



Original Research

## Presenting an Entropy-Based Systemic Risk Warning Model

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### ABSTRACT

Systemic risk is a type of financial instability that disrupts the functioning of the financial system and affects economic growth. The present study was developed with the aim of presenting a systemic risk warning model based on the entropy criterion in the financial markets of Iran. In terms of direction, the present research is of applied type and in terms of explanatory purpose, and the data collection method is library method. The statistical population of the country's financial markets research includes the capital market, money market, etc., and the time frame of this research is the data related to variables affecting systemic risk in the years 1998 to 2022. In this research, firstly, the identified criteria and indicators affecting systemic risk were ranked using Shannon entropy, Rennie entropy, and Tsallis entropy, and then systemic risk was measured with the MES criterion. The results of this research show that the most systemic risk is caused by the variable of banks' debt to the central bank, and the two variables of government debt and the ratio of government debt to GDP also have the highest systemic risk. According to the general theory of systems and the effectiveness and influence of financial markets on each other, the government and policy makers of the economic and financial sectors must take the necessary measures in order to create a systemic supervisory institution.

## 1 Introduction

Investigating the financial crisis requires analyzing the contagion and shocks that other factors affect the creation of the financial crisis. In general, contagion and fundamental shocks that are present in the acceleration of the financial crisis can be summarized in the discussion of systemic risk. Systemic risk, which not only refers to the structure of the company and the market, but also arises from the discussion of the global economy [16]. In short, it should be stated that systemic risk is made up of internal and external factors in such a way that a prediction model should be provided in order to reduce its effects [7]. In recent years, globalization and increased communication and innovations in financial markets have led to increased convergence and the creation of an interwoven financial system, and new channels of shock transmission have emerged due to the interconnectedness of institutions [20]. Today, there is

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a lot of evidence that shows that the price fluctuations of financial assets spread to other assets and markets. It is a proven fact that financial markets move closer to each other in times of crisis. Conditional correlation between assets is much higher during periods of financial crisis when market returns are low [2]. Financial markets have faced various uncertainties such as financial crisis, oil shocks, changes in currency policies and similar cases. The occurrence of shock, which is a mild degree of crisis, is always accompanied by macro and micro effects that may not be limited to the target market and may spread to other markets as well. Hence, examining the intensity and direction of fluctuations from one market to another is of particular importance. The heaviness of the costs arising from the financial crisis requires that the policy makers of the market take the necessary precautionary measures to prevent the occurrence of the crisis. Applying accurate and timely preventive measures at the macro level requires accurate identification of systemic risk in the financial sector. This type of risk actually shows the possible positions of the crisis and guides the policy makers in applying the necessary precautionary measures [29]. Systemic risk occurs when a failure or crisis in one part of the market spreads to other parts and turns into a widespread crisis; in such a way that the loss of one or more important and effective financial institutions is transferred to other institutions as well. In the financial system of any country, accurate and timely identification of systemic risk with the aim of preventing financial crisis is an undeniable necessity [31]. Today, the concept of systemic risk is considered as a fully accepted concept in the study of the phenomenon of financial instability and possible policy responses, especially in the field of macro-precautionary policy [10]. This concept is effective in understanding crises, especially the financial crisis, and based on the definition provided, it deals with various aspects of systemic risk. Regarding the background of the research, it should be noted that systemic risk is a new topic in the financial literature of the world and it has been less than a decade. But despite the newness of this issue, a large volume of studies on this issue have been formed in foreign countries, especially countries that have faced financial crisis. The conducted studies proposed many methods to calculate systemic risk. Despite this large volume of studies, until now Iranian researchers have not significantly addressed this issue [9]. Although systemic risk is known as the focus of the recent financial crisis, there is no single and consensus definition for it. For example, based on a basic definition, a set of conditions that threaten stability and stability and public trust in the financial system is known as systemic risk [7]. However, the recent financial crisis is a perfect case example for the definition of systemic risk, which shows how the creation of a crisis in one of the financial sectors causes widespread financial instability and, by expanding its scope outside the financial markets, disrupts the activities of the real sector of the economy [14]. To measure different dimensions of systemic risk, several metrics have been provided; however, determining which measure shows the relationship between financial markets and macroeconomics is still an open and relevant issue. The relationship between systemic risk and macroeconomic indicators is considered a virgin research topic, and studies regarding the mechanism of transferring systemic risk from the financial sector to the macroeconomics are at the beginning [18]. Choosing the right index to measure systemic risk is one of the most important and challenging issues. Considering the introduction of a wide range of criteria for measuring systemic risk, it can be seen that understanding the complex and compatible nature of the financial system requires choosing the appropriate method and index for measuring systemic risk. So far, various methods have been presented to calculate this risk, but in the end, it can be said that choosing a single method that is agreed upon by everyone is neither possible nor desirable. As a result, in order for the systematic risk measurement method to be reliable, relevant economic and financial concepts should be included in its prac-

tical application; For example, it is important to decide which variables and indicators from which institutions or markets are used in estimating the results, or which frequency of observations should be chosen with which confidence level [8]. For example, one of the criteria for measuring systemic risk is value at risk, which, in addition to its simple calculation, has problems and shortcomings such as incoherence. Therefore, the standard of conditional risk value or expected systemic leakage, supplements have been introduced for it. Using value-at-risk criteria will lead to overestimation [17]. While the two mentioned criteria provide more conservative estimates than the value at risk criterion [11]. The results of this study can help managers, decision makers, brokers and capital market activists in understanding the state of financial markets, including the capital market, currency market, etc. Next, in the second part, research literature and a review of previous studies will be discussed. In the third part, the research methodology is presented. In the fourth part, the research model will be reported. Finally, the last part is dedicated to the conclusion.

## 2 Theoretical Foundations and Research Background

Ludwig von Bertalanffy, an Austrian biologist and thinker, is considered one of the founders of the general theory of systems in the early 20th century, who for the first time presented the concept of thinking in 1928 which became known as the general theory of systems, and during the years 1930-1932, he presented the organic theory and made great strides in expanding and establishing it in other fields. According to his opinion, an organism is not just a sum of separate elements, but a system with system and totality. The goal of the general theory of systems is to discover the laws and the inherent order of phenomena, hence it can be considered the most fluid system theory, because no decisive theory has been presented in its theoretical framework. The special feature of this attitude is to pay attention to the whole or holism [33]. Systemic risk indicates the possibility of the entire financial system becoming critical in a situation where one or more parts of the market are in crisis. Market collapse often happens when one or more important and influential companies in the whole system suffer a crisis and start going bankrupt. Due to the strong relationship with other companies, this bankruptcy has a negative effect on other companies and will also involve them in crisis. As a result, these chain reactions lead to market anxiety and expose the market to a widespread crisis [1]. For this reason, it is called a system that has a pervasive effect on the entire system and quickly spreads throughout the entire capital market or the entire economy of the country and turns into a crisis [35]. In other words, systemic risk refers to the risks imposed by internal communication and dependence in a system or market, where the default of a single entity or a set of entities can cause a cascade default and potentially cause the bankruptcy or collapse of the entire system or market [34]. Entropy is a random variable that is defined in terms of the probability distribution of that variable and can be used as a suitable measure for randomness or uncertainty indicating the number of bytes required to transmit a message. The entropy of the system is related to the amount of information in it. A more ordered system can be described with fewer bytes of information, while a less ordered system needs more bytes of information to be described [13]. Shannon in 1948 showed that events with a high probability of occurrence show less information. On the contrary, the lower the probability of an event, the more information it provides. New information reduces uncertainties. Hence, the value of new information is proportional to the amount of uncertainty that is reduced. According to the order of uncertainty and parameter information, they are interdependent. Entropy theory is used as an index to quantify the relevant items [23]. The word entropy has different meanings in different disciplines. In some sciences, it is used in the sense of disorder and chaos, and in some sciences, it is used as the vector of time. Explaining exactly what entropy is not so simple; because entropy is not tangible and is often defined as a measure of disorder. In the field of finance, entropy

represents a type of measurement of the uncertainty of the state of the system and as an indicator to show the extent of changes in the market [15]. Regarding the background of the research, it should be noted that systemic risk is a new topic in the financial literature of the world and it has a lifespan of less than a decade. But despite the novelty of this issue, a large amount of research has been done on this issue in foreign countries, especially countries that have faced a financial crisis [4]. Fadaei Vaheh et al. [12] in their article titled "Investigating the effect of banks' risk and competitiveness indicators on the systemic risk with the final expected decline approach of Marginal Expected Shortfall (MES) using the GMM model, the relationship between macroeconomic indicators (interest rate, economic growth rate and inflation), risk (liquidity and default risk) and competitiveness (Herfindahl-Hirschman index and asset size) of banks, the results of modeling show a significant relationship between the default (credit) risk index and the systemic risk of the banking industry. And there is direct. Ostad Hashemi et al. [30] in his article, investigated the impact of macroeconomic variable shocks on the systemic risk of the banking system in Iran. The results show that the positive oil price shock, inflation uncertainty, exchange rate and bank interest rate have an increasing effect on systemic risk. Vahabzadeh et al. [36] in his article entitled Systemic risk contagion in Iran's financial markets, have investigated the contagion and transmission of shocks in Iran's financial markets by using simultaneous multi-Garch models and covariance changes. The results show that the country's capital market has the largest share and the banking system has the smallest share in creating systemic risk. Namaki et al. [28] in their article analyzed the effect of the local topology structure of financial institutions in the financial network on the level of systemic risk by using the conditional differential value-at-risk measure. The results showed that financial institutions with greater centrality have lower node strength, and smaller node degrees have higher systemic risk. The results of the research of Mohammad Alizadeh and colleagues [25] It has been shown that there is a positive correlation between systemic risk in the stock, oil and currency markets and there is risk contagion between these markets. Billio et al. [6] presented an entropy-based early warning index for systemic risk for banking crises in Europe. In a study, Lupu et al. [22] investigated the systemic risk dynamics of European companies using the Bayesian entropy integration approach with systemic risk measures such as final expected shortfall, CoVaR, and delta CoVaR. The results of their research show that banks, financial companies, insurance and real estate have a high tendency to generate surplus. Liu *et al.* (2020) showed that relative entropy or Kolbeck-Leibler divergence can be used to identify systemic risks and policy-induced shocks in stock markets. Yin et al. [37] the systemic risk in the international stock markets with the role of the oil market state that the international systemic risk is significantly affected by oil price shocks. Mike et al. [24] in their study, proposed a dynamic topic network (DTN) approach that combined topic modeling and network analysis to assess systemic risk in financial markets. Bevilacqua et al. [5] using an implicit measure of systemic risk, have provided significant predictability for macroeconomic recessions as well as one-year recessions. As it is clear from the studies, in general, the measurement and evaluation of systemic risk, especially in Iran, is considered a nascent issue, and there is little empirical evidence about how disturbances created in a specific financial sector can spread to the entire economy, and whether a specific financial sector has more or less risk than another [27]. The results of some research on cost stickiness show that selling and general administration (SGA) costs, as well as costs of goods sold, have highly sticky behaviors [38]. The results of another research show that there a reverse (negative) relationship between institutional ownership level, managerial ownership level, and ownership concentration level with liquidity. Also, there is a direct (positive) relationship between corporative ownership level and liquidity [39].

Based on other research indicates that there is a positive and significant relationship between institutional investors and passive institutional investors with conservatism. Other findings suggest that cost stickiness has a positive impact on the relationship between institutional investors and passive institutional investors with conservatism [40].

### 3 Methodology

In order to provide a solution for a problem, the current research is of an applied type and in terms of explanatory purpose, and the data collection method is a library method. The statistical population of this research includes financial markets such as the capital market, currency market, energy market, commodity market, and money market.

**Table 1:** Research Variables and Their Measurement Methods

Row	Variable symbol	Index Title	Method of Measurement
1	OP	Oil price returns	$R_t = \left( \frac{OP_t - OP_{t-1}}{OP_{t-1}} \right) * 100$
2	GP	Gold price yield per ounce	$R_t = \left( \frac{GP_t - GP_{t-1}}{GP_{t-1}} \right) * 100$
3	EX	Exchange rate returns	$R_t = \left( \frac{EX_t - EX_{t-1}}{EX_{t-1}} \right) * 100$
4	TP	Return of the total capital market index	$R_t = \left( \frac{Tepix_t - Tepix_{t-1}}{Tepix_{t-1}} \right) * 100$
5	IRI	Real interest rate	IRI= P * i* n
6	IR	Inflation Rate	$IR = \left( \frac{CPI_p - CPI_b}{CPI_b} \right)$
7	GDP	Gross Domestic Product	GDP = Consumption (C) + Investment (I) + Government Expenditure(G) + (Exports (X) _ Imports (M))
8	BBC	Banknotes and bills in circulation	-----
9	VBM	Volume of bills and muskets to Volume of money	VBM/VM
10	SD	Return on short-term investment deposits	$R_t = \left( \frac{SD_t - SD_{t-1}}{SD_{t-1}} \right) * 100$
11	LD	Return on long term investment deposit	$R_t = \left( \frac{LD_t - LD_{t-1}}{LD_{t-1}} \right) * 100$
12	RSL	The ratio of short-term to long-term deposits	SD/LD
13	NGS	Non-government sector debt ratio to banks	-----
14	BCB	Banks' debt yield to the central bank	$R_t = \left( \frac{BCB_t - BCB_{t-1}}{BCB_{t-1}} \right) * 100$
15	SMC	Speed of money circulation	GDP / Money supply
16	LG	Liquidity growth	-----
17	GD	Government debt yield	$R_t = \left( \frac{GD_t - GD_{t-1}}{GD_{t-1}} \right) * 100$
18	GDG	Return on the ratio of government debt to GDP	$R_t = \left( \frac{GDG_t - GDG_{t-1}}{GDG_{t-1}} \right) * 100$
19	NEP	Net energy production	-----
20	CAG	Ratio of current account to GDP	CA/GDP
21	CA	Current account (annual)	-----
22	PPI	Producer price index	Basic price of the product / current price of the product
23	CPI	Consumer Price Index	The price of goods in the base year/ the price of goods in the current year

In this research, because the issue of systemic risk and risk contagion is discussed among financial markets, there is no sample. It is statistical. The time frame of this research is the data related to the variables affecting systemic risk in the years 1998 to 2022, and the information and records are from the website of the Central Bank of the Islamic Republic of Iran at [www.cbi.ir](http://www.cbi.ir), the site of the Tehran Stock Exchange at [www.tsetmc.com](http://www.tsetmc.com) Economic and financial data bank at the address [www.data-bank.mefa.ir](http://www.data-bank.mefa.ir) and Oil Price.com site is collected and prepared quarterly.

According to the objectives of the research, the research questions are as follows:

- 1- What are the factors affecting systemic risk?
- 2- What is the state of entropy of the components affecting systemic risk?
- 3- What is the systemic risk based on the MES measure?
- 4- How is the systemic risk warning model in Iran's financial markets?

## 4 Findings

In Table 2, the summary of the descriptive statistics of the above variables can be seen between 1998 and 2022. The presented descriptive statistics include average, median, maximum, and minimum. First, the yield (growth) of each data was calculated as follows.

**Table 2:** Descriptive Statistics of Seasonal Data Yield from 1998 to 2022 (Percentage)

Variable	Minimum	Maximum	Median	Average	Std.dev	Jarque Bera Test	probability
Return of the total capital market index (TP)	-89	679	34	16	73	22985	0.0000
Return on long-term deposits (LD)	-2	33	7	7	12	18247	0.0000
Return on government debt (GD)	-13	324	6	10	36	5860	0.0000
Exchange rate returns (EX)	-15	260	5	5	13	1077	0.0000
Return on the ratio of government debt to GDP (GDG)	-21	324	6	10	36	5391	0.0000
Return of banks' debts to the central bank (BCB)	-39	54	9	6	20	249	0.0000

Based on the results of the above Table, the average growth of the total capital market index in the studied period was 16%, in this period, the total capital market index had a maximum growth of 679%. Also, the exchange rate has an average yield of 5% and the debts of the banks to the central bank have an average yield of 6%. Government debts have experienced an average return of 10% during the period under review. Considering that the data of this research is seasonal, therefore, checking and performing seasonal unit root tests were used to avoid false regression, and to check the significance of the variables. In order to check the seasonal unit root, the Heggy unit root test was used. Due to the fact that most macroeconomic variables are insignificant and also the size of the variables is very different from each other, first the growth of each variable is calculated, then the significance of each variable is examined. The results indicated that the variables are significant in the scope of the research. In the Heggy test, the null hypothesis indicates the existence of a unit root.

Assumption H0: the existence of a single root among the variables

Assumption H1: There is no single root among the variables

After that, it was determined that the returns of the above variables are at the mana level and do not have an annual unit root or a seasonal unit root. Therefore, the relationship between variables can be checked using regression methods and correlation coefficient, and there is no need to differentiate explanatory variables in the model. In this section, the correlation coefficient between the growths of each of the above variables is observed.

**Table 3:** Examining the Significance of Model Variables

Variable	Heggy's test		Result
	Annual unit root	Seasonal unit root	
Return of the total capital market index (TP)	0.0	0.0	Not accepting the null hypothesis
Return on long-term deposits (LD)	0.0	0.0	Not accepting the null hypothesis
Return on government debt (GD)	0.0	0.0	Not accepting the null hypothesis
Exchange rate returns (EX)	0.0	0.0	Not accepting the null hypothesis
Return on the ratio of government debt to GDP (GDG)	0.0	0.0	Not accepting the null hypothesis
Return of banks' debts to the central bank (BCB)	0.0	0.0	Not accepting the null hypothesis

After that, it was determined that the returns of the above variables are at the mana level and do not have an annual unit root or a seasonal unit root. Therefore, the relationship between variables can be checked using regression methods and correlation coefficient, and there is no need to differentiate explanatory variables in the model. In this section, the correlation coefficient between the growths of each of the above variables is observed.

**Table 4:** Correlation Coefficient between Variables

Variable	TP	EX	LD	GD	GDG	BCB
Return of the total capital market index (TP)	1					
Return on long-term deposits (LD)	0.05	1				
Return on government debt (GD)	0.02	-0.05	1			
Exchange rate returns (EX)	-0.04	0/1	0/3	1		
Return on the ratio of government debt to GDP (GDG)	-0.06	0.09	0/28	0/9	1	
Return of banks' debts to the central bank (BCB)	-0.09	-0.05	0/49	0.08	0.09	1

As can be seen, the return of long-term investment deposits and exchange rate have a positive correlation with the return of the total capital market index, but other variables have a negative correlation with the total capital market index. Also, variables such as the return on government debt and the growth of the ratio of government debt to GDP have a positive correlation with the exchange rate, on the other hand, the return on long-term investment deposits has a negative correlation with the exchange rate.

#### 4.1 Analysis of the First Question

Question: What are the factors affecting systemic risk based on internal and external empirical research? In order to select the variables affecting the systemic risk, the indicators and variables mentioned in the past domestic and foreign experimental researches were examined.

**Table 5:** Systematic Review of Texts to Select Research Variables

Component	Research questions
Study community	Various sources include all kinds of articles, theses, in which systemic risk has been identified and explained.
Research purpose	What are the factors affecting systemic risk in Iran's financial markets?
Research method	Identifying and prioritizing factors affecting systemic risk in Iran's financial markets
Research period	All domestically published practical articles from between 2010 and 2022 and available sources and articles between 2010 and 2022 AD

The study population was used to select the variables and indicators affecting systemic risk, domestically published practical articles from 2010 to 2022 and foreign articles published between 2010 and 2022 in scientific databases such as Google Scholar, Elsevier, Emerald, Noormags, Scientific Information Database (SID) and Civilica were used to search for research articles. At this stage, the researcher has systematically searched for articles published in foreign and domestic authoritative articles with the aim of determining valid, reliable and relevant documents in the appropriate time frame. First, relevant keywords are selected. These words are listed in a Table.

**Table 6:** Table of Selected Keywords for Searching in Databases

Row	Key Words
1	Systemic Risk
2	Financial Crisis
3	Systemic Crisis
4	Risk Contagion
5	Volatility Contagion
6	Financial Contagion
7	Expected systemic loss
8	Marginal Expected loss
9	Pervasive Risk

Validation of used publications:

**Table 7:** List of Databases Used in the Research

Data bases	Title site	Type of Document
Domestic	SID Civilica Noormags Magiran	Persian articles
Foreign	Science direct Elsevier Springer Emerald Scopus Google scholar	Foreign articles

Based on the systematic review of the research literature, all macro components and variables affecting the systemic risk in the country's financial markets, which have been used in past domestic and foreign researches, were identified and identified as described in Table 1.

#### 4.2 Analysis of the Second Question

Question: What is the state of entropy of the components affecting systemic risk?

Shannon's entropy state:

Shannon entropy is a probability measure  $P$  on a finite set  $X$  as follows:



Based on the obtained entropy information, all macro components and variables affecting systemic risk

$$S_n(p) = - \sum_{i=1}^n p_i \ln p_i \tag{1}$$

Which is  $\sum_{i=1}^n p_i = 1$   $p_i \geq 0$  and  $0 \ln 0 = 0$

Have been measured and ranked according to the Shannon entropy criterion as described in the following Table:

**Table 8:** Ranking of Variables Affecting Systemic Risk Based on Shannon's Entropy Criterion

Row	Component title
1	Return of the total capital market index (TP)
2	Return of banks' debts to the central bank (BCB)
3	Return on government debt (GD)
4	Exchange rate returns (EX)
5	Return on the ratio of government debt to GDP (GDG)
6	Return on long-term deposits (LD)

Rennie entropy state:

$$H_\alpha(x) = \frac{1}{1-\alpha} \log \sum_{i=1}^n p_i^\alpha \tag{2}$$

Based on the obtained information, the entropy of all macro components and variables affecting the systemic risk have been measured and ranked according to the entropy criterion as described in the following Table:

**Table 9:** Ranking of Variables Affecting Systemic Risk Based on the Rennie Entropy Criterion

Row	Component title
1	Return of the total capital market index (TP)
2	Return of banks' debts to the central bank (BCB)
3	Exchange rate returns (EX)
4	Return on long-term deposits (LD)
5	Return on government debt (GD)
6	Return on the ratio of government debt to GDP (GDG)

Tsallis entropy state:

For any positive real number  $\alpha$ , the alpha order entropy of a probability measure P on the finite set X is defined as follows:

$$H_\alpha(p) = \begin{cases} \frac{1}{\alpha-1} \left( 1 - \sum_{i \in X} p_i^\alpha \right), & \text{if } \alpha \neq 1 \\ - \sum_{i \in X} p_i \ln p_i, & \text{if } \alpha = 1 \end{cases} \tag{3}$$

Based on the obtained entropy information, all macro components and variables affecting systemic risk have been measured and ranked according to the Tsallis entropy criterion as described in the following Table:

**Table 10:** Ranking of Variables Affecting Systemic Risk Based on the Tsallis Entropy Criterion

Row	Component title
1	Return of the total capital market index (TP)
2	Return of banks' debts to the central bank (BCB)
3	Exchange rate returns (EX)
4	Return on long-term deposits (LD)
5	Return on government debt (GD)
6	Return on the ratio of government debt to GDP (GDG)

### 4.3 Analysis of the Third Question

Question: How is systemic risk based on Marginal Expected Shortfall?

Final Expected Dropout Criterion

Based on the study of Brownless and Engel (2012), the MES criterion on day  $t$  is defined as follows;

$$MES_{i,t}(C) = E_{t-1}[R_{i,t} | R_{m,t} < C] \tag{4}$$

$$ES_{mt}(C) = IE_{t-1}(r_{mt} | r_{mt} < c) = \sum_{i=1}^N W_{it} IE_{t-1}(r_{it} | r_{mt} < c) \tag{5}$$

Where  $R_{m,t}$  and  $R_{i,t}$  are the daily returns of the financial market (such as the daily return of the stock index) or the daily return of bank  $i$  shares on day  $t$ , respectively. Also,  $C$  is a threshold value that indicates the occurrence of a systemic event. This value is considered equal to 2% in this study.

Then MES is the partial derivative of ES of the system with respect to the weight of institution  $i$  in the financial system:

$$MES_{it}(C) = \frac{\partial ES_{mt}(C)}{\partial W_{it}} = IE_{t-1}(r_{it} | r_{mt} < C) \tag{6}$$

MES measures the increase in system risk (measured by ES) by the marginal increase in the weight of entity  $i$  in the system. The higher the MES of an institution, the greater its contribution to increasing systemic risk.

To estimate MES, the DCC model introduced by Engel (2002) is used. Therefore, the conditional average for both market share index returns and individual financial institutions' share returns is considered as the following relationship.

$$R_{m,t} = \mu_{m,t} + \sigma_{m,t} \epsilon_{m,t} \tag{7}$$

$$R_{i,t} = \mu_{i,t} + \sigma_{i,t} \rho_{i,t} \epsilon_{m,t} + \sigma_{i,t} \sqrt{1 - \rho_{i,t}^2} \eta_{i,t} \tag{8}$$

Where  $\epsilon_{m,t}$  and  $\eta_{i,t}$  are disturbance components that are assumed independently. Note that  $\epsilon_{m,t}$  and  $\eta_{i,t}$  are simply obtained from the Cholsky decomposition. The above relationship shows the conditional capital asset pricing model with variable beta coefficients over time. Therefore, the conditional average efficiency of the individual institution above can be rewritten as follows:

$$R_{i,t} = \mu_{i,t} + \frac{cov_{t-1}(R_{m,t} \cdot R_{i,t})}{\sigma_{m,t}^2} (R_{m,t} - R_{i,t}) + \sigma_{i,t} \sqrt{1 - \rho_{i,t}^2} \eta_{i,t} \quad (9)$$

$$R_{i,t} = \mu_{i,t} + \beta_{i,t} (R_{m,t} - \mu_{m,t}) + \sigma_{i,t} \sqrt{1 - \rho_{i,t}^2} \eta_{i,t} \quad (10)$$

Where  $\beta_{i,t}$  is the variable beta coefficient over time. Considering the above relationships and conditional volatility modeling using conditional correlations by the DCC model of multivariate GARCH models, MES is calculated as follows.

$$MES_{i,t}(C) = \mu_{i,t} + \sigma_{i,t} E_{t-1} \left[ \rho_{i,t} \epsilon_{m,t} + \sqrt{1 - \rho_{i,t}^2} \eta_{i,t} | \epsilon_{m,t} < \frac{C - \mu_{m,t}}{\sigma_{m,t}} \right] \quad (11)$$

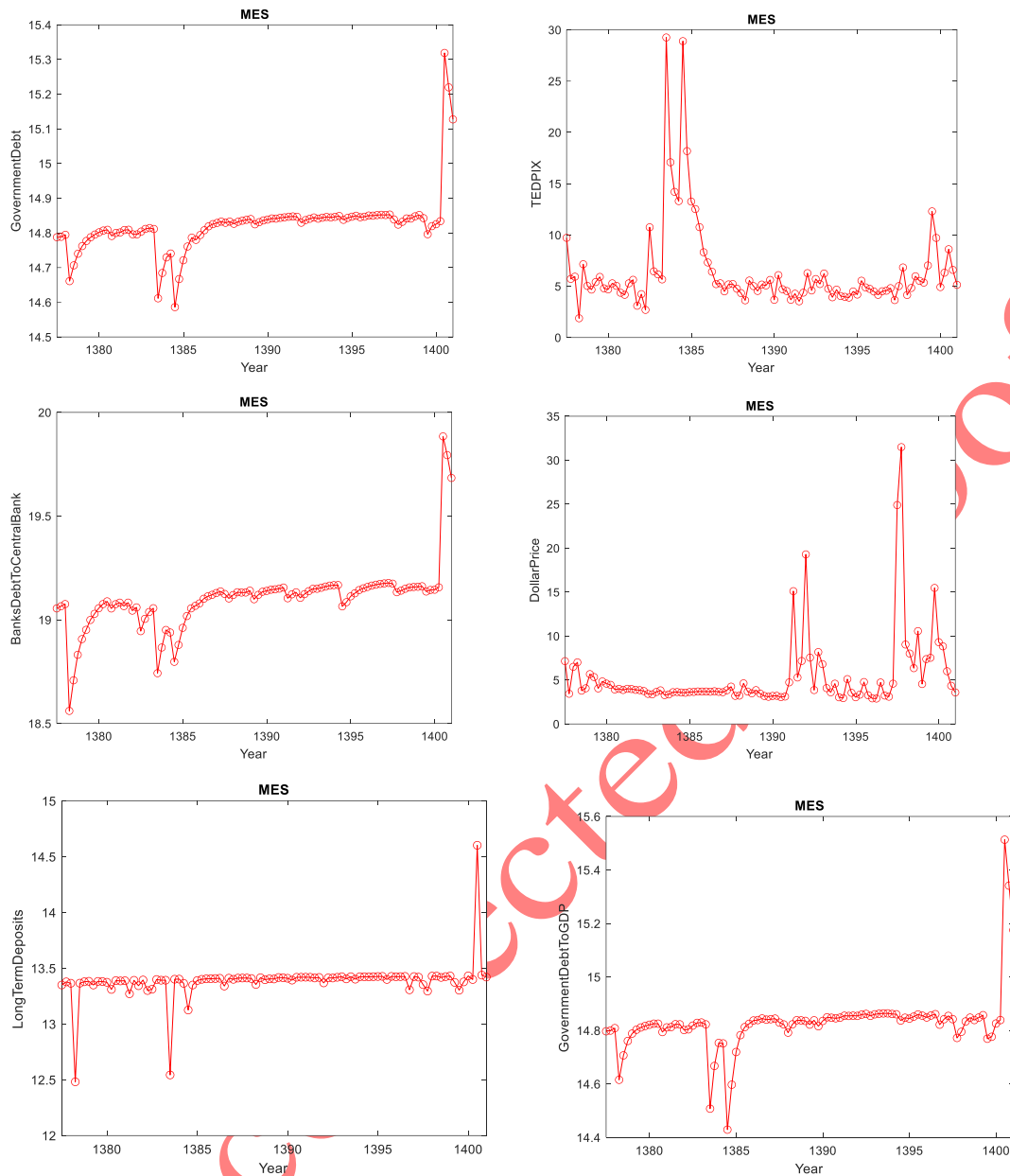
$$MES_{i,t}(C) = \mu_{i,t} + \sigma_{i,t} \rho_{i,t} E_{t-1} \left[ \epsilon_{m,t} | \epsilon_{m,t} < \frac{C - \mu_{m,t}}{\sigma_{m,t}} \right] + \sigma_{i,t} \sqrt{1 - \rho_{i,t}^2} E_{t-1} \left[ \eta_{i,t} | \epsilon_{m,t} < \frac{C - \mu_{m,t}}{\sigma_{m,t}} \right] \quad (12)$$

$$MES_{i,t}(C) = \mu_{i,t} + \sigma_{i,t} \rho_{i,t} E_{t-1} \left[ \eta_{i,t} | \epsilon_{m,t} < \frac{C - \mu_{m,t}}{\sigma_{m,t}} \right] \quad (13)$$

Marginal Expected Loss (MES), which is derived from expected loss (ES), defines systemic risk as the expected return on the stock of an individual financial institution, when the financial market is in critical condition. ES actually represents the average loss in critical conditions. That is, unlike VaR, which expresses the maximum loss in normal conditions, ES measures the average loss in a critical condition assuming that the institution or bank is in a critical condition. Therefore, the final expected return measure measures the average expected return on the stock of an individual financial institution conditional on the criticality of the financial market. The critical conditions of the financial market are different depending on the characteristics of each economy, and in countries where the financial markets have the ability to fluctuate more per day, a decline of more than 2% in the financial market is considered as a critical condition. Due to the impact of negative news on the economy, the GARCH GJR model was used in this research. In this model, whenever negative fluctuations have a greater impact, the model is well able to determine the conditional variance and conditional dynamic correlation between variables. Whenever the coefficient of leverage effect ( $\epsilon < 0$ ) in this model is zero, the model becomes a GARCH model.

$$\sigma_t^2 = K + \sum_{i=1}^P \gamma_i \sigma_{t-i}^2 + \sum_{j=1}^Q \alpha_j \epsilon_{t-j}^2 + \sum_{j=1}^Q \xi_j I | \epsilon_{t-j} < 0 | \epsilon_{t-j}^2 \quad (14)$$

In order to better understand the impact of each of the variables on the systemic risk in Iran's economy, the average of each of the risk criteria for these variables is presented in the Table below. Based on most criteria, the growth of government debt and the ratio of government debt to GDP have the greatest impact on systemic risk in Iran's economy.



**Fig. 1:** Overview of the Final Expected Fall of the Total Capital Market Index, Exchange Rate, Government Debt, Ratio of Government Debt to GDP, Long-Term Investment Deposits and Bank Debt to the Central Bank

**Table 11:** Average Systemic Risk Indicators in Financial Markets - Years 1998 to 2022

Variable	MES
Return of the total capital market index (TP)	6/5
Exchange rate returns (EX)	5/4
Return on long-term deposits (LD)	13/4
Return on government debt (GD)	14/8
Return on the ratio of government debt to GDP (GDG)	14/8
Return of banks' debts to the central bank (BCB)	19

Based on the results obtained, the highest systemic risk is caused by the variable of banks' debt to the central bank, and the average systemic risk of MES is the two variables of government debt and the

ratio of government debt to GDP in the review period of 14.8, and the lowest systemic risk of MES is related to the exchange rate variable, which is equal to 4.5.

#### 4.4 Analysis of the Fourth Question

How is the systemic risk warning model in Iran's financial markets?

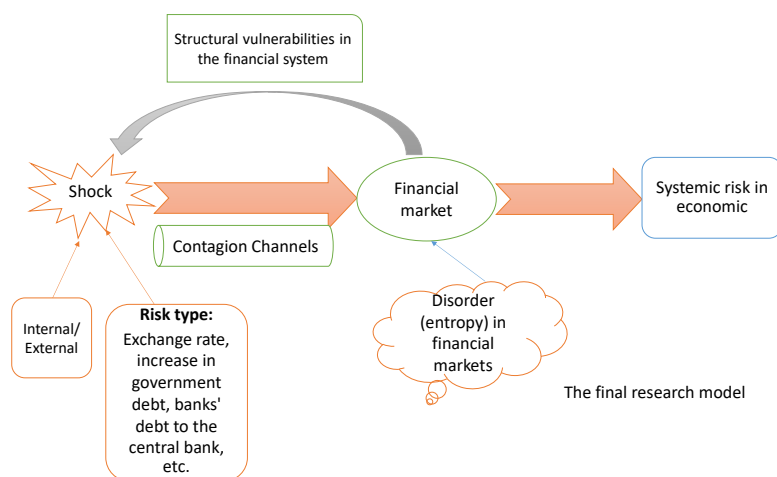


Fig. 2: Systemic Risk Warning Model in Financial Markets of Iran

#### 5 Discussion and Conclusions

After the financial crisis of 2007-2009, the issue of systemic risk as a macro-level risk that can affect the stability of the entire financial system has received much attention. In this era, it became clear that the one-dimensional view of the financial systems regulatory bodies on the individual risks of each financial institution, including the value at risk (VaR), is not sufficient to prevent financial crises, and the forgotten part of financial risks, which is the systemic or systematic risks of financial institutions, should be given special attention in policies and legislation [4]. In general, systemic risk provides a suitable criterion for monitoring financial markets by the government. Based on the criteria for measuring and predicting the share of systemic risk, regulatory departments can evaluate the companies that have a high share of systemic risk in their monitoring and thus maintain the stability of the financial system. Therefore, it is suggested that the supervisory and policy-making authorities, including the Ministry of Economy and Finance, the Central Bank, the Deposit Guarantee Fund, and the Securities and Exchange Organization, use the methods presented in this research to measure and predict systemic risk and identify important systemic institutions. In this research, using the seasonal data of macro variables of Iran's economy in the period of 1998 to 2022, it was investigated to determine the systemic risk between the variables of total capital market index, long-term investment deposits, government debts, exchange rate, banks' debt to the central bank and the ratio of government debts to GDP during the period. The results showed that according to the MES measure, the highest systemic risk is caused by the variable of banks' debt to the central bank, and the two variables of government debt and the ratio of government debt to GDP according to the MES measure have the highest systemic risk, and the lowest systemic risk based on the MES measure is related to the exchange rate variable. During the period under review in 2011 and 2017, the final expected fall of the total capital market index has reached its highest value. According to the results obtained from the measurement of systemic risk, it

is clear that the important factor of creating systemic risk in the financial markets of the country is the debt of the banks to the central bank and the debts of the government. When the gap between the government's current expenditures is not covered by the government's revenues, the government will inevitably use the resources of the central bank. Borrowing from the central bank is one of the most common approaches to compensate a part of the government's budget deficit. As the government's debts to the central bank increase, the monetary base increases, and as a result, the money supply will increase under the influence of the government's behavior. As the money supply changes, the demand of the entire economy changes. As aggregate demand in the economy changes, the general level of prices in the economy will change. It is obvious that these actions of the government will affect the demand for foreign exchange and consequently the nominal exchange rate of the market. Finally, government debts through the demand and supply gap, the exchange rate and the general level of prices will lead to changes in the supply of the entire economy and as a result changes in economic growth. The results of the present research are consistent with the findings of the research of Ostad Hashemi et al. [30] and Fadai Vahed et al. [12] and the research of Billio et al [6]. Using the obtained results, it is suggested that the government and the policy makers of the economic and financial sectors should create a system monitoring institution. Due to the fact that the collapse and bankruptcy of the markets are slightly different from individual financial companies, while the lack of liquidity and the resulting spread of risk from one financial institution to another may be worrisome, but the main concern is from the shocks that spread the collapse of the financial market and the liquidity crisis to other financial sectors and the macro economy. It is also suggested to the investors of the financial markets, due to the regime dependence between the financial markets and the spillover of turbulence between the said markets, the uncertainty of investing in these markets has increased, and in order to form a portfolio and in order to reduce risk, it is necessary for investors to have more groups of financial assets in their portfolios in long-term periods of time. It is also suggested to the researchers in the economic and financial fields to examine the transmission mechanism of uncertainty shocks in different sectors of the economy as well as different industries of the capital market using other econometric models and other time-varying parameter models. Future researchers are suggested to use other entropy measurement methods such as: joint entropy, approximate entropy, etc. in the ranking of variables.

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