Hashem Botshekan et al. (2021) investigated the dynamic correlation between the Global Economic Policy Uncertainty index (GEPU) and Non-Performing Loans (NPL) in Iran in the period from 2004 to 2021. They show that Iranian banks' Non-Performing Loans (NPL) are rather associated with Global Economic Policy Uncertainty (GEPU) during major global shocks such as the global financial crisis in 2008 or the Covid-19 pandemic probably because of sanction. To prove this claim we estimate the model for some countries with an open economy, like Japan, Singapore, the US, Turkey, and Spain. The result shows that this correlation is much higher in comparison to Iran.

Salahmanesh, et al (2023) study the Impact of Market Penetration Costs and Rival Countries' Exports on Iran’s Cement Export Profits in an Oligopoly Framework. They showed that the exports of competitors had a negative impact on Iran’s annual cement exports and that the share of penetration costs increased. Their research confirms the significance of this effect on the country's export profits.

Jamel Eddine Mkadmi et al (2023) investigate the relationship between COVID-19 pandemic, healthcare system, corporate governance and firm performance in developing countries. They examine the influence of COVID-19 on firm performance in a period between 2019 and 2020. The findings stipulated that during the COVID-19 epidemic, firm performance decline and that the COVID-19's negative impacts on company performance are less prominent in nations with more sophisticated healthcare systems, financial systems, and institutions.

Based on the existing interactions among the financial and real markets of the global economies, this article aims to provide a generic framework to predict the economic and financial indicators of a country based on its interactions of shocks among the Global Financial Markets using a dynamic system approach.

3. Material and Methods

This research provides a generic framework to forecast the economic and financial market performance of a given country by utilizing its interactions with other related financial markets performance and a system dynamic approach. The aim of this study is applied in nature, as opposed to basic research, which seeks to explore fundamental principles. Applied research focuses on addressing specific problems in practical situations, drawing on the findings of basic research as a starting point (Salkind, 2011).

The research methodology employed in this study combines econometric methods in time series analysis with simulation based on system dynamics for system modeling. System modeling provides an interactive environment in which researchers can manipulate the elements of the system and observe the resulting changes. Modeling is the process of creating a substitute for a real system, which enables researchers to gain insights through experimentation. Simulation involves conducting experiments using a model (Mi et al., 2011).

The following steps were implemented to achieve the objectives of this research:

- Defining the purpose of prediction.
- Identifying the variables that need to be predicted.
- Identifying the system components or elements.
- Explaining the interactions between the system components.

- Formulating prediction equations to determine cause-and-effect relationships.
- Using a system dynamic approach, creating an interactions network and determining the positive and negative effects of each variable or component on the other variables or components in the network.
- Implementing a simulation method to forecast the behavior of the variables.
- Analyzing and interpreting the findings and results.
- Assessing the findings and results.
- Repeating the process when the findings and/or results are not satisfactory.

3.1 The variables

In this study, the variables utilized are the returns of stock indices from markets that have significant trade relations with Iran in terms of commodity and service exports, as well as the returns of oil prices, gold prices, metals and mineral index. Table 1 illustrates the percentage of Iran's imports from 2005 to 2011.

Table 1: Portion of Iran's imports (2005- 2011)

Rank	Countries	Imports (USD)	Portion
1	United Arabic Emirates	92,331,271,828	26
2	Germany	33,606,787,002	10
3	China	31,947,516,072	9
4	Republic of Korea	21,450,300,154	6
5	Switzerland	16,855,452,239	5
6	France	14,184,723,594	4
7	Italy	13,291,579,386	4
8	Turkey	12,067,247,371	3
9	India	9,304,354,877	3
10	Japan	9,192,792,401	3
11	England	8,999,196,530	3
Total		263,231,221,454	75

Dynamic relationships are formulated between the stock market indices of Tehran, New York, London, Tokyo, Shanghai, Frankfurt, Paris, Milan, SIX Swiss, Istanbul, Korea, Bombay, and Dubai, as well as the price returns of oil, gold, and metals and mineral index, using econometric and system dynamics tools such as Excel, E-views, and Vensim. Finally, the obtained results of the financial market relationships are used to analyze the influence of these variables on Iran's real economy, including exports, imports, and production from 2005 to 2011 as example.

According to the above description, in this study, the following variables are used:

- *NYSE Composite Index:* this index covers all common stock listed on the New York Stock Exchange and comprises over 2000 U.S. and foreign stocks.

- *TEPIX*: This index is the major indicator of stock price movements in the Tehran Stock Exchange and represents the weighted market value of all stock prices.
- *FTSE 100 Index*: This index is comprised of blue-chip stocks listed on the London Stock Exchange and consists of the 100 companies with the highest market capitalization.
- *DAX:* This index is comprised of blue chip stocks listed on the Frankfurt Stock Exchange and consists of 30 major German companies.
- *CAC 40 index:* This index is widely used in the Paris stock exchange and consists of 40 largest French stocks terms on market capitalization.
- *FTSE MIB index:* This index is the benchmark stock market index on the Milan Stock Exchange and comprises 40 most liquid and capitalized Italian stocks.
- *SMI index:* This index includes20 top blue chip companies in the SIX Swiss Exchange, making it the most important index in the market.
- *XU100 index*: This index is the main indicator of stock market index in Istanbul Stock Exchange and measures the 100 selected companies in this market.
- *DFM General Index:* This index is a free-float market capitalization weighted price index on Dubai Financial Market and consists of the stocks listed companies in this market.
- *NIKKEI 225 index:* This index is the weighted price average of top 225 blue-chip Japanese companies listed on the Tokyo Stock exchange.
- *KOSPI Composite Index:* This index is a weighted capitalization index of all common stocks traded on the Korea Stock Exchange.
- *Shanghai Composite Index:* This index is a weighted capitalization index on the Shanghai Stock Exchange that comprises all S-shares and B-shares traded on this market.
- *BSE SENSEX:* This index is a free-float capitalization weighted index on the Bombay Stock Exchange and comprises 30 of major stocks traded on this market.
- *Oil Price:* This variable is the average spot price of crude oil the equally weighted on Brent, Dubai and West Texas Intermediate.
- *Gold Price:* This variable represents the average of daily rates of gold on the London afternoon fixing.
- *Metals and Minerals index:* This index includes the world prices of aluminum, copper, iron ore, lead, nickel, tin and zinc.
- *Iran's exports:* This variable represents the amount of Iran's exports.
- *Iran's imports:* This variable represents the amount of Iran's imports.
- *Iran's production:* This variable represents the amount of industrial productions in Iran.

To obtain the relevant data for the study, we used various sources such as Tehran and other stock exchanges, the World Bank, Yahoo Finance, and the Chamber of Commerce and Industries of Iran.

3.2 The methodology

Calculating the simple return is the first step. The next step is to calculate the regression equations, which consist of two parts. The non-randomized, controllable, or deterministic component, and the randomized, uncontrollable, or error component. The third step is to calculate the Ordinary Least Squares (OLS) to select the best-fitting line based on sample data. To achieve the minimizing of the residual sum of squares, Equation (1) is used.

$$\sum_{t=1}^{n} u^2 = \sum_{t=1}^{n}(y_t - \hat{y}_t)^2 = \sum_{t=1}^{n}[y_t - (\hat{a} + \hat{b}x_t)]^2 = \sum_{t=1}^{n}[y_t - \hat{a} - \hat{b}x_t]^2 \quad (1)$$

In a linear regression model, the residual value, real value in time t, and predicted value in time t are denoted by u, y_t, and xt, respectively. To calculate the coefficients â and $\hat{b}$, the partial derivatives with respect to â and $\hat{b}$ must be set to zero, and solving these equations simultaneously yields (2) and (3).

$$\hat{b} = (\sum x_t y_t - n\bar{x}\bar{y}) / (\sum x_t^2 - n\bar{x}^2) \quad (2)$$

$$\hat{a} = \bar{y} - \hat{b}\bar{x} \quad (3)$$

Where $\bar{x}$ and $\bar{y}$ represent the mean (average) of the x and y values, respectively. After obtaining the coefficients, Goodness-of-fit statistics are used to test the extent to which the sample regression function fits the data. (Brooks, 2008). The most important criteria for measuring goodness of fit are the coefficient of determination (R2) and the adjusted coefficient of determination $(\bar{R}^2)$. (Hirschey, 2008) Equation (4) and (5) show how to calculate (R2) and $(\bar{R}^2)$, respectively. Where the variables n and k represent the number of observations and estimated coefficients, respectively.

$$R^2 = 1 - [\sum (y_t - \hat{y})^2 / \sum (y_t - \bar{y})^2] \quad (4)$$

$$\bar{R}^2 = 1 - (1 - R^2)[(n-1)/(n-k)] \quad (5)$$

The model relies on five key assumptions, which can be tested with sufficient data. These include:

1. *Zero mean assumption:* The error term has a mean or zero, denoted as $E(u_t) = 0$
2. *Homoscedasticity assumption:* The error term has a constant variance, represented by $var(u_t) = \sigma^2$. The validity of this assumption is investigated in this research using the ARCH (Autoregressive Conditional Heteroscedasticity) test.

3. *Non-Auto correlated assumption:* The error terms are assumed to be non-correlated with each other over time, or in other words, the covariance of error terms is zero. Auto-correlation is assessed using different tests, such as the Breusch-Godfrey test. (Breusch, 1978; Godfrey, 1978).
4. *Independence between error and deterministic component:* The error term in the equation is uncorrelated with the independent variable(s), represented as $cov(u_t, x_t) = 0$
5. *The normality assumption:* The error terms are assumed to be normally distributed. However, if this assumption is violated, OLS estimators remain the best linear unbiased estimator (Gordon, 2012; Rawlings et. al, 1998).

In practice, these assumptions may not always hold true and at least one of them is often violated. This study examines assumptions (2) and (3) due to their significance.

3.2.1 Testing the stationery of time series

Stationarity is a crucial assumption in time series analysis. Non-stationary time series, when used in regression models, can result in spurious regression. Such regression may have a high coefficient of determination (R^2) and seemingly significant outcomes such as F and t statistics. However, its estimated residuals may exhibit a high degree of autocorrelation, rendering the least squares estimator, predictors, and test statistics unreliable and misleading. Since most of time series data display non-stationary behavior, statistical techniques have been developed to ensure that only stationary time series data is used in regression analysis (Tang et al., 2012). A time series is considered stationary when its mean, variance, and covariance remain constant over time. To determine whether a time series is stationary, several tests are available, with the augmented Dickey-Fuller unit root test being the most common. Dickey and Fuller (1979) introduced three different regression equations for a zero-lag length. If the number of lags is greater than zero, the expanded equations can be written as follows (Lim, 2011):

$$\Delta Y_t = \gamma Y_{t-1} + \beta_1 \Delta Y_{t-1} + \beta_2 \Delta Y_{t-2} + \ldots + \beta_k \Delta Y_{t-k} + \varepsilon_t \qquad (6)$$

$$\Delta Y_t = \delta + \gamma Y_{t-1} + \sum_{j=1}^{k} \beta_j \Delta Y_{t-j} + \varepsilon_t \qquad (7)$$

$$\Delta Y_t = \delta + \theta t + \gamma Y_{t-1} + \sum_{j=1}^{k} \beta_j \Delta Y_{t-j} + \varepsilon_t \qquad (8)$$

The difference among these three equations lies in the presence or absence of a constant and trend (represented by δ and θ_t). Equation (6) does not include a constant or trend. Equation (7) includes a constant. Equation (8) includes both a constant and a time trend.

3.2.2 System dynamics simulation

System dynamics is a theory based on the analysis of systems, with systematic thinking as a tool for understanding the relationships between structures, patterns, and events to identify root causes of issues (Soliman, 2005). A system is defined as an entity made up of combined, separate, but interdependent components (Heffernan et al., 2011), and the current world consists of interrelated operating markets that constitute a supra system.

System dynamics simulation is used to investigate the relationship between global financial markets and was created by J. Forrester in the 1950s. It combines theory, philosophy, and methods to analyze the behavior of a system (Müller, 2011). System dynamics is a methodology and mathematical modeling technique used to understand complex problems and issues. The dynamics of the financial system require consideration of changing variables over time, as the financial system cannot be assumed to be static.

System dynamics relies on feedback mechanisms, specifically causal loop diagrams. Feedback in a cause-and-effect system refers to information, decision, or action signals from the cause(s) to effect(s) (Meyers, 2010). Analyzing feedback loops can offer quantitative insight into a system's long-term behavior and serves as a means of representing mental models. Therefore, causal loop diagrams serve as a solid foundation for constructing a system dynamics model (Albach et al., 2012). The second crucial concept in creating a system dynamics model is stock and flow diagrams. In system dynamics, a stock denotes accumulation and the state of a variable. Mathematically, a stock represents the integral of one or more flows over time. In addition, a flow signifies the change in a stock and is measured per unit of time. Stock and flow diagrams are used in computer simulations.

4. The Results

4.1 Results of stationarity analysis of time series

In this study, we employed the Augmented Dickey-Fuller (ADF) unit root test to examine the stationarity of the time series. To determine the appropriate number of lags, we used the Schwarz information criterion and selected up to 11 lags. The results of the ADF test for the original series showed that they were not stationary. Therefore, we used the returns of the variables instead of their actual values. The results of the ADF test for the returns presented in Table 2.

Table 2: Results of augmented Dickey-Fuller unit root test

Variable	Lag	t-Statistic	1% MacKinnon Critical value	Result
R TEPIX	0	-5.948815	-3.512290	Stationary
R NYSE Composite Index	0	-7.134292	-3.512290	Stationary
R FTSE 100	0	-8.139310	-3.512290	Stationary
R NIKKEI 225	0	-7.629881	-3.512290	Stationary
R Shanghai Composite Index	0	-7.928133	-3.512290	Stationary
R DAX	0	-7.583623	-3.512290	Stationary
R CAC 40	0	-7.381500	-3.512290	Stationary
R FTSE MIB	0	-3.851572	-3.514426	Stationary
R SMI	0	-6.458942	-3.512290	Stationary
R XU 100	0	-8.777292	-3.512290	Stationary
R KOSPI Composite Index	0	-9.053857	-3.512290	Stationary
R BSE SENSEX	0	-7.849198	-3.512290	Stationary
R DFM	0	-6.829015	-3.512290	Stationary
R Oil Price	0	-6.056286	-3.512290	Stationary
R Gold Price	0	-8.929010	-3.512290	Stationary
R Metals & Minerals Index	0	-5.642191	-3.512290	Stationary
R Exports	0	-8.773348	-3.512290	Stationary
R Imports	0	-10.51623	-3.512290	Stationary

We found that all of the time series for returns were stationary, as the ADF test, statistic values were lower than the Mackinnon critical values at the 1% significance level. It is worth noting that the symbol 'R' before the variable names indicates simple returns.

4.2 Regression equations

Regression equations can be formulated in various ways. In this study, we first consider one variable as the dependent variable and then include all variables into the model. After estimating the regression equation, we sequentially eliminate non-significant variables until only the significant variables remain in the model. Finally, we exclude variables that create simultaneous loops or slightly increase the adjusted coefficient of determination, due to the limitations of the system dynamic model. The resulting regression equations presented below:

■ Tehran Stock Exchange Price Index Returns (R TEPIX)

R TEPIX= C(1)+ C(2)*R CAC 40+C(3)*R FTSE MIB+C(4)*R Metals & Minerals Index+ C(5)* R Gold Price+C(6)*R TEPIX(-1) (9)

■ London Stock Exchange Index Returns (R FTSE 100):

R FTSE 100=C(1)+ C(2)*R NYSE Composite Index+ C(3)*R NIKKEI 225 +C(4)* FTSE 100 (10)

■ Tokyo Stock Exchange’s Index Return (R NIKKEI 225):

NIKKEI 225= C(1)+ C(2)*R NYSE Composite Index +C(3)*R XU100 +C(4)* TEPIX(-1) (11)

■ Shanghai Stock Exchange Index Return (R Shanghai Composite Index):

R Shanghai Composit Index=C(1)+ C(2)*R NYSE Composite Index+C(4)*R Gold Price(-1)+C(5)*R DFM(-1) (12)

■ Frankfurt Stock Exchange Index Return (R DAX):

R DAX= C(1)+ C(2)*R NYSE Composite Index+C(3)*R NIKKEI 225(-1)+ C(4)* R SMI (-1) (13)

■ Paris Stock Exchange Index Returns (R CAC 40):

R CAC 40= C(1) + C(2)*R DAX (14)

■ Milan Stock Exchange Index Return (R FTSE MIB):

R FTSE MIB = C(1)+ C(2)*R CAC 40 (15)

■ Swiss Stock Market Index Return (R SMI):

R SMI = C(1)+ C(2)*R CAC 40 (16)

■ Istanbul Stock Exchange Index Return (R XU 100):

R XU 100 = C(1)+ C(2)*R Shanghai Composit Index+C(3)* R SMI (17)

■ Korean Stock Market Index (R KOSPI Composite Index):

R KOSPI Composite Index = C(1)+ C(2)*R NYSE Composite Index+C(3)*R XU100+C(4)* R TEPIX(-1) (18)

■ Mumbai Stock Market Index Return (R BSE SENSEX):

R BSE SENSEX =C(1)+C(2)*R FTSE 100+C(3)*R XU100 C(4)* R KOSPI Composite Index (19)

■ Dubai Financial Markets Index Returns (R DFM):

R DFM = C(1)+ C(2)*R Oil Price + C(3)*R BSE SENSEX+C(4)*R Oil Price(-1) (20)

■ Oil Price Returns (R Oil Price):

R Oil Price = C(1)+ C(2)*R NYSE Composite Index + C(3)*R FTSE 100+C(4)*R NYSE Composite Index(-1)+C(5)*R Gold Price(-1) (21)

■ Gold Price Returns (R Gold Price):

R Gold Price= C(1)+ C(2)*R Oil Price+ C(3)*R FTSE MIB+C(4)*R CAC 40(-1)+C(5)* R FTSE 100(-1) (22)

■ Metals & Minerals Index Return (R Metals & Minerals Index):

R Metals & Minerals Index =C(1)+C(2)*R NYSE Composite Index+C(3)*R Oil Price + C(4)*R Gold Price +C(5) R NYSE Composite Index (-1) (23)

■ Iran's Export Return (R Exports):

R Exports =C(1)+ C(2)*R NYSE Composite Index+ C(3)*R FTSE 100 +C(4)* R KOSPI Composite Index + C(5)*R XU100 + C(6)*R DFM+C(6)*R Oil Price(-1 C(6)* R Oil Price(-1) (24)

■ Iran's Import Return (R Imports):

R Imports= C(1)+ C(2)*R NYSE Composite Index+ C(3)*R FTSE 100 + C(4)* R Shanghai Composit Index (25)

■ Iran's Production Return (R Production):

Production = C(1)+ C(2)*R XU100+ C(3)*R KOSPI Composite Index+C(4)*R XU100(-1)+ C(5)*R Gold Price(-1) +C(6)*R Metals & Minerals Index(-1) oooo(26)

The following tables present the regression equations used for estimating the returns of twelve stock markets (Table 3), prices of commodities such as oil, gold, and metals and mine (Table 4), and Iran's real macroeconomic indicators including export, import, and production (Table 5).

Table 3: Regression equations for estimating the returns of stock markets

Variables	Coefficient	Std. Error	t-Statistic	Prob.
R TEPIX				
C	0.011250	0.005068	2.219684	0.0294
R CAC 40	-1.013366	0.265934	-3.810593	0.0003
R FTSE MIB	0.650864	0.230748	2.820677	0.0061
R Metals & Minerals Index	0.385634	0.080351	4.799362	0.0000
R Gold Price	-0.347051	0.127165	-2.729138	0.0079
R TEPIX(-1)	0.426517	0.088936	4.795777	0.0000
R FTSE 100				
C	0.001742	0.001997	0.872690	0.3855
R NYSE Composite Index	0.678585	0.056670	11.97425	0.0000
R NIKKEI 225	0.110165	0.048558	2.268732	0.0260
FTSE 100(-1)	-0.110704	0.046918	-2.359534	0.0208
R NIKKEI 225				
C	-0.003722	0.003966	-0.938455	0.3509
R NYSE Composite Index	0.670903	0.093440	7.180021	0.0000
R XU100	0.243542	0.052453	4.643064	0.0000
TEPIX(-1)	-0.258483	0.075229	-3.435951	0.0009
R Shanghai Composite Index				
C	0.001292	0.009789	0.132017	0.8953
R NYSE Composite Index	0.880308	0.174418	5.047124	0.0000
R Gold Price(-1)	0.442621	0.203836	2.171456	0.0329
R DFM(-1)	-0.242378	0.077284	-3.136201	0.0024
R DAX				
C	0.003464	0.003272	1.058828	0.2929
R KOSPI Composite Index	0.957261	0.066611	14.37097	0.0000
R NIKKEI 225(-1)	-0.167390	0.072999	-2.293047	0.0245
R SMI(-1)	0.237203	0.112558	2.107382	0.0383
R CAC 40				
C	-0.005911	0.002278	-2.594261	0.0112
R DAX	0.837706	0.039002	21.47842	0.0000
R FTSE MIB				
C	-0.005555	0.002251	-2.467460	0.0157
R CAC 40	1.105595	0.042617	25.94234	0.0000
R SMI				
C	0.001864	0.002440	0.763967	0.4471
R CAC 40	0.627787	0.046194	13.59014	0.0000
R XU 100				
C	0.007926	0.007851	1.009529	0.3158

R Shanghai Composite Index	0.200183	0.086065	2.325941	0.0226
R SMI	1.200806	0.207649	5.782859	0.0000
R KOSPI Composite Index				
C	0.006962	0.004376	1.590913	0.1157
R NYSE Composite Index	0.633337	0.103101	6.142888	0.0000
R XU100	0.316865	0.057876	5.474911	0.0000
R TEPIX (-1)	-0.251165	0.083007	-3.025844	0.0034
R BSE SENSEX				
C	0.005126	0.005313	0.964832	0.3376
R FTSE 100	0.575942	0.166777	3.453375	0.0009
R XU100	0.333831	0.083673	3.989715	0.0001
R KOSPI Composite Index	0.296972	0.123662	2.401480	0.0187
R DFM				
C	-0.017623	0.011485	-1.534435	0.1290
R Oil Price	0.368363	0.142462	2.585689	0.0116
R BSE SENSEX	0.381615	0.143451	2.660244	0.0095
R Oil Price (-1)	0.307135	0.140309	2.188998	0.0316

Table 4: Regression equations for estimating the prices and index of commodities

Variables	Coefficient	Std. Error	t-Statistic	Prob.
R Oil Price				
C	0.006196	0.008126	0.762448	0.4481
R NYSE Composite Index	1.249935	0.343923	3.634344	0.0005
R FTSE 100	-1.102326	0.406893	-2.709127	0.0083
R NYSE Composite Index (-1)	0.759041	0.149817	5.066455	0.0000
R Gold Price(-1)	0.383661	0.170951	2.244280	0.0277
R Gold Price				
C	0.010614	0.004341	2.444992	0.0168
R Oil Price	0.135004	0.070189	2.388820	0.0194
R FTSE MIB	-0.261588	0.197559	-3.726885	0.0004
R CAC 40(-1)	-0.690517	0.197559	-3.495241	0.0008
R FTSE 100(-1)	0.979265	0.247507	3.956509	0.0002
R Metals & Minerals Index				
C	-0.003223	0.005627	-0.572754	0.5685
R NYSE Composite Index	0.373828	0.110639	3.378806	0.0011
R Oil Price	0.318654	0.077010	4.137843	0.0001
R Gold Price	0.410356	0.124076	3.307304	0.0014
R NYSE Composite Index(-1)	0.352164	0.117625	2.993969	0.0037

Table 5: Regression equations for estimating Iran’s real macro economy indicators

Variables	Coefficient	Std. Error	t-Statistic	Prob.
R Exports				
C	0.014790	0.007582	1.950638	0.0548
R NYSE Composite Index	1.164601	0.359952	3.235436	0.0018
R FTSE 100	-0.977307	0.402428	-2.428523	0.0176
R KOSPI Composite Index	-0.573834	0.183649	-3.124632	0.0025
R XU100	0.306886	0.117028	2.622325	0.0106
R DFM	0.152481	0.069661	2.188899	0.0317
R Oil Price(-1)	0.217305	0.095029	2.286712	0.0250
R Imports				
C	0.014740	0.005577	2.643113	0.0099
R NYSE Composite Index	0.767232	0.257638	2.977946	0.0039
R FTSE 100	-0.748886	0.297904	-2.513853	0.0140
R Shanghai Composite Index	-0.131029	0.064396	-2.034719	0.0452
R Production				
C	0.000526	0.000917	0.574024	0.5676
R XU100	0.035725	0.012807	2.789571	0.0067
R KOSPI Composite Index	-0.045279	0.017957	-2.521580	0.0138
R XU100(-1)	-0.029497	0.010276	-2.870578	0.0053
R Gold Price(-1)	-0.047799	0.020689	-2.310321	0.0236
R Metals & Minerals Index (-1)	0.036952	0.013817	2.674377	0.0092

Table 6 displays results of the validation of all estimated regression models. The p-values for all models are less than 0.05, indicating that they are statistically significant. The coefficients of determination (R^2) indicate the percentage of changes in the dependent variable that are explained by the independent variables.

Table 6: Results of the validation of estimated regression models

Model	R^2	Adj. R^2	S.E. of regression	Sum squared reside	F-statistic	Prob. (F-statistic)
R TEPIX	0.44	0.40	0.041488	0.130814	11.90553	0.000000
R FTSE 100	0.84	0.83	0.017982	0.025222	133.2618	0.000000
R NIKKEI 225	0.67	0.66	0.035145	0.096344	53.61103	0.000000
R Shanghai Composite Index	0.31	0.28	0.081802	0.521942	11.70093	0.000002
R DAX	0.76	0.75	0.029569	0.068197	80.86143	0.000000
R CAC 40	0.85	0.85	0.020659	0.034572	461.3227	0.000000
R FTSE MIB	0.89	0.89	0.020504	0.034053	673.0050	0.000000
R SMI	0.70	0.69	0.022225	0.040009	184.6920	0.000000
R XU 100	0.40	0.39	0.070957	0.402797	26.85003	0.000000
R KOSPI Composite Index	0.66	0.65	0.038779	0.117296	51.14801	0.000000
R BSE SENSEX	0.66	0.65	0.047686	0.179639	51.58056	0.000000
R DFM	0.29	0.26	0.101166	0.798290	10.70266	0.000006

R Oil Price	0.42	0.39	0.067705	0.352970	13.88460	0.000000
R Gold Price	0.34	0.31	0.037796	0.109995	10.08861	0.000001
R Metals & Minerals Index	0.60	0.58	0.047140	0.171108	29.38138	0.000000
R Exports	0.39	0.34	0.065765	0.324377	7.825198	0.000001
R Imports	0.12	0.08	0.050270	0.199639	3.456872	0.020300
R Production	0.21	0.16	0.007496	0.004270	3.996982	0.002844

To test for heteroscedasticity in the residuals, the ARCH test was used in this study. Table 7 shows the results of these tests for all estimated regression models. The probabilities are higher than 0.05, indicating that the residual terms in all models are homoscedastic.

Table 7: Results of ARCH test for the estimated regression models

Model	F-statistic	Prob. F	χ^2-statistic	χ^2Prob.
R TEPIX	0.000686	0.9792	0.000703	0.9788
R FTSE 100	3.729034	0.0571	3.651097	0.0560
R NIKKEI 225	0.126228	0.7233	0.129217	0.7192
R Shanghai Composite Index	0.020781	0.8857	0.021302	0.8840
R DAX	0.002679	0.9589	0.002746	0.9582
R CAC 40	2.910910	0.0919	2.878929	0.0897
R FTSE MIB	1.716973	0.1938	1.722919	0.1893
R SMI	0.086982	0.7688	0.089060	0.7654
R XU 100	0.603669	0.4395	0.614127	0.4332
R KOSPI Composite Index	0.117066	0.7331	0.119852	0.7292
R BSE SENSEX	0.469663	0.4951	0.478594	0.4891
R DFM	1.857830	0.1767	1.861097	0.1725
R Oil Price	0.539400	0.4649	0.549305	0.4586
R Gold Price	2.473773	0.1198	2.459388	0.1168
R Metals & Minerals Index	0.033067	0.8562	0.033890	0.8539
R Exports	0.384075	0.5372	0.391893	0.5313
R Imports	0.252085	0.6170	0.257576	0.6118
R Production	0.062114	0.8038	0.063636	0.8008

The Breusch–Godfrey test was used to test linear correlation in the regression residuals. Table 8 shows the resulting statistics. The failure to reject the non-correlation assumption as the null hypothesis suggests that the residual terms in all models are not correlated, as all probabilities are higher than 0.05.

Table 8: Results of Breusch–Godfrey test for the estimated regression models

Model	F-statistic	Prob. F	χ^2-statistic	χ^2Prob.
R TEPIX	0.965597	0.4318	4.174872	0.3829
R FTSE 100	1.003347	0.4114	4.218478	0.3772
R NIKKEI 225	1.750475	0.1480	7.088177	0.1313
R Shanghai Composite Index	0.981923	0.4060	3.098990	0.3766
R DAX	1.689886	0.1614	6.863369	0.1433
R CAC 40	1.188621	0.3226	4.826919	0.3055
R FTSE MIB	2.016798	0.1004	7.871154	0.0964
R SMI	0.976934	0.4252	4.008789	0.4048
R XU 100	0.623801	0.6469	2.638404	0.6200
R KOSPI Composite Index	1.254828	0.2955	5.208646	0.2666
R BSE SENSEX	0.093002	0.9844	0.409657	0.9817
R DFM	2.269672	0.0697	8.960812	0.0621
R Oil Price	0.313737	0.8679	1.385844	0.8467
R Gold Price	0.404544	0.8048	1.778261	0.7765
R Metals & Minerals Index	2.352383	0.0619	9.362770	0.0526
R Exports	2.026042	0.1000	8.400843	0.0780
R Imports	1.351695	0.2589	5.581156	0.2327
R Production	0.263910	0.9002	1.184886	0.8806

4.3 Results from System Dynamics Simulations

Figure 1 presents the causal links for the relations among financial markets with the Iranian financial market and the real sector of the Iranian economy (commodities). In Figure 1, the New York Stock Exchange (NYSE) composite index returns were used as the driver for other variables in the causal relationships. Positive and negative relationships are denoted by (+) and (-), and delay is represented by two vertical lines (||). Positive and negative loops are identified as R and B, respectively. The simulated returns values for the Tehran Stock Exchange index were obtained based on the relationships between the Tehran Stock Exchange and the related global financial markets. These simulated values were converted into indexes for better understanding. Figure 2 and Figure 3 illustrate the impact of financial markets on Iranian's exports and production, respectively.

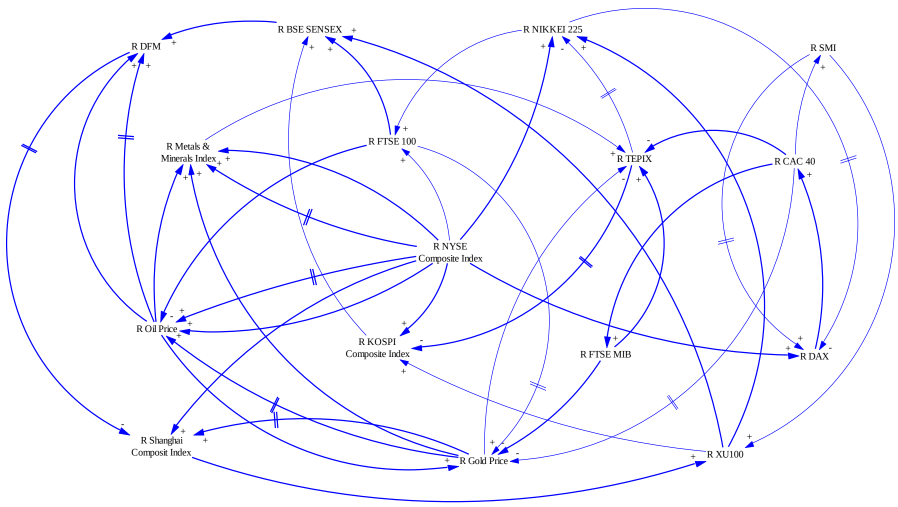

Figure 1: The causal loop diagram for the selected global financial markets

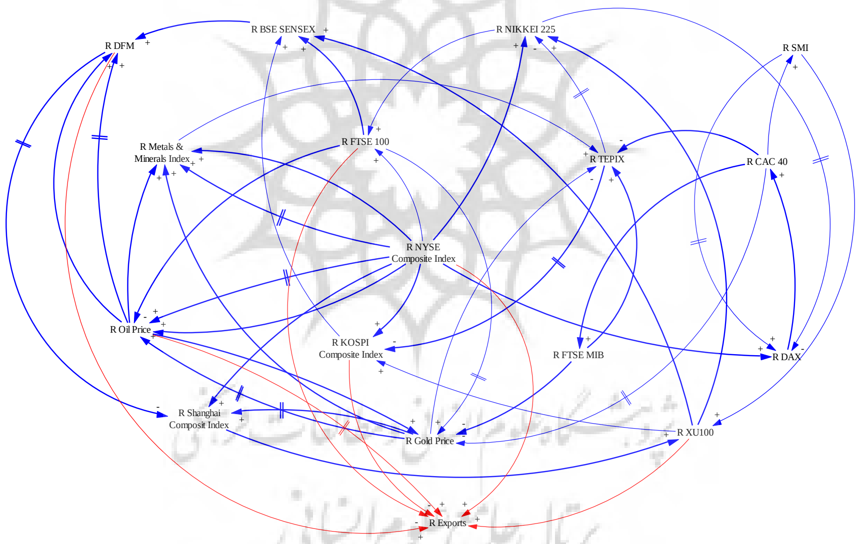

Figure 2: The impact of financial markets on Iran's exports

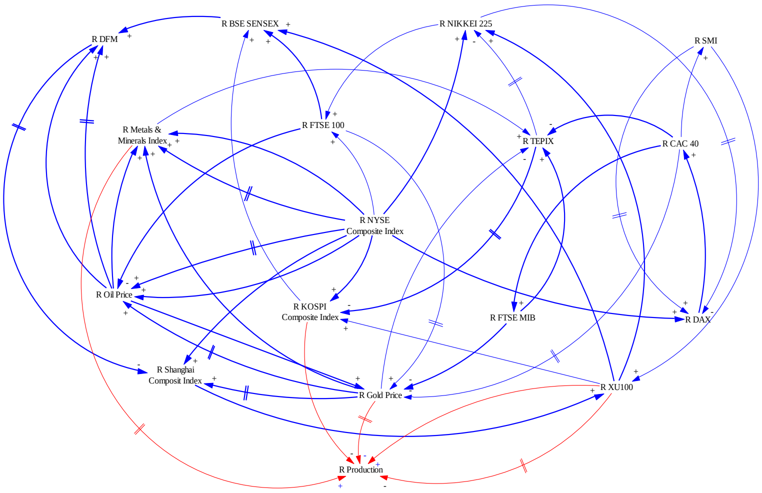

Figure 4-22 displays a comparison between the simulated values (in red) and the actual values (in blue) for the returns of the financial markets, commodities, as well as Iran's export, import, and production between the years 2005 and 2011.

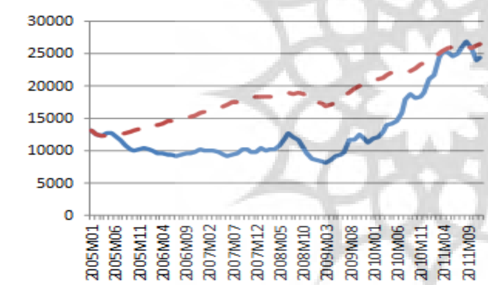

Figure 4: Simulated and real values for TEPIX (2005-2011)

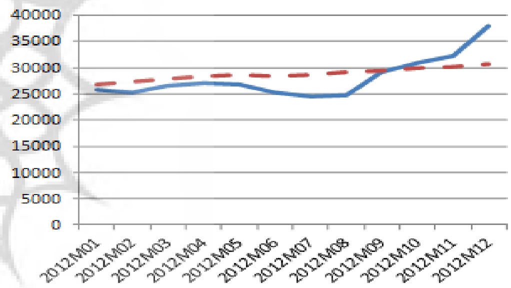

Figure 5: Simulated and real values for TEPIX (2012)

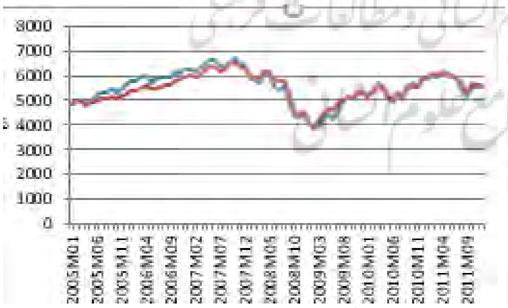

Figure 6: Simulated and real values for London Stock Exchange Index Return (2005-2011)

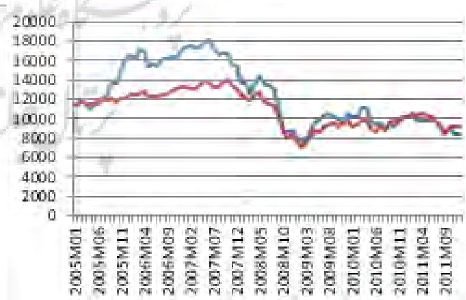

Figure 7: Simulated and real values for Tokyo Stock Exchange Index Return (2005-2011)

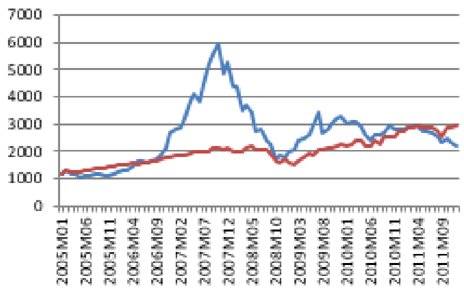

Figure 8: Simulated and real values for Shanghai Stock Exchange Index Return (2005-2011)

Figure 9: Simulated and real values for Frankfurt Stock Exchange Index Return (2005-2011)

Figure 10: Simulated and real values for Paris Stock Exchange Index Return (2005-2011)

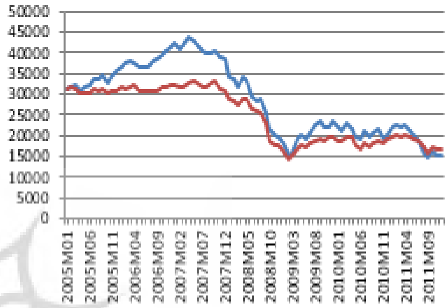

Figure 11: Simulated and real values for Milan Stock Exchange Index Return (2005-2011)

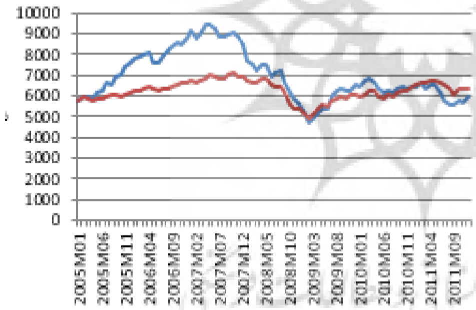

Figure 12: Simulated and real values for Swiss Stock Exchange Index Return (2005-2011)

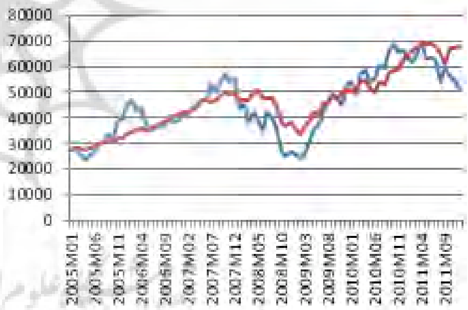

Figure 13: Simulated and real values for Istanbul Stock Exchange Index Return (2005-2011)

Figure 14: Simulated and real values for Korea Stock Exchange Index Return (2005-2011)

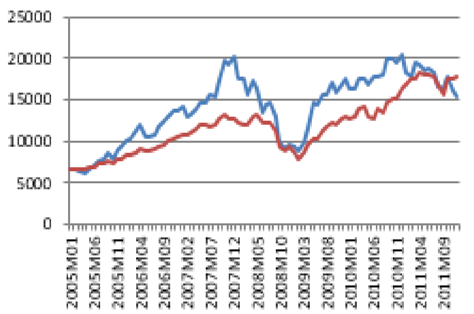

Figure 15: Simulated and real values for Mumbai Stock Exchange Index Return (2005-2011)

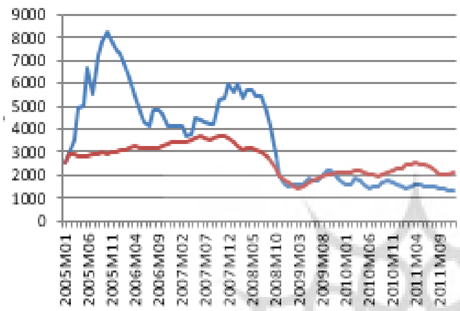

Figure 16: Simulated and real values for Dubai Stock Market Index Return (2005-2011)

Figure 17: Simulated and real values for Oil Price Index (2005-2011)

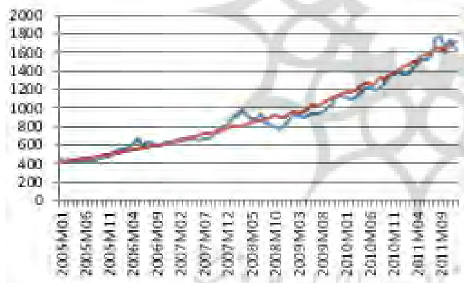

Figure 18: Simulated and real values for Gold Price Index (2005-2011)

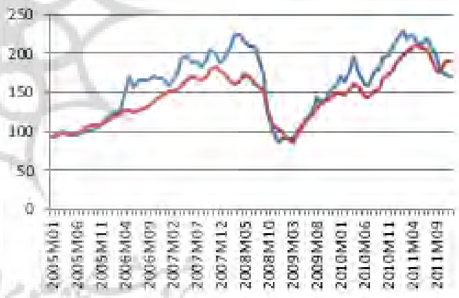

Figure 19: Simulated and real values for Metals & Mines Price Index (2005-2011

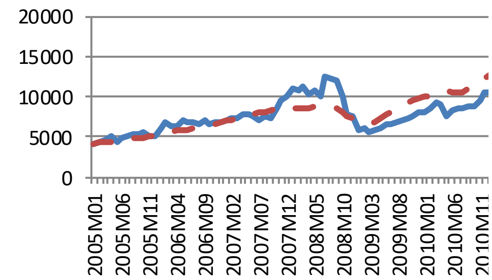

Figure 20: Simulated and real values for Iran's exports Index (2005-2011) in Million Dollars

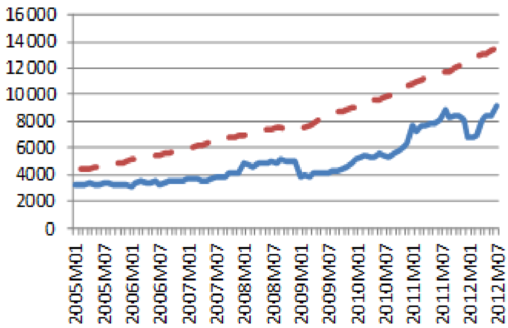

Figure 21: simulated values and real values for Iran's imports Index (2005-2012) in Million Dollars

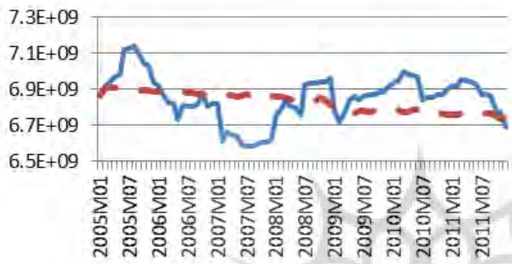

Figure 22: Simulated and real values for Iran's (Industrial) production Index (2005-2011) in Dollar

5. Conclusions and Final Remarks

In today's global economy, the interconnectivity of markets means that changes in one market can have varying impacts on related markets. Accurately predicting these mutual effects is of great importance to economic and financial policymakers. A system dynamic approach has been proposed to forecast economic and financial market performance indicators based on the interactions between related financial markets. The study focuses on the case of Iran during 2005-2011 and presents a framework to explain the process of forecasting.

The results show that the returns of the Tehran Stock Exchange Index are closely linked to the returns of the NYSE composite index, either simultaneously or with a one-month delay. Additionally, there are dynamic relationships between the NYSE and other markets, highlighting the need to recognize all elements of the system to identify global financial system behavior. The study also extracts regression equations for simulating the effects of interactions on the performance of related financial markets and on Iran's economic variables. The simulation results reveal that Iran's exports are relatively affected by international related financial markets, while imports and production do not follow the same trend.

The study's results align with the findings of other studies, including Huyghebaert and Wang (2010), Kenourgios et al (2010), Samarakoon (2011), Filis et al (2011), Sandoval and Franca (2012), Kaur and Arora (2018), Law (2019), Apergis and Eleftherion (2019), Bhandari and Kamaiah (2020), Muhammad Zubair Chishti (2021), Umar Muhammad Dabachi, et al. (2021), Hashem Botshekan et al. (2021), Salahmanesh, et al (2023), and Jamel Eddine Mkadmi et al (2023).

Results of this study demonstrate economic and financial variables can be accurately predicted using a systems dynamic framework. By employing the proposed framework and analyzing the cause-and-effect relationships, researchers can readily study and forecast the behavior of economic and financial variables in various regions worldwide such as the European Union, Asian countries, African countries, the United States, Australia, the United Kingdom, the Middle East, and any other given country or region., based on their past relationships. Overall, the proposed framework shows high accuracy in predicting economic and financial variables using dynamic systems. Researchers can use this framework to study and predict economic and financial behavior in different regions of the world, based on past data relationships.

6. Limitations

Two limitations of this research are the limitation of time scope and that the results of the study are specific to the Iranian economy.

Conflict of interest

The authors declare that there are no conflicts of interest regarding this a.

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مدل سازی پویایی سیستم برای پیش‌بینی شاخص‌های بازار اقتصادی و مالی با استفاده از روابط متقابل شوک‌ها در بین بازارهای مالی جهانی

هدف: در اقتصاد جهانی به هم‌پیوسته امروزی، تغییرات در یک بازار می‌تواند موجب تأثیراتی موج‌گونه در بازارهای مرتبط گردد و پیش‌بینی دقیق چگونگی این تأثیرات متقابل را برای سیاست‌گذاران اقتصادی و مالی و کارشناسان ضروری می‌سازد. روش‌های مختلفی برای پیش‌بینی تأثیر و تأثیرات متقابل بازارهای مالی ارایه شده است. در این مطالعه، چارچوبی عمومی برای شیوه بررسی و پیش‌بینی شاخص‌های بازار اقتصادی و مالی با استفاده از روابط متقابل شوک‌ها در بازارهای مالی جهانی و رویکرد سیستم پویا پیشنهاد شده است.

روش‌ها: برای نشان دادن مراحل چارچوب عمومی پیشنهادی و مدل‌سازی پویایی سیستم، شاخص‌های اقتصادی ایران و بورس اوراق بهادار تهران با استفاده از تعامل آن‌ها با یازده بازار مالی بزرگ جهانی مرتبط از جمله بازارهای مالی لندن، توکیو، شانگهای، فرانکفورت، پاریس، میلان، سوئیس، استانبول، کره، بمبئی و دبی پیش‌بینی می‌شوند. همچنین از بازده شاخص بورس نیویورک به عنوان محرک شوک برای سایر بورس‌های موجود در مدل استفاده می‌شود.

یافته‌ها: نتایج حاکی از آن است که مدل پیش‌بینی پیشنهادی با موفقیت شاخص‌های اقتصادی ایران و بورس اوراق بهادار تهران را پیش‌بینی کرده است. علاوه بر آن، این مطالعه نشان می‌دهد در حالی که صادرات ایران به بازارهای مالی جهانی حساس است، حساسیت واردات و بازده تولید به تغییرات در بازارهای مالی جهانی پایین است.

نتیجه: چارچوب کلی پیشنهادی و مدل‌سازی پویایی سیستم می‌تواند بینش‌های ارزشمندی برای پیش‌بینی اقتصادهای مختلف با استفاده از تعامل آنها با اقتصاد و امور مالی جهانی ارائه دهد.

کلمات کلیدی: شاخص های اقتصادی، بازارهای مالی، پیش بینی، پویایی سیستم، بورس اوراق بهادار تهران.