What Are Sources of Real Exchange Rate Fluctuations?

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Abstract

The paper investigates what sources of real exchange rate fluctuations are in a structural vector autoregression model for Korea vis-à-vis the United States. It first estimates three-variable VAR models with long-run zero restrictions and contemporary sign restrictions which are derived from the same theoretical model. The empirical results show that an important role of nominal shock in explaining real exchange rate fluctuations is not found in the both models. In addition, it estimates four-variable VAR models in which a nominal shock is separated by monetary policy and real exchange rate shocks. A monetary policy shock also does not have a strong influence on real exchange rate fluctuations. But a supply shock has a significant impact on them both in three- and four-VAR models. It implies that the won/dollar exchange rate can be regarded as a shock absorber.

JEL: C3, E42, F31, F33

Keywords: real exchange rates, long run zero restrictions, sign restrictions, shock absorber

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Ⅰ. Introduction

Since the Korean exchange rate system had been changed from the multi-currency basket system to the market average exchange rate system in March 1990, won/dollar exchange rates became to fluctuate highly through the periods of Asian currency crisis and global financial crisis. As already well known, it is impossible to linearly and nonlinearly forecast exchange rate changes in developed countries which are unconditionally leptokurtic and conditionally heteroskedastic. Won/dollar exchange rates also showed a similar pattern. In particular, after Korea converted the market average exchange rate system into the free floating exchange rate system in December 1997, this phenomenon became more severe to date. It was caused by the fact that exchange rates, ratios of two currencies, were closely related to foreign macroeconomic variables as well as domestic macroeconomic variables in the aftermath of drastic openness of foreign exchange and financial markets. That is, real exchange rates under the open economy absorb spillover effects of domestic macroeconomic shocks and play an important role on mechanism of domestic spillover of foreign shocks. Hence, a lot of literature is recently eager to analyze the relationship between real exchange rates and fundamental macroeconomic variables. In case of Korea, because it is a small open economy with high dependence of foreign trade, spillover effects of foreign macroeconomic shocks have more severe impact on its economy.

As a representative example, Clarida and Gali (1994) analyzed variance decomposition of structural VAR with three variables such as output, prices, and exchange rates under the long-run zero restrictions and found that nominal shocks did not play an important role in explaining exchange rate fluctuations. It implies that the exchange rate between main developed countries works just like a shock absorber. On the other hand, Farrant and Peersman (2006) estimated three- and four-variable VAR models with sign restrictions and discovered that nominal shocks played an important role in determination of real exchange rates in contrast to the empirical results of Clarida and Gali (1994). They showed that the exchange rate was considered as a source of shocks, not a shock absorber. In case of won/dollar exchange rates, however, this kind of research based on long-run zero restrictions and sign restrictions is not carried out until now in spite of importance of relationships between output, prices, and exchange rates.

This paper estimates structural VAR models for Korea vis-à-vis the United States based on the two country open economy macroeconomic theory and investigates interlinkage between real won/dollar exchange rates and fundamental macroeconomic variables such as relative industrial production, price level, and interest rates. The study first estimates structural VAR models with long-run zero restrictions and sign restrictions built on economic theories, as well as traditional VAR models using Cholesky decomposition. Especially, using both estimation methods of Clarida and Gali (1994) and Farrant and Peersman (2006) which led to different conclusions, it examines whether or not real and nominal shocks play important roles in explaining won/dollar exchange rate changes, that is, whether they are shock absorbers or sources of shocks. The paper also extends basic VAR models with three variables such as real exchange rates, industrial production, and prices to four-variable VAR models by adding interest rates in both countries. It reconfirms whether it leads to the same conclusion or not. Finally, rolling regression analyses are carried out in order to ascertain the possibility that the main results may be time-varying. In case of Korea vis-à-vis the United States, the sample period was not so long that it may lead to small sample biases and the exceptional periods such as the Asian currency crisis and the global financial crisis periods can distort estimation results. The long-run zero restriction assumptions also have the point in dispute in theoretical and empirical aspects. So these kinds of comprehensive analyses are required to avoid these problems.

According to the empirical results, a nominal shock does not play a decisive role in elucidating real exchange rate changes, when it uses three-variable VAR models which are composed of relative supply, demand, and nominal shocks under the long-run zero or sign restrictions. In case of four-variable VAR models in which a nominal shock is separated by monetary policy and real exchange rate shocks, a monetary policy shock does not have a strong influence on real exchange rate fluctuations, while a supply shock has a significant impact on them. Hence, the won/dollar exchange rate can be regarded as a shock absorber.

The subsequent sections of the paper are organized as follows. Section Ⅱ reviews the studies which examine dynamic interrelationships between GDP, prices, and exchange rates using structural VAR models. Section Ⅲ and Ⅳ explain the estimation methods of VAR models based on Cholesky decomposition, long-run zero restrictions, and sign restrictions. Section Ⅴ derives impulse response functions and variance decomposition of forecasting errors from the estimation results. In Section Ⅵ, their policy implications are examined. Section Ⅶ summarizes and concludes the paper.

Ⅱ. Literature Reviews

There are a lot of research literature which investigates interlinkages between real exchange rates and main domestic and foreign macroeconomic variables with VAR models until now, for example, Clarida and Gali (1994), Eichenbaum and Evans (1995), Chadha and Prasad (1997), Funke (2000), Faust and Roger (2003), Artis and Ehrman (2006), Farrant and Peersman (2006), Scholl and Uhlig (2006).

Clarida and Gali (1994) developed the theoretical models of Dornbusch (1976) and Obstfeld (1985) into a VAR model of open economy with three relative variables and analyzed impacts of supply, demand, and nominal shocks on real exchange rates. They used a long-run triangular identification scheme proposed by Blanchard and Quah (1989) and found that demand shocks explained most of real exchange rate fluctuations. It means that the real exchange rate play a role as a shock absorber. The same conclusion was reached by Funke (2000) who investigated UK-Euro area and Chadha and Prasad (1997) who applied Clarida and Gali (1994) model to yen/dollar exchange rates. On the other hand, Artis and Ehrmann (2006) assumed the short-run zero restriction condition under which nominal shocks did not have contemporaneous impacts on output and showed that the exchange rate was not a shock absorber, but a source of shocks. Eichenbaum and Evans (1995) examined the effects of U.S. monetary policy on exchange rates with a VAR model which assumed Cholesky decomposition.

In recent years, a lot of research estimated VAR models with sign restrictions on the basis of economic theories in various fields such as business cycles, exchange rates, and monetary and fiscal policies. For example, Faust and Roger (2003) relaxed identification assumption of existing research and then analyzed an effect of monetary policy on exchange rates. Scholl and Uhlig (2006) investigated a relationship between exchange rates and forward discount puzzle using sign restrictions. Farrant and Peersman (2006) examined Clarida and Gali (1994) model using sign restrictions instead of long-run zero restrictions and found that nominal shocks had permanent effects. The long-run zero restriction assumption is widely known to have problems of small sample bias, measurement error, and theoretical counterargument. In short, in contrast with the argument of Clarida and Gali (1994), the exchange rate is not a shock absorber, but a source of shocks.

However, even though interactions between won/dollar exchange rates and key macroeconomic variables are very important from the standpoint of a small open economy, domestic analyses of their relationships under long-run zero restriction and sign restriction assumptions are not almost carried out to date. According to the empirical results in developed countries, impacts of nominal shocks on exchange rates are different, depending on whether long-run zero restrictions or sign restrictions are assumed. On the other hand, as Korea is a small open economy with complete openness of goods and financial markets, it is expected that won/dollar exchange rates are not significantly influenced by nominal and monetary policy shocks without regard to the assumption considered. The study focuses on whether this expectation is consistent with the empirical results.

Ⅲ. Estimation Model

The paper considers the following structural three-variable VAR model based on Clarida and Gali (1994).

$$\mathrm{A}Z_t = \mathrm{c} + \mathrm{A}_1 Z_{t-1} + \cdots + \mathrm{A}_p Z_{t-p} + u_t, \qquad \mathrm{E}(u_t u_t') \equiv \mathrm{H} \tag{1}$$

$$\mathrm{A}Z_t = \mathrm{c} + \mathrm{A}_1 Z_{t-1} + \cdots + \mathrm{A}_p Z_{t-p} + H^{1/2}\nu_t, \quad \mathrm{E}(\nu_t \nu_t') \equiv \mathrm{I} \tag{2}$$

Where $Z_t = [\Delta y_t,\ \Delta q_t,\ \Delta p_t]'$ is a 3×1 endogenous variable vector and Δ implies a first difference. Here y_t represents log industrial production relative to the US. q_t indicates the log real exchange rate of Korea against the US. The real exchange rate is defined such that an increase stands for a depreciation. p_t denotes log consumer prices relative to the US. Covariance matrices H and I are 3 x 3 diagonal matrix and identity matrix, respectively. $u_t = [u_{s,t},\ u_{d,t}, u_{n,t}]'$ or $\nu_t = [\nu_{s,t},\ \nu_{d,t}, \nu_{n,t}]'$ ($u_t = H^{1/2}\nu_t$) is the 3 x 1 residual vector which are composed of three shocks such as supply, demand, and nominal shocks, and is not correlated with other variables and its own lagged variables. Equation (1) can be expressed as the following reduced-form.

$$Z_t = \mathrm{A}^{-1}\mathrm{c} + \mathrm{A}^{-1}\mathrm{A}_1 Z_{t-1} + \cdots + \Lambda^{-1}\mathrm{A}_p Z_{t-p} + \mathrm{A}^{-1}u_t \tag{3}$$

$$= \mathrm{d} + \mathrm{B}_1 Z_{t-1} + \cdots + \mathrm{B}_p Z_{t-p} + \varepsilon_t, \quad E\varepsilon_t\varepsilon_t' \equiv \Omega \tag{4}$$

Using $u_t = H^{1/2}\nu_t$, equation (4) can be expressed as follows.

$$Z_t = X_t'\Theta + \varepsilon_t = X_t'\Theta + \mathrm{A}^{-1}u_t = X_t'\Theta + \mathrm{A}^{-1}H^{1/2}\nu_t \tag{5}$$

Where $X_t = [1,\ Z_{t-1}, \cdots, Z_{t-p}]'$ and $\Theta = [d, \mathrm{B}_1, \cdots, \mathrm{B}_p]'$. Using $\mathrm{E}u_t u_t' = H$ and $\varepsilon_t = \mathrm{A}^{-1} u_t$, Ω is expressed as follows.

$$\Omega = \mathrm{A}^{-1} H (\mathrm{A}^{-1})' \tag{6}$$

In the case of a three-variable VAR model in which parameter Θ and covariance matrix Ω are constant, equation (6) has nine unknown variables, while only six equations are derived from estimates of reduced-form covariance matrix Ω. Therefore, in order to just identify a structural parameter matrix A, additional restrictions or assumptions are necessary.

The paper first analyzes three-variable VAR models in cases of Cholesky decomposition and Clarida and Gali's (1994) long-run zero restrictions. Next, in order to complement drawbacks of the former two methods, it estimates the identical VAR models with contemporary sign restriction conditions of Farrant and Peersman (2006). Finally, it compares the estimation results of three-variable VAR models with those of four-variable VAR models in which interest rate variables are additionally considered.

1. Cholesky Decomposition

Cholesky decomposition is traditionally used as an easy way of deriving the estimates of structural parameters from those of reduced-form parameters and covariance matrix. When the order of three variables sets up as $Z_t = [\Delta y_t,\ \Delta q_t,\ \Delta p_t]$ for Choleksy decomposition, three restriction conditions in which upper right factors of A, α_{yq}, α_{yp}, and α_{qp} are zero respectively are added. Therefore, the model mentioned above can be just identified. As Table 1 shows, $\frac{\partial y_t}{\partial u_{d,t}}$, $\frac{\partial p_t}{\partial u_{n,t}}$, and $\frac{\partial q_t}{\partial u_{n,t}}$ are equal to zero, respectively. But in the modern society in which information and communication technologies are developed, the assumption that a monetary policy authority responds one period later may be unrealistic. The empirical studies also suggested that the impulse responses based on Cholesky decomposition were located in a tail part of possible impulse response distributions.

2. Clarida and Gali's (1994) Long-Run Zero Restrictions

Clarida and Gali (1994) identified structural parameters from reduced-form VAR models with three variables by adding the three long-run restrictions derived from the theoretical model. As shown in Table 2, a structural supply shock ($u_{s,t}$ or $\nu_{s,t}$) has a permanent impact on a relative output level (y_t) in the long run. But this is not a case in a structural demand shock ($u_{d,t}$ or $\nu_{d,t}$) and a structural nominal shock ($u_{s,t}$ or $\nu_{s,t}$). Structural supply and demand shocks also influence a long-run level of real exchange rates, whereas a structural nominal shock does not have a long-run impact on the real variables such as real output and real exchange rates. But three structural shocks change a relative price level in the long run.

3. Farrant and Peersman's (2006) Contemporary Sign Restrictions

Farrant and Peersman (2006) suggested that a small sample bias and a measurement error could distorted the estimation results, when the long-run zero restrictions were imposed. According to the hysteresis theory and some equilibrium growth models, a nominal shock also has a real long-term effect. Therefore, the paper tries to examine the credibility of existing models, by identifying three shocks under the sign restriction assumptions. If the impulse responses of traditional models are similar to the median impulse responses obtained under the sign restriction assumption, the results can be reliable. Table 3 shows the sign restrictions based on Clarida and Gali's (1994) short-run dynamic model. According to Clarida and Gali's (1994) short-run dynamic model, a positive supply shock ($u_{s,t}$ or $\nu_{s,t}$) increases relative industrial production (y_t), while decreases relative consumer price (p_t). Real exchange rates (q_t) vary case by case. On the other hand, a positive demand shock ($u_{d,t}$ or $\nu_{d,t}$) increases relative consumer price as well as relative output, and appreciates real exchange rates. A positive nominal shock ($u_{s,t}$ or $\nu_{s,t}$) increases relative output and relative consumer prices like a demand shock. But it depreciates real exchange rates on the contrary to a demand shock.

Ⅳ. Estimation Methods

This section explains the estimation methods of VAR models with Clarida and Gali's (1994) long-run restrictions and Farrant and Peersman's (2006) contemporary sign restrictions. In the impulse response analysis using contemporary sign restrictions, because each of impulse responses is the response based on an individual theoretical model, the effect of a structural shock on the here and the hereafter can be interpreted to be know-nothing. Sign restrictions are also based on a theoretical model such as Clarida and Gali (1994).

1. Clarida and Gali's (1994) Long-Run Zero Restrictions

Under the assumption of no constant in the three-variable VAR model which satisfies Clarida and Gali's (1994) long-run zero restrictions, equation (2) can be expressed as the following MA (moving average) form.

$$
\begin{aligned}
Z_t &= (\mathrm{A} - \mathrm{A}_1 L - \cdots - \mathrm{A}_p L^p)^{-1} H^{\frac{1}{2}} \nu_t \\
&= \Delta_o \nu_t + \Delta_1 \nu_{t-1} + \Delta_2 \nu_{t-2} + \cdots \\
&= \Delta(\mathrm{L}) \nu_t
\end{aligned} \tag{7}
$$

Under the same assumption with equation (7), equation (4) can be represented as the following MA (moving average) form.

$$
\begin{aligned}
Z_t &= (I - \mathrm{B}_1 L - \cdots - \mathrm{B}_p L^p)^{-1} \varepsilon_t \\
&= \epsilon_t + \Gamma_1 \epsilon_{t-1} + \Gamma_2 \epsilon_{t-2} + \cdots \\
&= \Gamma(\mathrm{L}) \epsilon_t
\end{aligned} \tag{8}
$$

Equations (7) and (8) show $\varepsilon_t = \Delta_0 \nu_t = \Delta_0 u_t / H^{1/2}$. According to equations (3) and (4), $\Delta_0 = \mathrm{A}^{-1} H^{1/2}$. Since $\mathrm{E}(\nu_t \nu_t') \equiv I$, $\mathrm{E}(\varepsilon_t \epsilon_t') = \Delta_0 \Delta_0' = \Omega$. In case of the current period (L=0), $\Delta(0) \equiv \Delta_0$ and in the long run (L=1), $\Delta(1) \equiv \Delta_0 + \Delta_1 + \Delta_2 + \cdots$, because $\Delta(\mathrm{L}) \equiv \Delta_0 + \Delta_1 L + \Delta_2 L^2 + \cdots$. Therefore, when the restriction that demand and nominal shocks do not affect long-run output level is assumed like Clarida and Gali (1994), the first row and second column and the first row and third column of $\Delta(1)$ are equal to zero ($\delta_{12}(1) = \delta_{13}(1) = 0$), respectively. In the same way, when the restriction that a nominal shock does not influence long-run real exchange rates is given, the second row and third column of $\Delta(1)$ is equal to zero ($\delta_{23}(1) = 0$).

By using $\Gamma_0 \equiv I$, $\Gamma_1 \equiv \Delta_1 \Delta_0^{-1}$, $\Gamma_2 \equiv \Delta_2 \Delta_0^{-1}$, and so on, which are derived from equation (8), $\Gamma(1) \equiv \Gamma_0 + \Gamma_1 + \Gamma_2 + \cdots = \Delta(1) \Delta_0^{-1}$ is obtained. Hence, matrix $\Gamma(1) \Omega \Gamma(1)'$ is calculated from estimates of Ω and $\Gamma(1)$ gotten from reduced form MA. By utilizing $E\varepsilon_t\epsilon_t' = \Delta_0\Delta_0' = \Omega$ and $\Gamma(1) = \Delta(1)\Delta_0^{-1}$, $\Gamma(1)\Omega\Gamma(1)'$ can be expressed as follows.

$$\Gamma(1)\Omega\Gamma(1)' = \Delta(1)\Delta(1)' \tag{9}$$

When M is assumed to be the lower triangular matrix obtained from a Cholesky decomposition of $\Gamma(1)\Omega\Gamma(1)', MM'$ is represented as follows.

$$MM' = \Gamma(1)\Omega\Gamma(1)' \tag{10}$$

Since a long-run zero restriction implies that $\Delta(1)$ is lower triangular matrix, $\Delta(1) = M$ is obtained. When $\Delta(1) = M$ is plugged into $\Gamma(1) \equiv \Delta(1)\Delta_0^{-1}$, Δ_0 is derived as follows.

$$\Delta_0 = \Gamma(1)^{-1}M \tag{11}$$

In short, Δ_0 can be identified by using the long-run restriction in which $\Delta(1)$ is a lower triangular matrix. When the estimates of Δ_0 are given, time series of structural shocks and Δ_i (*i*=1, 2, ⋯) are also identified. The paper dynamically analyzes impacts of structural supply, demand, and nominal shocks on industrial production, real exchange rates, and prices, respectively, using equation (7) and these estimates.

2. Farrant and Peersman's (2006) Sign Restrictions

In addition to Cholesky decomposition and long-run restriction assumptions used before, structural parameters can be derived by imposing various restrictions based on economic theories on parameters or by using heteroskedasticity of covariance matrix. This section discusses Farrant and Peersman's (2006) method which identifies an attainable range of impulse response functions by imposing sign restrictions based on economic theories on contemporary structural parameters. Cholesky decomposition and long-run restriction assumptions have the problem that their impulse responses do not necessarily have the signs which are consistent with economic theories. In contrast, from an agnostic point of view, this method focuses on deriving structural shocks to which impulse responses coincide with economic theories from reduced-form shocks. These structural shocks are not also correlated with other shocks and their own lagged shocks.

By making use of relationships between reduced-form and structural shocks discussed above, the estimates of the following structural shocks can be calculated.

$$\varepsilon_t = \mathrm{A}^{-1}u_t = \Delta_0 H^{1/2}u_t = \Delta_0 \nu_t \tag{12}$$

Where A is assumed to be a lower triangular matrix on a basis of Cholesky decomposition. u_t and ν_t are the structural shocks of which covariance matrices are H and I, respectively. By using the square matrix which has a characteristic of $\mathrm{Q}'\mathrm{Q} = \mathrm{QQ}' = \mathrm{I}$, a structural shock ν_t can be transformed into a new structural shock ν_t^* as follows.

$$\varepsilon_t = \Delta_0 Q'Q\nu_t = \Delta_0^* \nu_t^* \tag{13}$$

Where since the covariance matrix of ν_t and QQ' are identity matrices, the covariance matrix of ν_t^* are also an identity matrix. Therefore, ν_t and ν_t^* have the same covariance matrix, whereas they have different impacts on a reduced-form shock ε_t and Z_t, as shown in equation (13).

Householder and Givens transformation methods are generally used in order to form an orthogonal matrix Q. The study uses the former method and gets an orthogonal matrix. When the Householder transformation method is used in three-variable VAR models, 3 x 3 random variables are extracted from $\mathrm{N}(0, I_3)$ and then decomposed using the QR factorization. Δ_0^* and ν_t^* are derived by using the orthogonal matrix Q_H obtained from QR decomposition, as shown in equation (13) and then impulse response analyses are carried out. The study gets a lot of impulse response functions through the orthogonal matrix Q_H and considers only the impulse response functions among which contemporary responses satisfy sign restriction conditions.

Ⅴ. Estimation Results

The paper first estimates three-variable VAR models using real won/dollar exchange rates, Korea and U.S. industrial productions, and consumer prices during the period from January 1990 to May

2015 (Data Source: IMF). Monthly data are considered and the sample size is 305.

1. Unit Root and Cointegration Tests

This section first carries out unit root and cointegration tests, before the estimation results are investigated. The unit root test results are represented in Table 4, when the lag length is four. Table 4 shows that relative industrial production, relative consumer price, and real won/dollar exchange rate levels have unit root, while their changes do not have unit root, regardless of the test method or the trend. Table 5 represents the Johansen's cointegration test results for three variables, when the lag length is four. Three variables do not have a cointegration relation at the 95% level. Therefore, it estimates VAR models for difference variables.

2. Impulse Response Analysis

This section examines three kinds of impulse responses based on Cholesky decomposition, Clarida and Gali's (1994) long-run restrictions, and sign restrictions, respectively. The lag length is selected to be two, according to AIC, AICc, and SIC criterions. The Householder and Givens transformations are together used in order to select the contemporary impulse responses which satisfy sign restriction conditions. In case of the Givens transformation method, the study does not find any impulse responses which satisfy all the contemporary sign restriction conditions of Clarida and Gali (1994) shown in Table 3. Hence, the empirical analysis make use of the contemporary sign restriction conditions represented in Table 6. It is assumed that a positive demand shock decreases real exchange rates, while a positive nominal shock increases them in Table 3. In Table 6, however, the impact of demand and nominal shocks on real exchange rates are assumed to be uncertain. It is already well known that interest rates and exchange rates move in the same direction in the Chicago model of exchange rate determination with the flexible price. The contrary is the case in the (New) Keynesian exchange rate model with the sticky price.

The estimation results of impulse responses are represented in Tables 7, 8, and 9. Each Table shows the median impulse responses obtained from simulation. The numbers in parentheses describe fifth and ninety fifth percentiles, respectively.[1] Table 7 shows the cumulative impulse responses of relative industrial production changes to positive one standard deviation shocks. Zero month implies a contemporary response to a shock. Therefore, contemporary responses of relative industrial production changes to demand and nominal shocks become zero, when Cholesky decomposition is used. When Clarida and Gali's (1994) long-run zero restrictions are used, their cumulative responses become zero after 24 months. On the other hand, they have all minus values after 24 months under the Cholesky decomposition assumption, while plus values after 24 months under the sign restriction assumption using the Householder transformation method. In case of a positive supply shock, cumulative responses of industrial production changes have plus values without relation to estimation models and analysis periods.

Table 8 shows cumulative responses of real won/dollar exchange rate changes to one standard deviation shocks. Under the Cholesky decomposition assumption, contemporary responses of real won/dollar exchange rate changes to a nominal shock become zero. Under the Clarida and Gali's (1994) long-run zero restriction assumption, their cumulative responses become zero after 24 months. On the other hand, under the Cholesky decomposition and sign restriction assumptions, their cumulative median responses have all minus values after 24 months in contrast with Table 3. As already mentioned before, in the Chicago theory of exchange rate determination, interest rates and exchange rates move in the same direction. Under the assumptions of Cholesky decomposition and Clarida and Gali's (1994) long-run zero restrictions, cumulative median responses of real won/dollar exchange rate changes to positive demand shocks have plus values after 24 months, in contrast with Table 3. But under the sign restriction assumption, their responses are negative, even though their statistical significance is very low, as fifth and ninety fifth percentiles show. On the other hand, positive supply shocks decrease real won/dollar exchange rates like in Euro area without relation to the models used. According to Farrant and Peersman (2006), positive supply shocks depreciate real currency values in England and Japan, whereas appreciate Euro's value. In case of Canada, responses of real exchange rates do not have a statistical significance.[2]

Table 9 represents cumulative median responses of relative consumer price changes between Korea and the US to one standard deviation shocks. Positive supply shocks decrease consumer prices

[1] It reports median, fifth and ninety fifth percentiles obtained from one thousand simulations in Cholesky decomposition and Clarida and Gali's (1994) long-run restrictions, and one million simulations in Householder's sign restrictions.

[2] The empirical results often show that positive supply shocks lead to an appreciation in other countries. Detken et al. (2002) suggested that this result was caused by real wealth effect and domestic bias of consumption.

after 24 months, while the contrary is the case in positive demand and nominal shocks. The results do not depend on the models used. But in case of sign restrictions a fifth percentile has a negative value. It implies that their responses may be uncertain.

3. Variance Decomposition Analysis

This section examines variance decomposition of forecasting errors under the assumptions of Cholesky decomposition, Clarida and Gali's (1994) long-run zero restrictions, and sign restrictions. The estimation results of variance decompositions are represented in Tables 10, 11, and 12. Each Table shows median variance decompositions obtained from simulations and the numbers in parentheses describe error bands of fifth and ninety fifth percentiles. Table 10 shows variance decompositions of industrial production changes. An explanation ratio of supply shock for variance of industrial production changes exceeds 60%, while that of a nominal shock is less than 3%. The results do not vary largely, depending on the models used.

Table 11 displays variance decompositions of real won/dollar exchange rate changes. An explanation ratio of a relative demand shock for variance of real exchange rate changes is highest after 24 months without relation to estimation methods. It is highest as a 96.7% in Cholesky decomposition, whereas lowest as a 55.6% in Clarida and Gali's (1994) long-run zero restrictions. According to Farrant and Peersman (2006), under the long-run zero restriction assumption, an explanation ratio of a relative demand shock reaches 84% in England, 75% in Euro area, 80% in Japan, and 89% in Canada, respectively. However, when sign restrictions are utilized instead of long-run zero restrictions, a demand shock's role becomes weaker, while a nominal shock's role becomes stronger. On the other hand, this study shows that a demand shock's role becomes stronger, while a nominal shock's role does not change remarkably. An explanation ratio of a supply shock is the second highest. In particular, in case of long-run zero restrictions, its ratio arrives at 43.9%. A nominal shock can explain less than 1% of variance of real exchange rate changes, regardless of estimation methods. It suggests that the exchange rate plays a role as a shock absorber. Farrant and Peersman (2006) found a nominal shock's important role in explaining exchange rates by using sign restrictions. In spite of using the same method, however, the paper leads to the other conclusion.

Table 12 describes variance decompositions of consumer price changes. Explanation ratios of supply, demand, and nominal shocks for variance of price changes are different from the cases of other variables. A demand shock's explanation ratio for variance of inflation is the highest after 24 months in case of Clarida and Gali's (1994) long-run zero restrictions and sign restrictions. But a nominal shock's explanation ratio is the highest in case of Cholesky decomposition, while lowest in the sign restriction conditions.

4. Four-Variable VAR Models

Because Artis and Ehrmann (2000) and Farrant and Peersman (2006) divided a nominal shock into monetary policy and real exchange rate shocks, this study also analyzes four-variable VAR models which compose of relative industrial production, relative consumer prices, relative interest rates between Korea and the US, and won/dollar exchange rates. According to AIC and AICc criteria, two is selected as a lag length. Historically, one part of exchange rate fluctuations may be explained as a response against a monetary shock. When two shocks are considered separately, a real exchange rate shock may be resulted from exchange rate movements which is not explained by time varying premium of exchange rates and fundamentals. But it is likely that real exchange rate shocks may be purely real. Money market rates of IMF are used as interest rates. They are used without taking logarithms and interest rate differentials are multiplied by -1 in order to represent positive shocks as expansionary monetary policy shocks. This section investigates only the case of sign restrictions to save space. Table 13 shows contemporary sign restriction conditions for each shock in four-variable VAR models.

Tables 14 displays the estimation results of cumulative impulse responses under sign restriction conditions based on the Householder transformation method.[3] A positive supply shock cumulatively increases median industrial production changes, whereas decreases median price and real exchange rate changes. It also drops median interest rate changes in the long run. But the ninety fifth percentiles in interest rates and real exchange rates have opposite signs against each median. It implies that their statistical significance is not strong. A positive demand shock increases median industrial production, price, and interest rate changes, but decreases median real exchange rate changes. A positive monetary policy shock increases median industrial production and price changes, while decreases median interest rate and real exchange rate changes. The relationship between relative Korean interest rates and won/dollar exchange rates does not correspond with a Keynesian theory, but a Chicago

[3] It reports median, fifth, and ninety fifth percentiles derived from ten million simulations.

theory. A positive real exchange rate shock increases median industrial production, price, and interest rate changes. According to Farrant and Peersman (2006), the influence of pure real exchange rates is strong in the short run, but becomes weaker in the long run. But this study suggests that it is strong in the long run as well as the short run for the three variables except industrial production in case of Korea.

Tables 15 shows the estimation results of variance decompositions under sign restrictions. A supply shock is the biggest and a real exchange rate shock is the second biggest in explaining variance of industrial production changes. Explanation ratios of demand and nominal shocks are very low. In case of prices, a real exchange rate shock is the biggest in explaining its variance. In case of interest rates, a real exchange rate shock is the biggest and a supply shock is the second biggest in explaining its variance. In case of real exchange rates, the impacts of real exchange rate and supply shocks on them are also the biggest and the second biggest, respectively. Explanation ratios of demand and nominal shocks are low. The paper shows that a role of a nominal shock is not important, in contrast with Farrant and Peersman (2006). The won/dollar exchange rate is suggested to play a role as a shock absorber.

5. Rolling Regression Analysis

Lastly, the paper carries out rolling regression analyses in order to investigate how the empirical results shown in Tables 14 and 15 change through time. Figures 1 and 2 present the empirical results of cumulative impulse responses and variance decompositions based on rolling regressions, respectively. The four-variable VAR models with sign restrictions described in Table 13 are adopted as the estimation models. In rolling regressions, 240 (20-year) samples from 305 samples are chosen in each estimation. Since the first sample among fixed 240 samples is replaced with the new sample in each estimation, total 65 estimation results are presented in Figures 1and 2. The numbers 1 and 65 in y axis in Figures show the cumulative impulse responses for the period from January 1990 to December 2009 and for the period from June 1995 to May 2015, respectively.[4]

As Figure 1 shows, in recent years, positive supply shocks decrease won/dollar exchange rates less than before, while positive demand shocks increase rather than decrease them. On the other hand, positive monetary policy shocks bring down won/dollar exchange rates without relation to the time

[4] When 120 (10-year) samples instead of 240 (20-year) samples are even used in rolling regressions, the main results are not largely changed, but their volatility becomes bigger.

period. As already shown above, the relative fall in domestic interest rates drop won/dollar exchange rates in the model of exchange rate determination in which the purchasing power parity is accepted even in the short run. According to domestic empirical results, in Korea in which the stock market is perfectly opened to foreign investors, decrease in domestic interest rates increases domestic stock prices, which decrease won/dollar exchange rates through the inflow of foreign capital. When the purchasing power parity assumption is accepted, it is possible for positive supply shocks to decrease won/dollar exchange rates by the fall in relative domestic prices, while the reverse is the case in demand shocks. Pavlova and Rigobon (2007) provided that if preference for foreign goods was bigger than that for domestic goods, positive demand shocks increased exchange rates. Recently, the impacts of supply, demand, monetary policy, and exchange rate shocks on industrial production become weaker. So do the impacts of supply and monetary policy shocks on prices.

Figure 2 describes the empirical results of variance decompositions obtained from the same method as that in Figure 1. We can find that the explanation ratios for each variance do not change largely. The explanation ratios of monetary policy shocks for exchange rate volatility seem to be small regardless of the time period, while those of supply shocks increase bigger lately. The explanation ratios of supply shocks for variance of industrial production changes become smaller in recent years. The result is contrary in case of exchange rate shocks. Supply shocks recently explain the larger parts of inflation variance.

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Ⅵ.. Policy Implications

The empirical results of impulse responses demonstrate that only a supply shock certainly increases industrial production, but that demand and nominal shocks do not. The empirical results of variance decompositions also reveal that explanation ratios of a supply shock for variance of industrial production changes exceed 60% after 24 months without relation to the estimation methods. But a nominal shock's explanation ratio is less than 3%. Rolling regression analyses also support this conclusion. These empirical results suggest that Korea should carry out the long-term supply policy rather than the short-term demand policy such as monetary and fiscal policies.

Cumulative median responses of real won/dollar exchange rate changes after 24 months to a positive nominal shock have negative values, regardless of the estimation methods. It implies that relative Korean interest rates and won/dollar exchange rates move together in the same direction, as the Chicago theory of exchange rate determination with a flexible price suggests. In case of the US versus several developed countries, interest rates and exchange rates move in the opposite direction, as the (New) Keynesian theory of exchange rate determination theory with a sticky price insists. The domestic studies show the mixed empirical results. They depend on which model is chosen between structural and reduced-form models in case of Korea. It calls on the monetary authority to carefully carry out monetary and foreign exchange policies.

According to the empirical results of variance decompositions, an explanation ratio of a nominal shock for variance of real exchange rate changes is less than 1% after 24 months, regardless of the estimation methods. This conclusion is different from that of Farrant and Peersman (2006) who found the important role of a nominal shock, even though this study uses the same method as them. The won/dollar exchange rate seems to play a role as a shock absorber.

When put together, the impact of a nominal shock or a monetary policy shock on won/dollar exchange rates is weak. In addition, rolling regression analyses show that the impacts of real and nominal shocks on industrial production become weaker in recent years. These results require the Korean policy authority to cautiously carry out monetary and fiscal policies, and to take direct measures to promote inbound and domestic investments.

Ⅶ. Conclusions

The paper examines interrelations between real won/dollar exchange rates and fundamental macroeconomic variables such as relative industrial production, relative prices, and relative interest rates between Korea and U.S. It estimates structural VAR models based on the two-country open macroeconomic theory using monthly data from 1990 to date. Cholesky decomposition, Clarida and Gali’s (1994) long-run zero restrictions, and sign restrictions are used in order to derive structural parameters from reduced-form VAR parameters. The Householder transformation method is considered for sign restrictions. The paper investigates what the sources of real exchange rate fluctuations are by comparing the empirical results of impulse responses and variance decompositions.

In three-variable VAR models, a nominal shock does not play an important role in explaining real won/dollar exchange rates in contrast to Farrant and Peersman (2006), even though their sign restrictions as well as Clarida and Gali’s (1994) long-run zero restrictions are used. So, it implies that the won/dollar exchange rate can play a role as a shock absorber. In four-variable VAR models in which a nominal shock is divided into monetary policy and real exchange rate shocks, a monetary policy shock does not play an important role as determinants of real won/dollar exchange rates, while a supply shock has a significant impact on short- and long-term won/dollar exchange rates. Rolling regression analyses also support this conclusion. They also demonstrate that the impacts of real and nominal shocks on industrial production become weaker lately. These empirical results suggest that Korea as a small open economy should cautiously carry out monetary and fiscal policies and take direct measures to promote inbound and domestic investments.

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Table 1 Cholesky Decomposition

	y	q	P
Supply Shock	$\frac{\partial y_t}{\partial u_{s,t}}$?	$\frac{\partial q_t}{\partial u_{s,t}}$?	$\frac{\partial p_t}{\partial u_{s,t}}$?
Demand Shock	$\frac{\partial y_t}{\partial u_{d,t}} = 0$	$\frac{\partial q_t}{\partial u_{d,t}}$?	$\frac{\partial p_t}{\partial u_{d,t}}$?
Nominal Shock	$\frac{\partial y_t}{\partial u_{n,t}}$?	$\frac{\partial q_t}{\partial u_{n,t}} = 0$	$\frac{\partial p_t}{\partial u_{n,t}} = 0$

Table 2 Clarida and Gali (1994)'s Long Run Zero Restrictions

	y	q	P
Supply Shock	$\frac{\partial y_{t+\infty}}{\partial u_{s,t}} \geq 0$	$\frac{\partial q_{t+\infty}}{\partial u_{s,t}}$?	$\frac{\partial p_{t+\infty}}{\partial u_{s,t}} \leq 0$
Demand Shock	$\frac{\partial y_{t+\infty}}{\partial u_{d,t}} = 0$	$\frac{\partial q_{t+\infty}}{\partial u_{d,t}} \leq 0$	$\frac{\partial p_{t+\infty}}{\partial u_{d,t}} \geq 0$
Nominal Shock	$\frac{\partial y_{t+\infty}}{\partial u_{n,t}} = 0$	$\frac{\partial q_{t+\infty}}{\partial u_{n,t}} = 0$	$\frac{\partial p_{t+\infty}}{\partial u_{n,t}} \geq 0$

Table 3 Contemporary Sign Restrictions Based on Clarida and Gali (1994)

	y	q	P
Supply Shock	$\frac{\partial y_t}{\partial u_{s,t}} \geq 0$	$\frac{\partial q_t}{\partial u_{s,t}}$?	$\frac{\partial p_t}{\partial u_{s,t}} \leq 0$
Demand Shock	$\frac{\partial y_t}{\partial u_{d,t}} \geq 0$	$\frac{\partial q_t}{\partial u_{d,t}} \leq 0$	$\frac{\partial p_t}{\partial u_{d,t}} \geq 0$
Nominal Shock	$\frac{\partial y_t}{\partial u_{n,t}} \geq 0$	$\frac{\partial q_t}{\partial u_{n,t}} \geq 0$	$\frac{\partial p_t}{\partial u_{n,t}} \geq 0$

Table 4 Unit Root Test (Lag = 4)

Test Method		ADF		PP	
		Constant	Trend	Constant	Trend
Level	Industrial Production	-1.264	-1.806	-1.259	-1.781
	Consumer Price	-2.973	-2.121	-3.032	-2.102
	Real Won/$ Exchange Rates	-2.467	-2.448	-2.456	-2.436
Difference	Industrial Production	-7.552**	-7.592**	-7.565**	-7.603**
	Consumer Price	-8.176**	-8.642**	-8.206**	-8.718**
	Real Won/$ Exchange Rates	-7.246**	-7.244**	-7.217**	-7.215**

Note: 1) Industrial production and consumer price are expressed as a difference between Korea and U.S., after taking logarithm for each variable.
2) ** denotes significant in the 1% level.

Table 5 Cointegration Test: Johansen Test (Lag = 4)

H_0	Variables	Trend	λ_{max}	Criterion (95%)	Trace	Criterion (95%)
r=0	Industrial Production, Consumer Price, Real Won/$ Exchange Rates	X	20.676	21.144	30.566	31.618
		O	14.370	24.482	25.208	39.098

Note: 1) Industrial production and consumer price are expressed as a difference between Korea and U.S., after taking logarithm for each variable.
2) H_0: r=0 implies the null hypothesis that the cointegration vector does not exist.

Table 6 Contemporary Sign Restrictions

	y	q	P
Supply Shock	$\frac{\partial y_t}{\partial u_{s,t}} \geq 0$	$\frac{\partial q_t}{\partial u_{s,t}}$?	$\frac{\partial p_t}{\partial u_{s,t}} \leq 0$
Demand Shock	$\frac{\partial y_t}{\partial u_{d,t}} \geq 0$	$\frac{\partial q_t}{\partial u_{d,t}}$?	$\frac{\partial p_t}{\partial u_{d,t}} \geq 0$
Nominal Shock	$\frac{\partial y_t}{\partial u_{n,t}} \geq 0$	$\frac{\partial q_t}{\partial u_{n,t}}$?	$\frac{\partial p_t}{\partial u_{n,t}} \geq 0$

Table 7 Impulse Responses – Industrial Production

Month	Estimation Method	Supply Shock	Demand Shock	Nominal Shock
0	Cholesky	2.063 (1.879, 2.245)	0.000 (0.000, 0.000)	0.000 (0.000, 0.000)
	Clarida-Gali	2.425 (2.151, 2.801)	0.943 (0.504, 1.448)	-0.032 (-0.095, 0.026)
	Sign Restrictions	1.400 (0.458, 2.031)	0.864 (0.071, 1.920)	0.846 (0.069, 1.900)
3	Cholesky	2.041 (1.734, 2.386)	-0.640 (-1.010, -0.379)	-0.097 (-0.345, 0.157)
	Clarida-Gali	2.170 (1.838, 2.546)	0.229 (0.040, 0.534)	0.061 (0.026, 0.105)
	Sign Restrictions	1.579 (0.506, 2.208)	0.900 (-0.563, 2.120)	0.875 (-0.563, 2.115)
24	Cholesky	2.197 (1.849, 2.655)	-0.698 (-1.159, -0.405)	-0.068 (-0.362, 0.253)
	Clarida-Gali	2.325 (1.950, 2.832)	0.000 (0.000, 0.000)	0.000 (0.000, 0.000)
	Sign Restrictions	1.595 (0.501, 2.255)	0.931 (-0.485, 2.170)	0.913 (-0.485, 2.163)

Note: 1) Numbers in Table present cumulative median impulse responses obtained from simulations.
2) Numbers in parentheses denote fifth and ninety fifth percentiles, respectively.

Table 8 Impulse Responses – Real Won/Dollar Exchange Rates

Month	Estimation Method	Supply Shock	Demand Shock	Nominal Shock
0	Cholesky	0.007 (-0.244, 0.246)	2.497 (1.826, 3.409)	0.000 (0.000, 0.000)
	Clarida-Gali	-1.591 (-2.625, -0.942)	1.369 (0.628, 2.267)	-0.129 (-0.217, -0.061)
	Sign Restrictions	-0.173 (-1.614, 1.312)	0.074 (-2.317, 2.484)	0.382 (-2.312, 2.493)
3	Cholesky	-1.057 (-1.633, -0.428)	3.785 (2.761, 5.330)	-0.084 (-0.495, 0.381)
	Clarida-Gali	-1.931 (-2.932, -1.266)	3.007 (2.193, 4.080)	-0.050 (-0.129, 0.001)
	Sign Restrictions	-0.910 (-2.842, 1.304)	-0.605 (-3.585, 3.159)	-0.442 (-3.582, 3.181)
24	Cholesky	-1.127 (-1.828, -0.509)	3.367 (2.444, 4.866)	-0.197 (-0.673, 0.325)
	Clarida-Gali	-2.096 (-3.311, 1.377)	2.893 (2.187, 3.866)	0.000 (0.000, 0.000)
	Sign Restrictions	-0.859 (-2.757, 1.297)	-0.521 (-3.494, 3.133)	-0.361 (-3.493, 3.155)

Note: 1) Numbers in Table present cumulative median impulse responses obtained from simulations.
2) Numbers in parentheses denote fifth and ninety fifth percentiles, respectively.

Table 9 Impulse Responses – Consumer Price

Month	Estimation Method	Supply Shock	Demand Shock	Nominal Shock
0	Cholesky	0.000 (-0.036, 0.039)	-0.001 (-0.041, 0.040)	0.397 (0.365, 0.435)
	Clarida-Gali	0.004 (-0.206, 0.229)	0.258 (-0.053, 0.555)	0.382 (0.351, 0.419)
	Sign Restrictions	-0.270 (-0.392, -0.088)	0.162 (0.013, 0.369)	0.165 (0.014, 0.369)
3	Cholesky	0.015 (-0.075, 0.100)	0.230 (0.136, 0.356)	0.528 (0.453, 0.612)
	Clarida-Gali	-0.154 (-0.282, -0.030)	0.323 (0.060, 0.596)	0.538 (0.462, 0.624)
	Sign Restrictions	-0.379 (-0.571, -0.076)	0.261 (-0.189, 0.581)	0.272 (-0.190, 0.582)
24	Cholesky	-0.040 (-0.145, 0.053)	0.221 (0.128, 0.360)	0.484 (0.411, 0.576)
	Clarida-Gali	-0.123 (-0.253, 0.005)	0.157 (0.047, 0.295)	0.492 (0.427, 0.576)
	Sign Restrictions	-0.376 (-0.544, -0.101)	0.230 (-0.159, 0.536)	0.239 (-0.161, 0.538)

Note: 1) Numbers in Table present cumulative median impulse responses obtained from simulations.
2) Numbers in parentheses denote fifth and ninety fifth percentiles, respectively.

Table 10 Variance Decompositions – Industrial Production

Month	Estimation Method	Supply Shock	Demand Shock	Nominal Shock
0	Cholesky	0.998 (0.980, 1.000)	0.002 (0.000, 0.002)	0.000 (0.000, 0.000)
	Clarida-Gali	0.867 (0.759, 0.954)	0.133 (0.045, 0.240)	0.000 (0.000, 0.001)
	Sign Restrictions	0.776 (0.165, 0.988)	0.151 (0.001, 0.779)	0.025 (0.002, 0.253)
3	Cholesky	0.880 (0.792, 0.950)	0.120 (0.050, 0.208)	0.000 (0.000, 0.001)
	Clarida-Gali	0.810 (0.675, 0.931)	0.188 (0.068, 0.321)	0.001 (0.000, 0.003)
	Sign Restrictions	0.630 (0.147, 0.896)	0.202 (0.102, 0.787)	0.023 (0.002, 0.222)
24	Cholesky	0.870 (0.777, 0.945)	0.130 (0.054, 0.220)	0.001 (0.000, 0.003)
	Clarida-Gali	0.796 (0.654, 0.926)	0.203 (0.073, 0.342)	0.001 (0.000, 0.002)
	Sign Restrictions	0.628 (0.147, 0.895)	0.203 (0.103, 0.787)	0.023 (0.002, 0.221)

Note: 1) Numbers in Table present median variance decompositions obtained from simulations.
2) Numbers in parentheses denote fifth and ninety fifth percentiles, respectively.

Table 11 Variance Decompositions – Real Won/Dollar Exchange Rates

Month	Estimation Method	Supply Shock	Demand Shock	Nominal Shock
0	Cholesky	0.000 (0.000, 0.000)	1.000 (1.000, 1.000)	0.000 (0.000, 0.000)
	Clarida-Gali	0.566 (0.195, 0.933)	0.431 (0.064, 0.797)	0.004 (0.001, 0.009)
	Sign Restrictions	0.197 (0.002, 0.894)	0.764 (0.074, 0.991)	0.006 (0.000, 0.142)
3	Cholesky	0.028 (0.012, 0.051)	0.969 (0.946, 0.985)	0.003 (0.003, 0.005)
	Clarida-Gali	0.441 (0.167, 0.702)	0.555 (0.294, 0.826)	0.004 (0.001, 0.008)
	Sign Restrictions	0.158 (0.028, 0.733)	0.804 (0.238, 0.956)	0.006 (0.003, 0.121)
24	Cholesky	0.029 (0.013, 0.054)	0.967 (0.942, 0.983)	0.004 (0.002, 0.006)
	Clarida-Gali	0.439 (0.164, 0.692)	0.556 (0.305, 0.828)	0.004 (0.001, 0.010)
	Sign Restrictions	0.158 (0.028, 0.732)	0.804 (0.239, 0.956)	0.006 (0.003, 0.121)

Note: 1) Numbers in Table present median variance decompositions obtained from simulations.
2) Numbers in parentheses denote fifth and ninety fifth percentiles, respectively.

Table 12 Variance Decompositions – Consumer Price

Month	Estimation Method	Supply Shock	Demand Shock	Nominal Shock
0	Cholesky	0.000 (0.000, 0.000)	0.000 (0.000, 0.000)	1.000 (1.000, 1.000)
	Clarida-Gali	0.035 (0.000, 0.252)	0.289 (0.008, 0.666)	0.627 (0.300, 0.943)
	Sign Restrictions	0.199 (0.002, 0.899)	0.758 (0.066, 0.991)	0.006 (0.000, 0.149)
3	Cholesky	0.081 (0.006, 0.282)	0.208 (0.033, 0.507)	0.665 (0.424, 0.885)
	Clarida-Gali	0.104 (0.025, 0.344)	0.411 (0.099, 0.712)	0.438 (0.217, 0.726)
	Sign Restrictions	0.167 (0.036, 0.813)	0.800 (0.220, 0.955)	0.006 (0.002, 0.121)
24	Cholesky	0.081 (0.015, 0.275)	0.306 (0.058, 0.612)	0.570 (0.319, 0.843)
	Clarida-Gali	0.101 (0.027, 0.330)	0.472 (0.124, 0.763)	0.385 (0.172, 0.694)
	Sign Restrictions	0.166 (0.037, 0.811)	0.800 (0.222, 0.955)	0.006 (0.003, 0.120)

Note: 1) Numbers in Table present median variance decompositions obtained from simulations.
2) Numbers in parentheses denote fifth and ninety fifth percentiles, respectively.

Table 13 Contemporary Sign Restrictions (4 Variables)

	y	p	r	q
Supply Shock	$\frac{\partial y_t}{\partial u_{s,t}} \geq 0$	$\frac{\partial p_t}{\partial u_{s,t}} \leq 0$	$\frac{\partial r_t}{\partial u_{s,t}}$?	$\frac{\partial q_t}{\partial u_{s,t}}$?
Demand Shock	$\frac{\partial y_t}{\partial u_{d,t}} \geq 0$	$\frac{\partial p_t}{\partial u_{d,t}} \geq 0$	$\frac{\partial r_t}{\partial u_{d,t}} \geq 0$	$\frac{\partial q_t}{\partial u_{d,t}}$?
Monetary Policy Shock	$\frac{\partial y_t}{\partial u_{n,t}} \geq 0$	$\frac{\partial p_t}{\partial u_{n,t}} \geq 0$	$\frac{\partial r_t}{\partial u_{n,t}} \leq 0$	$\frac{\partial q_t}{\partial u_{n,t}}$?
Real Exchange Rate Shock	$\frac{\partial y_t}{\partial u_{q,t}} \geq 0$	$\frac{\partial p_t}{\partial u_{q,t}} \geq 0$	$\frac{\partial r_t}{\partial u_{q,t}} \geq 0$	$\frac{\partial q_t}{\partial u_{q,t}} \geq 0$

Table 14 Impulse Responses (4 Variables, Sign Restrictions)

Variables	Month	Supply Shock	Demand Shock	Monetary Policy Shock	Real Exchange Rate Shock
y	0	1.372 (0.576, 1.947)	0.547 (0.048, 1.651)	0.752 (0.051, 1.787)	0.532 (0.039, 1.720)
	3	1.487 (0.657, 2.175)	0.793 (-0.280, 1.908)	0.987 (0.103, 2.029)	-0.062 (-0.643, 1.326)
	24	1.500 (0.624, 2.220)	0.774 (-0.191, 1.950)	1.027 (0.164, 2.104)	0.008 (-0.586, 1.430)
p	0	-0.258 (-0.380, -0.103)	0.115 (0.011, 0.325)	0.131 (0.018, 0.325)	0.115 (0.011, 0.361)
	3	-0.360 (-0.553, -0.103)	0.075 (-0.134, 0.430).	0.088 (-0.128, 0.418)	0.357 (0.130, 0.587)
	24	-0.351 (-0.528, -0.128)	0.080 (-0.108, 0.409)	0.071 (-0.114, 0.400)	0.312 (0.102, 0.545)
r	0	-0.119 (-0.496, 0.296)	0.325 (0.022, 0.745)	-0.515 (-0.811, -0.161)	0.366 (0.030, 0.794)
	3	-0.218 (-0.667, 0.321)	0.350 (-0.060, 0.910)	-0.616 (-1.006, -0.133)	0.632 (0.210, 1.052)
	24	-0.202 (-0.635, 0.332)	0.352 (-0.030, 0.905)	-0.605 (-0.986, -0.137)	0.598 (0.192, 1.025)
q	0	-0.125 (-1.301, 1.108)	-0.816 (-1.933, 2.247)	-0.641 (-1.884, 0.786)	1.925 (0.200, 2.508)
	3	-0.838 (-2.466, 1.026)	-1.640 (-2.990, 2.620)	-1.591 (-3.094, 0.411)	2.181 (0.185, 3.290)
	24	-0.782 (-2.396, 1.049)	-1.558 (-2.905, 2.629)	-1.481 (-2.979, 0.506)	2.180 (0.206, 3.246)

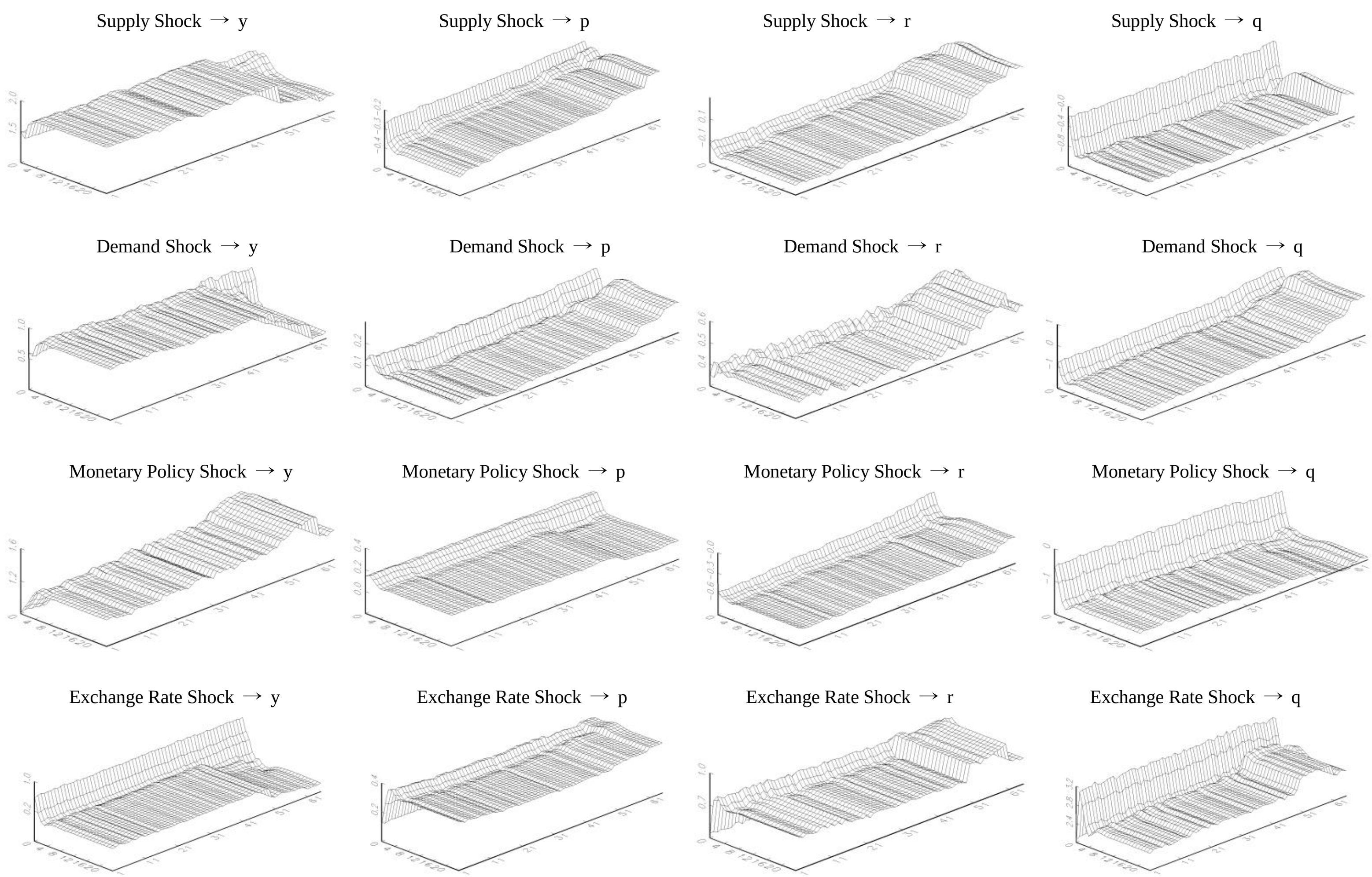
Note: 1) Numbers in Table present cumulative median impulse responses obtained from simulations.
2) Numbers in parentheses denote fifth and ninety fifth percentiles, respectively.

Table 15 Variance Decompositions (4 Variables, Sign Restrictions)

Variables	Month	Supply Shock	Demand Shock	Monetary Policy Shock	Real Exchange Rate Shock
y	0	0.771 (0.261, 0.973)	0.022 (0.003, 0.157)	0.014 (0.000, 0.146)	0.132 (0.001, 0.662)
	3	0.669 (0.213, 0.884)	0.021 (0.003, 0.139)	0.014 (0.002, 0.134)	0.159 (0.105, 0.684)
	24	0.667 (0.212, 0.883)	0.021 (0.003, 0.138)	0.014 (0.001, 0.133)	0.159 (0.106, 0.684)
p	0	0.150 (0.003, 0.844)	0.007 (0.000, 0.138)	0.043 (0.000, 0.650)	0.626 (0.018, 0.981)
	3	0.135 (0.015, 0.733)	0.008 (0.002, 0.140).	0.036 (0.004, 0.607)	0.697 (0.109, 0.946)
	24	0.135 (0.016, 0.732)	0.008 (0.003, 0.139)	0.036 (0.005, 0.606)	0.698 (0.110, 0.946)
r	0	0.319 (0.006, 0.889)	0.009 (0.000, 0.172)	0.147 (0.009, 0.673)	0.308 (0.004, 0.859)
	3	0.257 (0.044, 0.760)	0.009 (0.002, 0.144)	0.118 (0.008, 0.573)	0.444 (0.137, 0.861)
	24	0.256 (0.047, 0.758)	0.009 (0.002, 0.143)	0.117 (0.008, 0.571)	0.445 (0.139, 0.861)
q	0	0.086 (0.001, 0.664)	0.002 (0.000, 0.067)	0.030 (0.000, 0.554)	0.816 (0.079, 0.979)
	3	0.098 (0.030, 0.626)	0.006 (0.003, 0.073)	0.032 (0.007, 0.472)	0.813 (0.098, 0.942)
	24	0.098 (0.030, 0.625)	0.007 (0.004, 0.073)	0.033 (0.007, 0.470)	0.813 (0.099, 0.941)

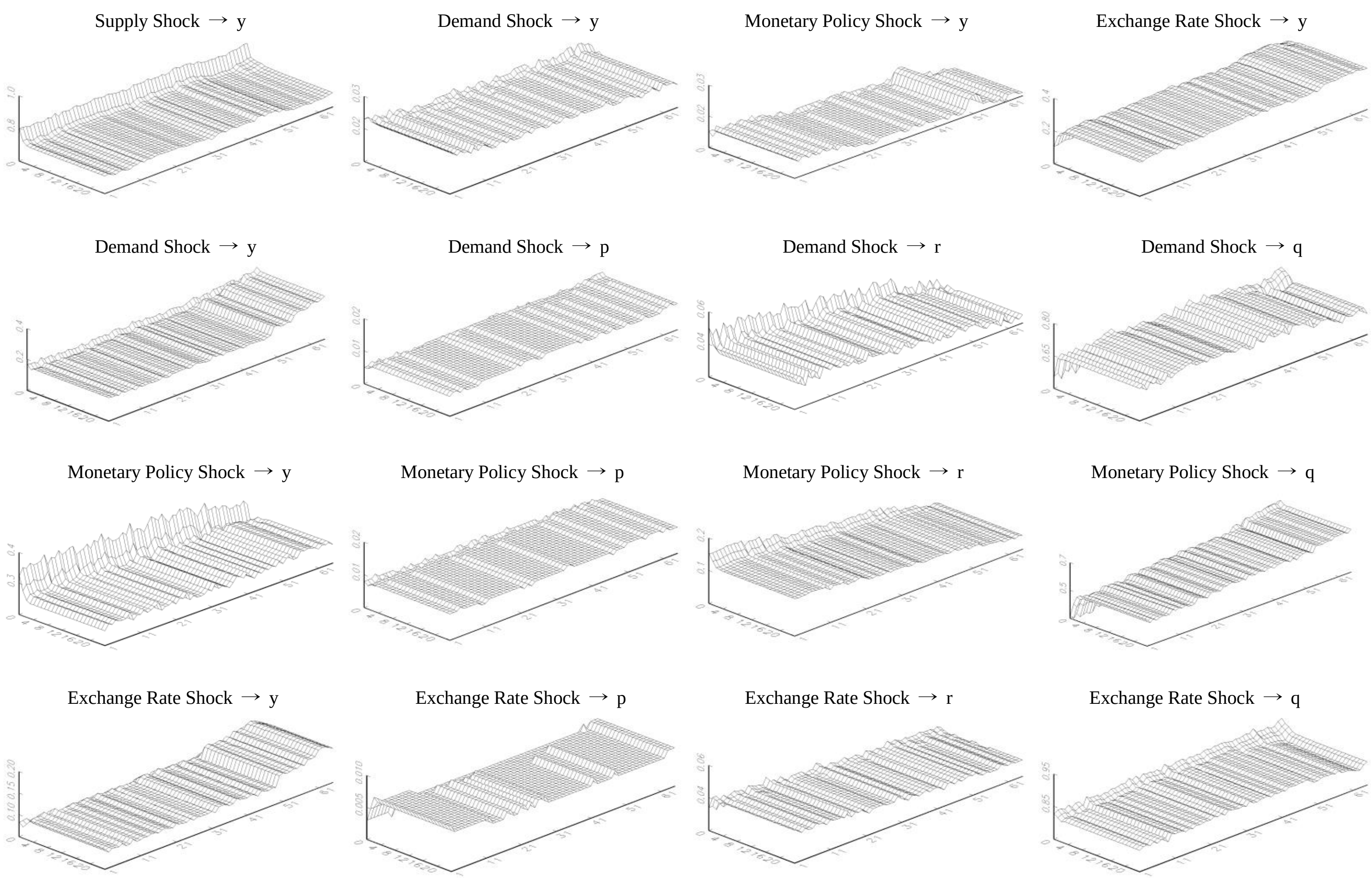
Note: 1) Numbers in Table present cumulative median impulse responses obtained from simulations.
2) Numbers in parentheses denote fifth and ninety fifth percentiles, respectively.

Figure 1 Cumulative Impulse Responses (4 Variables, Sign Restrictions)



Note: It shows the estimation results of rolling regressions. The first number 1 and the last number 65 in y axis presents cumulative median impulse responses for the period from January 1990 to December 2009 and for the period from June 1995 to May 2015, respectively.

Figure 2 Variance Decompositions (4 Variables, Sign Restrictions)



Note: It shows the estimation results of rolling regressions. The first number 1 and the last number 65 in y axis presents median variance decompositions for the period from January 1990 to December 2009 and for the period from June 1995 to May 2015, respectively.