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Prediction Model Estimation and Dynamic Characteristics Analysis of Exchange Rate and KOSDAQ Index

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Abstract- In this study, a predictive model based on vector autoregressive model (VAR) was estimated using monthly multivariate time series data of exchange rate (ER) and KOSDAQ index (KOSDAQ), and dynamic characteristics analysis of ER and KOSDAQ using impulse response function was carried out. To this end, the ADF unit root test was performed to confirm the stability of the data, the linear dependence relationship between variables was examined by the Granger causality test, and the existence of a constant term was confirmed by the t-statistic. The VAR model was identified using the AICC statistic of the minimum information criterion. In order to avoid spurious regression of the identified model, the cointegration test was performed for the cases that the error correction term had a constant intercept and that the VECM(p) term had a constant intercept and no linear trend. And it was found that the cointegration coefficient did not exist. Therefore, the prediction model of ER and the KOSDAQ could be estimated by the VAR model. As a result of the prediction, ER and KOSDAQ were predicted to remain stable after about 3 months. And the dynamic response in the forecasting model was evaluated using the impulse response function. As a result of the analysis, it was analyzed that when the shock of ER occurred, the effect of the shock disappeared after about 8 months in KOSDAQ, and that when the shock of KOSDAQ occurred, the effect of the shock disappeared after about 5 months in ER.

Keywords*: VAR, VECM, Granger causality test, Cointegration test, Impulse response function*

1. Introduction

As the global economy continues to suffer from the supply shock caused by the Ukraine crisis, external conditions such as the accelerated US interest rate hike and the possibility of China's economic slowdown are rapidly deteriorating. The International Monetary Fund (IMF) recently predicted that the global economy in 2022 will be significantly slower than in 2021 due to the Ukraine crisis etc. In Korea’s domestic economy, inflationary pressures in all directions, including import prices, producer prices, and consumer prices, are expanding due to the surge in international crude oil and raw material prices, and the depreciation in the Korean won against the US dollar. Korean won is suffering from weakness, with the won-dollar exchange rate exceeding the highest exchange rate (1,300 won) for the first time since the financial crisis. As a result of the strong dollar, although the situation is the same in major countries except for the United States, it was found that the rate of decline in the value of the Korean won was steeper than that of major countries. It is observed that the high exchange rate phenomenon will be prolonged due to the continued global inflation, steep austerity by the US Fed, and the prolonged war in Ukraine. This has a negative impact on the national economy, such as raising domestic prices and increasing the burden of repayment of foreign debt. The exchange rate is an economic indicator that affects all of the bond, stock and real estate markets. In general, the exchange rate moves in the opposite direction to the stock index. If there is a lot of dollar outflow, liquidity decreases, causing a financial market crunch, in turn, causing the stock index to fall and the exchange rate to rise. In addition, it has a negative effect on the stock and real estate markets because it has the side effect of increasing market interest rates by reducing real household income due to inflation. However, there are times when the rise in exchange rate helps the economy. The reason that Korea was able to thrive in a short period of time even after receiving a bailout from the IMF during the foreign exchange crisis was thanks to the strengthening of price competitiveness of export products due to the high exchange rate. As such,

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the exchange rate has two sides, both helping the economy and putting it at risk, so it is necessary to carefully observe the exchange rate movement to analyze and manage the relationship with other assets. Existing studies on exchange rates and stock indices are as follows. Ehlers and Takáts (2013) analyzed the structural relationship between variables using the structural VAR model and argued that the impulse-response relationship supports the argument of the portfolio rebalancing model [1]. Cho (2016) analyzed the correlation between the KOSPI and the won/dollar exchange rate using daily data by the heteroscedasticity method, and found that the impact of the won/dollar exchange rate shock on the KOSPI was significant in the positive (+) direction [2]. Pyo and Oh (2016) analyzed, by an error correction model using annual panel data, that when the real exchange rate of the won/dollar rose, the export volume decreased, although not at a significant level [3]. Kim (2020) analyzed the correlation between stock indices (KOSPI, KOSDAQ) and six social contribution companies using a vector autoregressive model and showed that there is a correlation between Korean stock indices and social contribution companies. Kim & Kim (2018) analyzed the correlation between KOSPI index and global companies, and showed that 14 companies analyzed and the KOSPI index had a correlation [5]. Kim & Rhee (2017) conducted a study on the correlation between the KOSPI index and sustainable companies, and analyzed that the KOSPI index had a preemptive influence on SK Chemicals, KB Financial Group, and Hana Financial Group, but not on KT, LG Chemicals, KCC, and Hyundai E&C. On the other hand, it was analyzed that Hana Financial Group, KB Financial Group, and KCC had an effect on the KOSPI index [6]. Maria Rosaria Ferrante, Enrico Fabrizi, and Carlo Trivisano (2018) performed an analysis through a questionnaire. Due to the small size of data available for the subpopulation to be analyzed, some of the average and sum estimates for the target countries, industries, and business classes might not be accurate, but it was generally believed that the business survey moved the industrial economy ahead of time [7]. Philip Vermeulen (2014) presented that the business survey index (BSI) for several companies in an industry could be an economic indicator predicting the real economy in the short term [8]. In this study, a prediction model is estimated with the VAR model using the exchange rate (ER) and KOSDAQ time series data from January 2010 to December 2021 provided by Economic Statistics System of the Bank of Korea, and analyze the dynamic characteristics using the impulse response function.

2. Research model

2.1 VAR(p) model

The vector autoregressive model (VAR), a vector time series model, was used to estimate the prediction model between exchange rate and the KOSDAQ index. The VAR model is a model that is explained by the lagged variables of each endogenous variable considering only endogenous variables without separate exogenous variables, and is used as a prediction model for economic and financial time series data. The VAR(p) model, in which the l-dimensional multivariate time series $Z_t = (Z_{1t}, Z_{2,t}, \cdots, Z_{lt})'$ at time t is consisted of an autoregressive process with past p lags, is defined as (Equation 1).

$$Z_t = \delta + \Phi_1 Z_{t-1} + \cdots + \Phi_p Z_{t-p} + \varepsilon_t = \delta + \sum_{i=1}^{p} \Phi_i Z_{t-i} + \varepsilon_t \quad (1)$$

Where δ is an $l \times 1$ constant vector, Φ_i is an $l \times l$ lag regression coefficient matrix between the current variable and the lag variables, and ε_t is a multivariate white noise process.

2.2 Granger causality test

If Z_t follows the VAR(p) model and the coefficient matrix $\Phi(B)$ can be divided into $\Phi_{ij}(B)$, $i, j = 1,2$, then the VAR(p) model can be expressed as (Equation 2).

$$\begin{pmatrix} \Phi_{11}(B) & \Phi_{12}(B) \\ \Phi_{21}(B) & \Phi_{22}(B) \end{pmatrix} \begin{pmatrix} Z_{1t} \\ Z_{2t} \end{pmatrix} = \begin{pmatrix} \delta_1 \\ \delta_2 \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} \quad (2)$$

In (Equation 2), if $\Phi_{12} = 0$, the vector Z_{1t} affects Z_{2t}, but Z_{2t} does not affect Z_{1t}. The future value of Z_{1t} can be explained by the past value ofZ_{1t}, but has no relation to the past value of Z_{2t}, whereas the future value of Z_{2t} is affected by the past values of Z_{1t} and Z_{2t}. To test this, the modified Wald test, which performs the chi-square (χ^2) test only on the first p coefficients that are optimal lags, was performed [9], [10].

2.3 Cointegration test

If $l \times l$ matrix $\Pi = \alpha\beta'$ is a full rank coefficient matrix, i.e. $rank(\Pi) = l$, then all time eries of Z_t are $I(0)$ stationary time series. If $rank(\Pi) = 0$, it means $\Pi = 0$, which means, in turn, if the cointegration vector does not exist, all time series of Z_t are $I(1)$ nonstationary time series and are predicted by applying the VAR(p) model to the differenced time series. However, if $0 < rank(\Pi) = m < l$, there are m mutually independent linear equations that are stationary. And it is predicted using the vector error correction model. The cointegration coefficient test determines the number of columns that are linearly independent of $\Pi = \alpha\beta'$, that is, the value of the cointegration coefficient m. The models considered in this study are (Equation 3) and (Equation 4) [11], [12].

$$\nabla Z_t = \alpha(\beta_0 + \beta' Z_{t-1}) + \sum_{i=1}^{p-1} \Phi_i \nabla Z_{t-i} + \varepsilon_t \quad (3)$$

$$\nabla Z_t = \delta_0 + \alpha\beta' Z_{t-1} + \sum_{i=1}^{p-1} \Phi_i \nabla Z_{t-i} + \varepsilon_t \quad (4)$$

Trace statistics for testing the null hypothesis that cointegration vectors exist are as shown in (Equation 5).

$$\lambda_{trace} = -n \sum_{i=r+1}^{k} \log(1 - \lambda_i) \quad (5)$$

where n is the number of observations, and λ_i are the eigenvalues.

2.4 Impulse response function

In the VAR(p) model, the shock response function is a moving average model derived from the model, and shows how all variables in the model respond to the shock over time when an unexpected shock is given in the economy. The vector autoregressive model can be converted to the MA(∞) model if the AR(p) model of (Equation 1) satisfies the invertibility condition [13], [14]. That is, as the time series in which all of the eigenvalues of Φ exist within a unit circle, Z_t can be expressed as the Vector Moving Average (VMA(∞)) by ε_t (Equation 6).

$$Z_t = \mu + \Psi(B)\varepsilon_t \quad (6)$$

where $\Psi(B)$ coefficient represents the effect of Z_1 on the impulse of ε_t as a function of time s, which is called the impulse response function. $\phi_{ij(s)}$, an individual element of $\Psi(B)$, is the impulse or innovation coefficient that exerts on the ith variable Z_i for 1 period at time s when ε_j changes by 1 unit.

3. Results

3.1 Stationary test

The time series data used in this study is a vector time series data $(z_t) = [(z_{1,t}, z_{2,t})']$ composed of $(z_{1,t}) = (ER_t)$, $(z_{2,t}) = (KOSDAQ_t)$. As shown in (Figure 1), the exchange rate (ER) and the KOSDAQ index (KOSDAQ) were found to be nonstationary time series data with a trend.

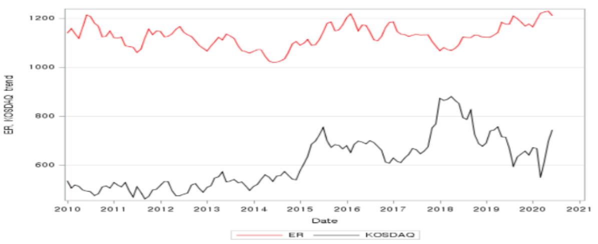

Figure 1- Time series trend of ER and KOSDAQ index

In addition, as a result of performing the ADF unit root test to test the stationarity for the variables of the exchange rate and KOSDAQ index, as shown in Table 1, p values of the Tau statistics were all greater than the significance level of 0.05, which appeared as a nonstationary time series with a unit root. Therefore, in order to remove the trend, the unit root test was performed with the first difference(∇) for each variable, and as shown in Table 2, p values of the Tau statistics were all smaller than the significance level of 0.05, which was confirmed as a stationary time series without a unit root.

Table 1. Unit root test of ER and KOSDAQ

Augmented Dickey-Fuller Unit Root Tests			
Variable	Type	Tau	Pr < Tau
ER	Zero Mean	-0.02	0.6755
	Single Mean	-2.10	0.2457
	Trend	-2.57	-2.57
KOSDAQ	Zero Mean	0.51	0.8233
	Single Mean	-1.48	0.5432
	Trend	-2.92	0.1592

Table 2. Unit root test of ∇ER and ∇KOSDAQ

Augmented Dickey-Fuller Unit Root Tests			
Variable	Type	Tau	Pr < Tau
∇ER	Zero Mean	-5.05	<.0001
	Single Mean	-5.03	0.0001
	Trend	-5.23	0.0002
∇KOSDAQ	Zero Mean	-5.07	<.0001
	Single Mean	-5.11	<.0001
	Trend	-5.07	0.0003

In addition, as a result of performing t-tests on the existence of constant term, p-value of each t-statistic was 0.4508 and 0.5429 respectively, indicating that there was no constant term at the significance level of 0.05. And it was found that positive lags exist in the schematic representation of the cross-correlation coefficient to confirm the linear dependency relationship between the exchange rate and the KOSDAQ index. As a result of performing the Granger causality test on the hypotheses of (Equation 7), as shown in (Table 3), the p-values of the chi-square statistics were all smaller than the significance level of 0.05, indicating that each variable had a linear dependency relationship.

$$H_{10}: \{\nabla ER\} \nleftarrow \{\nabla KOSDAQ\}$$
$$H_{11}: \{\nabla ER\} \leftarrow \{\nabla KOSDAQ\} \quad (7)$$

H_{10}: {∇KOSDAQ} ↚ {∇ER}
H_{11}: {∇KOSDAQ} ← {∇ER}

Table 3. Granger causality test

Test	DF	Chi-Square	Pr > ChiSq
Test 1	4	34.70	0.0001
Test 2	4	9.88	0.0225

3.2 VAR model identification

In this study, the order p was determined with an AICC (AIC corrected) statistic by the minimum information criterion (MINIC). As a result in (Table 4), since the AICC value of the AR3 row in the MA0 column was 12.590336, the smallest value, it was identified as a VAR(3) model.

Table 4. VAR(3) model identification

Minimum Information Criterion Based on AICC						
Lag	MA0	MA1	MA2	MA3	MA4	MA5
AR0	12.63959	12.512082	12.536868	12.546102	12.53208	12.586173
AR1	12.605718	12.564348	12.573945	12.608157	12.600457	12.638671
AR2	12.600506	12.582247	12.619566	12.663556	12.662443	12.696491
AR3	12.590336	12.622541	12.668963	12.693118	12.669899	12.726906
AR4	12.655629	12.601351	12.663834	12.638244	12.67762	12.738192
AR5	12.652213	12.642066	12.711004	12.711004	12.711685	12.784398

3.3 Cointegration test

To avoid spurious regression, Trace statistic of the cointegration coefficient test proposed by Johansen was used, and two cases were tested; when the error correction term had a constant intercept and when the VECM(p) term had a constant intercept and no linear trend. The result is shown as in (Table 5). (1) of (Table 5) is the result of the case where the error correction term has a constant intercept. For the hypotheses $H_0: m = 0 \ vs. \ H_1: m > 0$, since trace=10.0253 < 5% and Critical Value=19.99, H_0 was adopted, that is, rank=0. (2) of (Table 5) is the result of the case where the VECM(p) term had a constant intercept and no linear trend. For the hypotheses $H_0: m = 0 \ vs. \ H_1: m > 0$, since trace=9.3372 < 5% and Critical Value=15.34, H_0 was adopted, that is, rank=0. This means that the cointegration coefficient did not exist, and the VAR(3) model could be applied. Therefore, estimation formula of the prediction model is the same as (Equation 8) without the constant term.

$$\nabla Z_t = \Phi_1 Z_{t-1} + \Phi_2 Z_{t-2} + \Phi_3 Z_{t-3} + \varepsilon_t \qquad (8)$$

Table 5. Cointegration test

Cointegration Rank Test Using Under Restriction (1)					
H0 : Rank=r	H1 : Rank > r	Trace	5% Critical Value	Drift in ECM	Drift in Process
0	0	10.0253	19.99	Constanr	Constant
1	1	0.0177	2.1992		
Cointegration Rank Test Using Trace (2)					
H0 : Rank=r	H1 : Rank > r	Trace	5% Critical Value	Drift in ECM	Drift in Process
0	0	9.3372	15.34	Constant	Linar
1	1	1.5648	3.84		

3.4 Prediction model estimation

If a prediction model estimated by the estimation formula (Equation 8) is obtained from the parameter estimates (Table 6), it is as (Equation 9).

$$\begin{pmatrix} \nabla ER_t \\ \nabla KOSDAQ_t \end{pmatrix} = \begin{pmatrix} 0.38058 & 0.06891 \\ -0.02633 & 0.11055 \end{pmatrix} \begin{pmatrix} \nabla ER_{t-1} \\ \nabla KOSDAQ_{t-1} \end{pmatrix} + \begin{pmatrix} -0.28616 & -0.01657 \\ 0.16218 & -0.03008 \end{pmatrix} \begin{pmatrix} \nabla ER_{t-2} \\ \nabla KOSDAQ_{t-2} \end{pmatrix} + \begin{pmatrix} 0.02986 & 0.03575 \\ -0.18888 & -0.00026 \end{pmatrix} \begin{pmatrix} \nabla ER_{t-3} \\ \nabla KOSDAQ_{t-3} \end{pmatrix} \qquad (9)$$

Table 6. Parameter estimates

Model Parameter Estimation			
Equation	Parameter	Estimate	Variable
∇ER	AR1_1_1	0.38058	ER(t-1)
	AR1_1_2	0.06891	KOSDAQ(t-1)
	AR2_1_1	-0.28619	ER(t-2)
	AR2_1_2	-0.01657	KOSDAQ(t-2)
	AR3_1_1	0.02986	ER(t-3)
	AR3_1_2	0.03575	KOSDAQ(t-3)
$\nabla KOSDAQ$	AR1_1_1	-0.02633	ER(t-1)
	AR1_1_2	0.11055	KOSDAQ(t-1)
	AR2_1_1	0.16218	ER(t-2)
	AR2_1_2	-0.03008	KOSDAQ(t-2)
	AR3_1_1	-0.18888	ER(t-3)
	AR3_1_2	-0.00026	KOSDAQ(t-3)

3.5 Model test

After fitting the estimated VAR(3) model (Equation 9), the multivariate Portmanteau test results for the residual time series vector are as shown in (Table 7). The time series variables of the exchange rate and KOSDAQ index showed no autocorrelation and cross-correlation coefficients up to the maximum delay lag of 12.

Table 7. Multivariate Portmanteau test

Portmanteau Test for Cross Correlations of Residuals		
Up To Lag	Chi-Square	Pr > ChiSq
4	7.92	0.0947
5	12.17	0.1439
6	17.08	0.1467
7	19.19	0.2592
8	22.51	0.3135
9	29.10	0.2162
10	31.16	0.3102
11	37.33	0.2374
12	38.53	0.3557

As shown in the significance test result of the cross-correlation matrix (CCM) (Figure 2), it was found that there was no auto-correlation and no cross-correlation coefficient at lag 1 or more.

Schematic Representation of Cross Correlations of Residuals													
Variable/Lag	0	1	2	3	4	5	6	7	8	9	10	11	12
ER	+−	..	..	..	..	..	..	..	..	..	..	..	..
KOSDAQ	−+	..	..	..	..	..	..	..	..	..	..	.−	..
+ is > 2*std error, - is < -2*std error, . is between													

Figure 2- Significance test of cross-correlation matrix

(Figure 3) and (Figure 4) show the prediction results of the exchange rate and the KOSDAQ index using the VAR(3) model. As seen in (Figure 3), it is predicted that the exchange rate will rise for about 3 months and then maintain a stable trend.

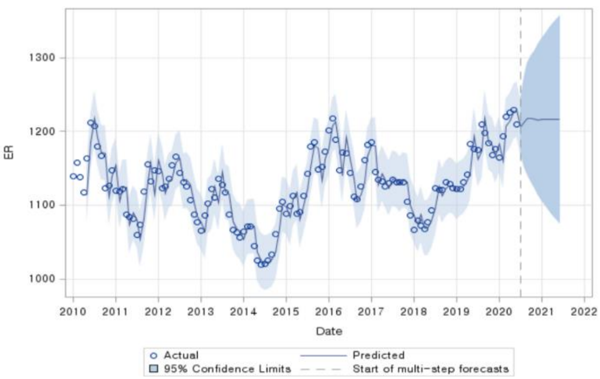

Figure 3- ER prediction by VAR(3)

(Figure 4) is the result of predicting the KOSDAQ index, and it was predicted to remain stable after falling for about 3 months.

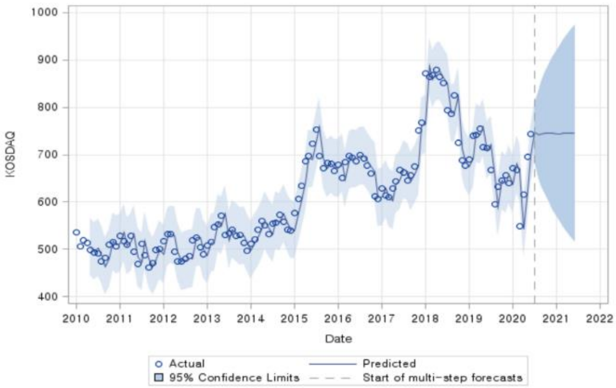

Figure 4- KOSDAQ prediction by VAR(3)

3.6 Dynamic characteristic analysis

(Figure 5) and (Figure 6) analyze the results of dynamic responses of other variables as time elapses when an impact is applied to one variable in the VAR(3) model using the impulse response function. (Figure 5) shows the shock response of the exchange rate and the KOSDAQ index when a shock occurs in exchange rate. When a shock occurs in exchange rate, the KOSDAQ index rises immediately, but after that, the ripple effect starts to disappear, and the effect of the shock disappears after about 8 months.

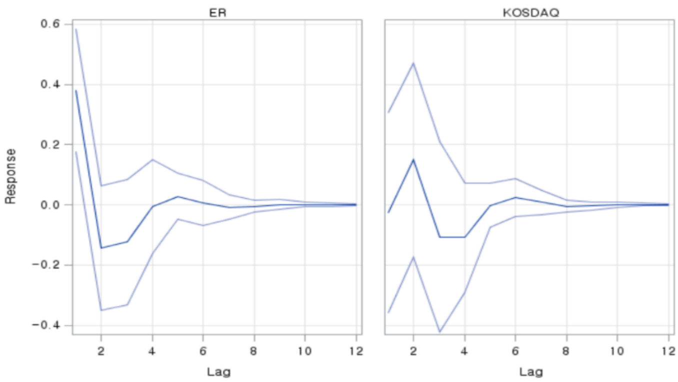

Figure 5- Response to shock in ER

(Figure 6) shows the shock response of the exchange rate and the KOSDAQ index when a shock occurs in the KOSDAQ index. When a shock occurs in the KOSDAQ index, the exchange rate falls, and the effect of the shock disappears after about 5 months.

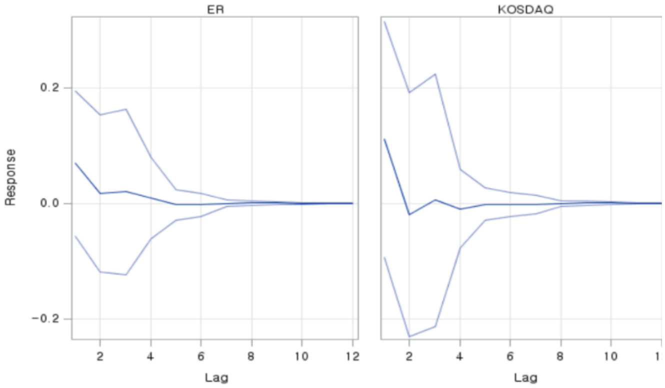

Figure 6- Response to shock in KOSDAQ

4. Conclusion

The 'three highs' era is being recreated as high inflation caused by rising oil and raw material prices, high interest rates due to inflationary pressures, followed by a high exchange rate due to the intensive US tight monetary policy, etc. In particular, the high exchange rate has a positive aspect of improving export price competitiveness, but it leads to an increase in import prices, aggravating domestic inflationary pressure, which in turn acts as a vicious cycle that acts as a pressure to raise interest rates. The speed of exchange rate fluctuations is more important than the direction. If the exchange rate fluctuates significantly in a short period of time, uncertainty about import or export prices increases, which may shrink trade and cause unexpected losses, which may eventually threaten the national economy. Therefore, this study estimated the prediction model of the exchange rate and the KOSDAQ index, and predicted the exchange rate and the KOSDAQ index. The exchange rate was predicted to rise for about 3 months and then maintain a stable trend, and the KOSDAQ index was predicted to decrease for about 3 months and then maintain a stable trend. In addition, it was analyzed that the KOSDAQ index rise immediately when an exchange rate shock occurs, but after the shock, the ripple effect starts to disappear, and the effect of the shock disappears after about 8 months, and that the exchange rate will fall when the KOSDAQ index shock occurs, but the effect will disappear after about 5 months. Although the economy of major countries is recovering recently, various domestic and foreign risks exist. Therefore, it is necessary to put a lot of research and effort into preparing a customized response plan for each risk factor so that it does not spread to the domestic real economy through the financial market.

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