Structural VAR analysis of monetary transmission mechanism and central bank's response to equity volatility shock in Taiwan

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Abstract

This research applies recursive Structural Vector Auto Regression (SVAR) model with short-run restriction by testing two kinds of shocks: monetary and volatility. The first SVAR estimates the shock of contractionary monetary policy on Taiwan's key monthly macroeconomic variables including exports, CPI, exchange rate, money supply, and Taiwan Weighted Stock Exchange (TWSE) Index. The second SVAR estimates the shock of Generalized Autoregressive Conditional Heteroskedasticity (GARCH) volatility of TWSE on Taiwan's daily exchange rate, overnight interbank loan rate, and Taiwan Government Bond Index (TGBI). The first SVAR model shows that prize puzzle has been evident in Taiwan. The second SVAR model found flight to safety into bond market after the volatility shock in equity market. Combining the results of both models and based on other literature reviews, we can also infer that effectiveness of contractionary and expansionary monetary policy exhibits non-linearity in Taiwan.

Disclaimer: I certify that I have the right to deposit the contribution with MPRA

I. INTRODUCTION

The game plan of Taiwan's Central Bank of Republic of China (CBC) has always been centered around preventing the New Taiwan Dollar (NTD) from breaking certain ceiling to keep up the competitiveness of high tech exports because since the early 1980s, Taiwan has become an export led economy and enjoyed a period of miraculous economic growth after the establishment of the Hsin-Chu Science Based Industrial Park which has led Taiwan becomes world's leading exporter in high-tech products. Currently, Taiwan's exchange regime is under managed floating exchange rate system. In the past twenty years, the range of USD/NTD has been hovered between 27.45 and 35.06. Then in 2008, the collapse of Lehman Brothers had posed an unprecedented challenge to CBC. The realized volatility of Taiwan Weighted Stock Exchange Index (TWSE) had jumped to as high as 60 compared to 20-year long-run average at 18. In just less than one year before the bankruptcy of Lehman Brothers, the discount rate of CBC was just peaked in December, 2007 at 3.375, the highest level in the last five years. To urgently respond to the Lehman repercussion on Taiwan's financial markets and economy, CBC had aggressively cut discount rate for five times in just six months in 2008. Following the launch of Quantitative Easing (QE) as means of stimulating economy across the US, Europe, and Japan, the CBC has also lowered the discount rate by a total of 200 basis points as of July, 2016.

As a former trader of equity derivatives in Taiwan, Japan, Hong Kong markets and government bond in Taiwan and the US markets, I am extremely passionate about the impact of monetary policy on financial markets, how central bank responds to financial market shocks, and how financial market volatility responds to different regime changes. Many literatures have done similar research and inspired me. For example, Nielsen and Shephard (2006) concluded that that jumps in financial markets are mostly caused by governmental announcements (p. 19). Bloom (2009) found that volatility shocks are strongly correlated with other measures of uncertainties like firm level earnings, output, and employment in his SVAR model (p. 623).

In this paper, I will start with research on Taiwan's monetary policy transmission mechanism that exhibits impact of shocks of contractionary monetary policy on key macroeconomic variables using monthly data. Then in the second model, I will analyse financial market uncertainty shock on daily overnight interbank loan rate, exchange rate, and bond market using daily frequency data. Both sections will be using Vector Auto Regression (VAR) model in which Romer (2012) defines it as a system of equations where each variable is regressed on a set of its own lagged values and lagged values of each of other variables (p. 225). Then I will make them become Structural-VAR (SVAR) to allow the prediction of intervention effect.

Both SVAR models will implement recursive identification with short-run restriction that utilizes Cholesky decomposition for impulse response analysis. My scheme of the matrix form using lower-triangular Cholesky decomposition is based on the findings of Christiano, et al (2005), Erceg and Levin (2006), and Fujiwara and Takahashi (2012), but ordering and variables used are not exactly the same. In the first monthly frequency SVAR analysis on contractionary monetary policy. I run monthly data from July, 1996 to June, 2016 with a total observation of 240. The estimated results exhibit prize puzzle which happens when contractionary monetary policy has failed to ease price level significantly in both CPI and equity market. In the second SVAR analysis on financial market with the shock on TWSE volatility. I run daily data from 4 January, 2005 to 29 July, 2016 with a total observation of 2865. Volatility shock usually happens whenever there is crash in equity market. Wu (2001) noted that volatility in equity

market is asymmetric in which returns and returns volatility are negative correlated (p. 856). Dendramis, et al (2015) mention that shift in volatility is often referred as structural breaks and may lead to financial crisis and large fluctuation in business cycle (p. 130). Back to my model, the estimated result shows that increase in TWSE volatility has induced downtrend in overnight interbank loan rate, depreciation of NTD, and increase in bond price.

In the following, I will first build the SVAR models in section II and discuss the results and findings in section III. Finally, section IV summarizes the conclusion and lists possible extensions for future study.

II. MODEL

(A) Monthly frequency SVAR model on contractionary monetary policy shock

To examine the shock of monetary policy on macro economy, I apply recursive identification with short run restriction on the monthly frequency SVAR model. The variables in the estimation order are log(exports), log(Consumer Price Index (CPI)), CBC discount rate, log(USD/NTD exchange rate), log(M2 money supply), log(TWSE). Export and CPI data are extracted from Taiwan's National Statistics of Republic of China. Discount rate, USD/NTD, M2 money supply, and TWSE are obtained from statistical database of CBC. The USD/NTD provided is the nominal exchange rate using direct quote scheme. Most fundamentally, in this monthly SVAR model, I initially make sure that export, CPI, and M2 money supply have been seasonally adjusted by using X-13 method and ensure that entire system is stationary by using VAR stability condition check on EViews. The purposes of doing so are to prevent from high variance caused by seasonal patterns and spurious regression. Then I rely on Hannan-Quinn information criterion (HQ) as my optimal lag selection criteria because HQ is more efficient when the number of observation is huge. Hannan and Quinn (1979) prove that HQ is able to underestimate the order of autoregression less than other model selection methods when observation is large (p. 7). According to HQ of optimal lag selection test on EViews, It suggests using lag length 2.

My ordering for this model is based on the assumptions that shock of increase in CBC discount rate instantaneously influence the export, followed by CPI, exchange rate, CBC discount rate, money supply, and TWSE index. I use the methodology of Christiano, et al (2005) as partial reference which places central bank discount rate at the middle, output and inflation at the top, and stock price index at the bottom of column vector of shocks (p.4). I specifically pick export data to replace output in the monthly frequency SVAR model because export has always been the lifeline of Taiwan economy which represents 70 percent of GDP. Moreover, using the export level as the first variable in the SVAR ensures the impact of export level is already controlled for when looking at the impact of discount rate shocks. The six-variable VAR model is shown below:

$LEXPO = C1 + \sum_{i=1}^{k} \alpha 1i\, LEXPOt - i + \sum_{i=1}^{k} \beta 1i LCPI\, t - i + \sum_{i=1}^{k} \delta 1i LNTDt - i + \sum_{i=1}^{k} D1i\, TIt - i + \sum_{i=1}^{k} E1i LMSt - i + \sum_{i=1}^{k} F1i LTWSEt - i + U\, 1t$

$LCPI = C2 + \sum_{i=1}^{k} \alpha 2i\ LEXPOt - i + \sum_{i=1}^{k} \beta 2iLCPI\ t - i + \sum_{i=1}^{k} \delta 2iLNTDt - i + \sum_{i=1}^{k} D2i\ TIt - i + \sum_{i=1}^{k} E2iLMSt - i + \sum_{i=1}^{k} F2iLTWSEt - i + U\ 2t$

$LNTD = C3 + \sum_{i=1}^{k} \alpha 3i\ LEXPOt - i + \sum_{i=1}^{k} \beta 3iLCPI\ t - i + \sum_{i=1}^{k} \delta 3iLNTDt - i + \sum_{i=1}^{k} D3i\ TIt - i + \sum_{i=1}^{k} E3iLMSt - i + \sum_{i=1}^{k} F3iLTWSEt - i + U\ 3t$

$TI = C4 + \sum_{i=1}^{k} \alpha 4i\ LEXPOt - i + \sum_{i=1}^{k} \beta 4iLCPI\ t - i + \sum_{i=1}^{k} \delta 4iLNTDt - i + \sum_{i=1}^{k} D4i\ TIt - i + \sum_{i=1}^{k} E4iLMSt - i + \sum_{i=1}^{k} F4iLTWSEt - i + U\ 4t$

$LMS = C5 + \sum_{i=1}^{k} \alpha 5i\ LEXPOt - i + \sum_{i=1}^{k} \beta 5iLCPI\ t - i + \sum_{i=1}^{k} \delta 5iLNTDt - i + \sum_{i=1}^{k} D5\ iTIt - i + \sum_{i=1}^{k} E5iLMSt - i + \sum_{i=1}^{k} F5iLTWSEt - i + U\ 5t$

$LTWSE = C6 + \sum_{i=1}^{k} \alpha 6i\ LEXPOt - i + \sum_{i=1}^{k} \beta 6iLCPI\ t - i + \sum_{i=1}^{k} \delta 6iLNTDt - i + \sum_{i=1}^{k} D6\ iTIt - i + \sum_{i=1}^{k} E6iLMSt - i + \sum_{i=1}^{k} F6iLTWSEt - i + U\ 6t$

Where: LEXPO denotes log(export), LCPI denotes log(CPI), LNTD denotes log(USD/NTD),TI denotes CBC discount rate, LMS denotes log(M2 money supply), LTWSE denotes log(TWSE), and U represents white-noise disturbance.

My explanation for identification of this monthly SVAR model is in the following. Export is not affected by any other variables in the short-run. CPI is contemporaneously affected by export. CBC discount rate is contemporaneously affected by export and CPI. USD/NTD is contemporaneously affected by export, CPI, CBC discount rate. M2 money supply is contemporaneously affected by all of the above except TWSE. Lastly, TWSE is affected by all other variables. The matrix form using lower-triangular Cholesky decomposition which exhibits relationship between the reduced form errors and the structural disturbances is shown below:

$$
\begin{bmatrix} Uexpo \\ Ucpi \\ Untd \\ Uti \\ Ums \\ Utwse \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ t_{21} & 1 & 0 & 0 & 0 & 0 \\ t_{31} & t_{32} & 1 & 0 & 0 & 0 \\ t_{41} & t_{42} & t_{43} & 1 & 0 & 0 \\ t_{51} & t_{52} & t_{53} & t_{54} & 1 & 0 \\ t_{61} & t_{62} & t_{63} & t_{64} & t_{65} & 1 \end{bmatrix} \begin{bmatrix} \varepsilon_{expo} \\ \varepsilon_{cpi} \\ \varepsilon_{ntd} \\ \varepsilon_{ti} \\ \varepsilon_{ms} \\ \varepsilon_{twse} \end{bmatrix}
$$

Where: we can express shock, Uexpo as a function of structural shock ε_{expo}, and so on.

(B) Daily frequency SVAR model on volatility shock

To examine the shock of TWSE volatility on financial market, I apply recursive identification with short run restriction on the daily frequency VAR model. The variables in the estimation order are log(USD/NTD exchange rate), TWSE volatility, overnight interbank loan rate, and log(price of Taiwan Government Bond Index (TGBI)) which is an equally weighted index comprised of 2-Year, 5-Year, 10-Year, and 20-Year treasury bonds and is used as the benchmark for Taiwan bond market in this research. I firstly obtain daily TWSE closing price from CBC and then apply GARCH (1.1) model by excel spreadsheet to estimate daily volatility. All parameters of GARCH in exhibit IX of appendix section are estimated using maximum likelihood estimation on the log likelihood function. GARCH is a type of stochastic volatility

models that take random shocks into account. Bollerslev (1986) introduced Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model that explains leptokurtic behaviour of financial markets, assumes returns are uncorrelated because the conditional mean does not depend on previous returns, and assumes conditional variance are a weighted combination of all previous squared excess returns. (p. 311). Then TBGI data is obtained from the database of Taipei Exchange. Overnight interbank loan rate and NTD are obtained from the CBC database. Moreover, in this daily SVAR model, I once again ensure that entire system is stationary by using VAR stability condition check on EViews to eliminate the risk of spurious regression. Lastly, I also rely on HQ for optimal lag selection and it suggests using lag length 8.

Fujiwara and Takahashi (2012) analysed global financial market interdependence with VAR and their ordering is based on market closing time (p. 138). In this research, my ordering is based on the market opening hour and liquidity. Foreign exchange market operates 24 hours per trading day. Thus, the last closing price in US trading hour will have strong impact on the opening of Taiwan equity and bond markets as well as banking system at 9 AM local time. Thus, USD/NTD exchange rate is the first variable based on not only market timing but also being the largest market in terms of trading volume. The second variable should be the volatility of TWSE because equity market has the second best liquidity, while overnight interbank loan rate and bond markets are not only mostly traded by institutional investors but also have much lower liquidity than that in Taiwan's equity market. The four-variable VAR model is shown below:

$LNTD = C1 + \sum_{i=1}^{k} \alpha 1i\ LNTDt - i + \sum_{i=1}^{k} \beta 1iTSVOL\ t - i + \sum_{i=1}^{k} \delta 1iTONIt - i + \sum_{i=1}^{k} D1i\ LTBt - i + U_{1t}$

$TSVOL = C2 + \sum_{i=1}^{k} \alpha 2i\ LNTDt - i + \sum_{i=1}^{k} \beta 2iTSVOL\ t - i + \sum_{i=1}^{k} \delta 2iTONIt - i + \sum_{i=1}^{k} D2i\ LTBt - i + U_{2t}$

$TONI = C3 + \sum_{i=1}^{k} \alpha 3i\ LNTDt - i + \sum_{i=1}^{k} \beta 3iTSVOL\ t - i + \sum_{i=1}^{k} \delta 3iTONIt - i + \sum_{i=1}^{k} D3i\ LTBt - i + U_{3t}$

$LTB = C3 + \sum_{i=1}^{k} \alpha 4i\ LNTDt - i + \sum_{i=1}^{k} \beta 4iTSVOL\ t - i + \sum_{i=1}^{k} \delta 4iTONIt - i + \sum_{i=1}^{k} D4i\ LTBt - i + U_{4t}$

Where: LNTD denotes log(USD/NTD), TSVOL denotes TWSE volatility, TONI denotes overnight interbank loan rate, LTB denotes log(TGBI), and U represents white-noise disturbance.

My explanation for identification of this daily SVAR model is in the following. USD/NTD is not affected by any other variables. TWSE volatility is contemporaneously affected by exchange rate. Overnight interbank interest rate is then affected by exchange rate and equity market. Finally, the least liquid Taiwan government bond market will be affected by all other variables. The matrix form using lower-triangular Cholesky decomposition which exhibits relationship between the reduced form errors and the structural disturbances is shown below:

$$\begin{bmatrix} U_{ntd} \\ U_{tsvol} \\ \\ \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ t_{21} & 1 & 0 & 0 \\ & & & \\ & & & \end{bmatrix} \begin{bmatrix} \varepsilon_{ntd} \\ \varepsilon_{tsvol} \\ 5 \\ \end{bmatrix}$$

Utoni	=	t_{31}	t_{32}	1	0	ε_{toni}
Utb		t_{41}	t_{42}	t_{43}	1	ε_{tb}

Where: we can express the shock Untd as a function of structural shock, ε_{ntd}, and so on.

III. RESULTS

(A) Result of monthly frequency SVAR on contractionary monetary policy

Exhibit III in appendix section shows the impulse response functions of one standard deviation of positive CBC discount rate (TI) shock on LEXPO, LCPI, LNTD, LMS, and LTWSE. Following an unexpected, temporary, and exogenous increase in the CBC discount rate for the estimated period, Taiwan's export does not go down significantly until after 12 months. The positive growth in export firstly is peaked by the second month and then down 0.6 percent for the unexpected one percent increase in CBC discount rate. Moreover, despites CBC's effort to cease inflation, price puzzle somewhat happens in Taiwan. Friedman (1968) had argued that monetary action takes a longer time to affect the price level than to affect the monetary totals (p. 15). In Taiwan's case, CPI continues to grow right after positive interest rate shock and will not touch apex until after ten months. Sims (1992) defines price puzzle as positive response of the price level to a contractionary monetary policy and also found that in many countries, response of price to monetary shock is positive initially but will get weaker and eventually turns to negative. (p. 988). In the foreign exchange market, NTD instantaneously appreciate by only 0.002 percent for the positive one percent shock to CBC discount rate. Then NTD reversed to depreciation versus the baseline after 22 months. This phenomenon could be explained by Taiwan Central Bank's preference to set a cap on NTD appreciation but no floor on NTD depreciation because Taiwan is an export-led economy. Chen and Wu (2008) also found that NTD is undervalued compared to its discount rate level (p. 181). Furthermore, Chen (2013) notes that under sterilization of central bank, interest rate policy can only explains indirect intervention of central bank behaviour, but cannot capture direct intervention of central bank behaviour (p. 5). Chen, et al (2009) also argue that effect of Taiwan's monetary policy on its output is usually insignificant due to CBC's foreign exchange interventions (p. 16). Shen and Chen (2004) point out that Taiwan central bank will enforce the so called "slowdown policy" when NTD is appreciating and "let-it-go policy" when NTD is depreciating (p. 200). The response of CBC discount rate to the shock itself will immediately elevated by about 0.08 percent in the first month and then peaked by the sixth month. It will eventually reach steady state after about five years. Although money supply will also drop immediately after the shock to CBC discount rate, the retreat was not significant and will only lasted for seven months. After one year, money supply will make positive reversal and remain slightly above baseline. At last, similar to the trend of exports, TWSE index will continue to go up and reach the climax by the seventh month but only will go up by 0.02 percent after the one percent increase in CBC discount rate. Overall, the deviations had been very small in export, CPI, NTD, discount rate, money supply, and equity market. We can also infer that Taiwan's contractionary monetary policy is less effective in the short-run than in the long-run especially when it comes to cooling down equity market and CPI.

The above results show that when Taiwan CBC is implementing contractionary monetary policy, it will carefully ensure that volatility of structural change in all economic activities will be insignificant. According to variance decomposition, which helps uncovering interrelationships among the variables, only minor percentage of fluctuations in export, CPI, NTD, M2 money supply, and TWSE have been attributed to positive interest rate shock.

Among the highlights, the highest is TWSE which has slightly more than six percent of fluctuation attributed to the positive interest rate shock by the 11th month. The second highest is CPI which will have about 6.2 percent of fluctuation owing to positive interest rate shock by the 22nd month. The least is export which will reach more than 3 percent of fluctuation due to contractionary monetary shock by the 26th month. Similar results have been found in the US too. Boivin and Giannoni (2001) stress that since 1980s, although response of output and inflation to unexpected shock of Fed fund rate were small, that does not mean monetary policy is less effective, rather, it has been enforced in a stabilizing approach by smoothing the volatility in interest rate (p. 32). Moreover, investors may interpret interest rate hike as signal of strong economic growth during bullish stock market and interest rate cut as signal of bearish market. They are likely to pour more money into stock market even after interest rate hike. Keynesian theory has tried to explain this phenomenon. Caporale and Soliman (2010) found that decrease in short-term interest rate will, in fact, negatively affect asset prices and demand for money based on their findings in the US, UK, and Germany (p. 13).

Back to Taiwan, if examine causality using Granger causality test which can assist determining whether past and current values can forecast future values, TWSE will Granger cause CBC discount rate as exhibit II shows that we can reject the null hypothesis that TWSE does not Granger cause CBC discount rate at 95 percent confidence interval. However, the other way around shows that CBC discount rate does not Granger cause TWSE. Altogether, CBC discount rate can also Granger cause export, CPI, and NTD but failed to Granger cause M2 money supply at 95 percent confidence interval. At last, I check the robustness of SVAR model using unrestricted VAR. Both results resemble each other.

(B) Result of daily frequency SVAR on volatility shock

Exhibit VII in appendix section shows the impulse response functions of one standard deviation of positive volatility (TSVOL) shock on LNTD, TONI, and LTB. Following an unexpected, temporary, and exogenous increase in the daily GARCH volatility of TWSE index for the estimated period, NTD will appreciate but by very small margin in the first two weeks and then reverse to depreciation. Volatility will rise 2.49 percent on the first day in response to one percent increase in volatility shock. After reaching the summit on the first day, volatility keeps diminishing and become insignificant exactly by the 90th day. Usually, the CBC will step in to calm down the fear on TWSE by intervening the exchange rate market and by decreasing discount rate which also has direct impact on the overnight interbank loan rate. Therefore, we can see that deviation of overnight interbank loan rate will only stay positive for the first three days. Central bank policy has direct effect on overnight interbank loan rate as well. Allen, et al (2009) note that most central banks use open market operation to target the interest rate on overnight interbank market. They can buy or sell securities to affect the amount of liquidity held by banks (p. 644). By the 80th day after volatility shock, overnight interbank loan rate will decreased by 0.01 percent. Furthermore, whenever there is shock to equity market volatility, there will be a situation so called the "flight to safety" in which investors will shift asset allocation from equity to bond. Baele, et al (2014) explain flight to safety as a situation when bond returns are positive, equity returns are negative after jump in equity volatility (p. 31). Therefore, as Taiwan's equity market turmoil begins, TGBI will start increasing after first week of fluctuation. Although from the impulse response table, TGBI looks like only jump 0.0006 percent by the 100th day which is around the peak, this magnitude is actually quite large for bond index and the persistence of bond's bull market trend had been strong after the equity volatility shock. Overall, in variance decomposition which indicates how the variances of endogenous variables are explained by volatility shock in this model, after 50 days, eight

percent each for interbank rate and TGBI fluctuation can be attributed to jump in equity volatility. Only less than five percent of NTD fluctuation is due to equity volatility shock. If looking at Granger causality in exhibit VI of appendix, GARCH volatility of TWSE index and TGBI can Granger cause to each other since we reject the null hypothesis at 95 percent confidence interval. At last, I check the robustness of SVAR model using unrestricted VAR. Both results resemble each other.


IV. SUMMARY & CONCLUSION

In the first SVAR model on CBC discount rate shock, Taiwan's contractionary monetary policy maybe seemly ineffective in stabilizing price inflation especially during the first ten months but it also shows that when CBC is implementing such contraction policy it will ensure that overall economic activity will not be negatively affected with huge fluctuation. By achieving such goal, CBC will immediately activate sterilization to ensure that increase in interest rate does not jeopardize export which is the most important lifeline of Taiwan economy. In the second SVAR model where I use shock on equity's GARCH volatility, CBC's immediate response with expansionary monetary policy, which is directly linked to daily overnight interbank rate, has been highly effective in calming down the fear factor on the equity market and driving up the government bond prices that reflects demand for flight to safety.

For future extension, I plan to use Implied Volatility Index (VIX) in lieu of GARCH volatility because implied volatility is the market volatility derived from Black-Scholes options pricing model. Taiwan has its own VIX index and has one of the most active equity index options markets in the world. VIX is usually more sensitive to news impact and trade in premium compared to historical volatility. However, next time, I prefer to switch to Japan market in which Nikkei 225, JPY, and Japanese Government Bonds (JGB) index are the most volatile among Asian equity, foreign exchange, and fixed income markets. On the contrary, Taiwan's financial markets are much less exciting because of extremely low impulse response to policy announcement shock. In addition, I always wanted to go further by using non-recursive identification scheme but EViews often failed to handle the computation of non-recursive model for higher frequency data; therefore, next time I better convert all data to quarterly frequency. As for further studies in monetary policy transmission mechanism, Walsh (2010) points out that VAR fails to incorporate forward-looking variables (p.24) and mainstream central bankers have shifted to the Dynamic Stochastic General Equilibrium (DSGE) model which combines rational expectations with a microeconomic foundation. (p. 28). Therefore, in the future, I prefer to use DSGE model to examine various uncertainty shocks on macroeconomic variables and financial markets.

Appendix

Exhibit I. Stationary test for monthly frequency VAR model with TI shock

Inverse Roots of AR Characteristic Polynomial
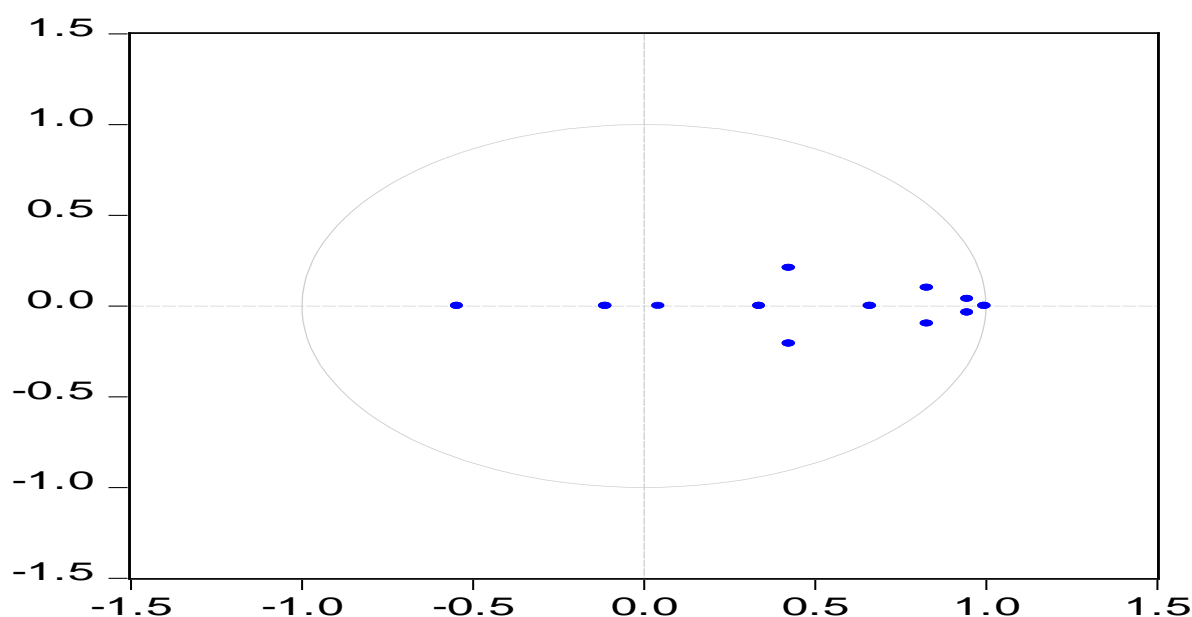
No root lies outside the unit circle.
VAR satisfies the stability condition.

Exhibit II. Granger Causality for monthly frequency VAR model with TI shock

Pairwise Granger Causality Tests
Date: 10/01/16   Time: 10:14
Sample: 1996M07 2016M06
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
LCPI does not Granger Cause LEXPO	238	3.54127	0.0305
LEXPO does not Granger Cause LCPI		24.2790	3.E-10
LNTD does not Granger Cause LEXPO	238	3.17047	0.0438
LEXPO does not Granger Cause LNTD		1.13362	0.3236
TI does not Granger Cause LEXPO	238	8.14116	0.0004
LEXPO does not Granger Cause TI		0.13582	0.8731
LMS does not Granger Cause LEXPO	238	9.13022	0.0002
LEXPO does not Granger Cause LMS		10.9128	3.E-05
LTWSE does not Granger Cause LEXPO	238	2.89069	0.0575
LEXPO does not Granger Cause LTWSE		0.29580	0.7442
LNTD does not Granger Cause LCPI	238	0.15290	0.8583
LCPI does not Granger Cause LNTD		1.05519	0.3498
TI does not Granger Cause LCPI	238	5.09593	0.0068
LCPI does not Granger Cause TI		0.90994	0.4040
LMS does not Granger Cause LCPI	238	8.96215	0.0002
LCPI does not Granger Cause LMS		2.20193	0.1129

LTWSE does not Granger Cause LCPI	238	3.86076	0.0224
LCPI does not Granger Cause LTWSE		1.17679	0.3101
TI does not Granger Cause LNTD	238	4.18300	0.0164
LNTD does not Granger Cause TI		3.08676	0.0475
LMS does not Granger Cause LNTD	238	2.05113	0.1309
LNTD does not Granger Cause LMS		0.67166	0.5118
LTWSE does not Granger Cause LNTD	238	3.12755	0.0457
LNTD does not Granger Cause LTWSE		1.60811	0.2025
LMS does not Granger Cause TI	238	0.34059	0.7117
TI does not Granger Cause LMS		1.61281	0.2015
LTWSE does not Granger Cause TI	238	14.3109	1.E-06
TI does not Granger Cause LTWSE		1.24423	0.2901
LTWSE does not Granger Cause LMS	238	2.06753	0.1288
LMS does not Granger Cause LTWSE		1.40187	0.2482

Exhibit III. Impulse response to TI, July 1996 to June 2016

Response to Cholesky One S.D. Innovations ± 2 S.E.
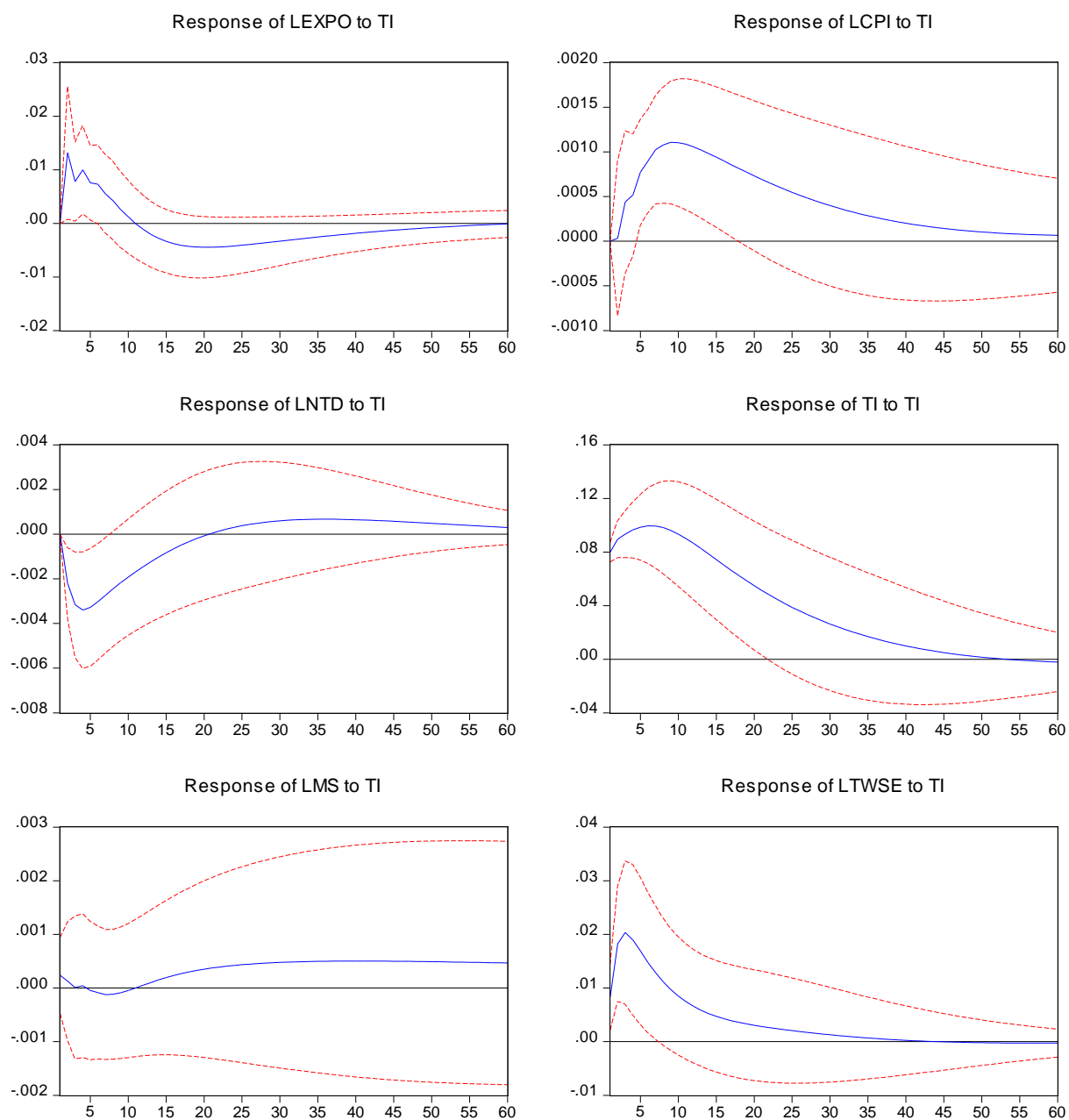
Where: LEXPO denotes log(export), LCPI denotes log(CPI), LNTD denotes log(USD/NTD),TI denotes CBC discount rate, LMS denotes log(M2 money supply), and LTWSE denotes log(TWSE).

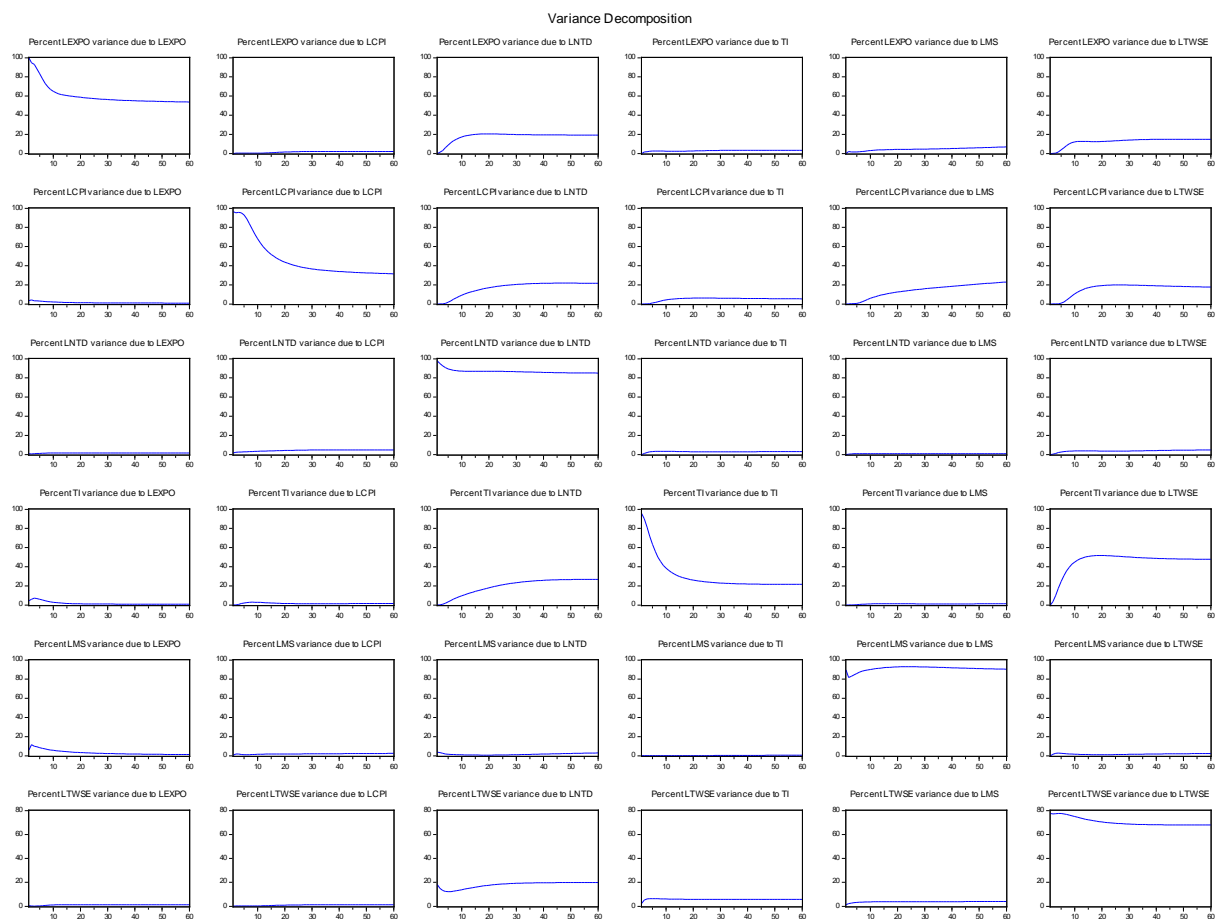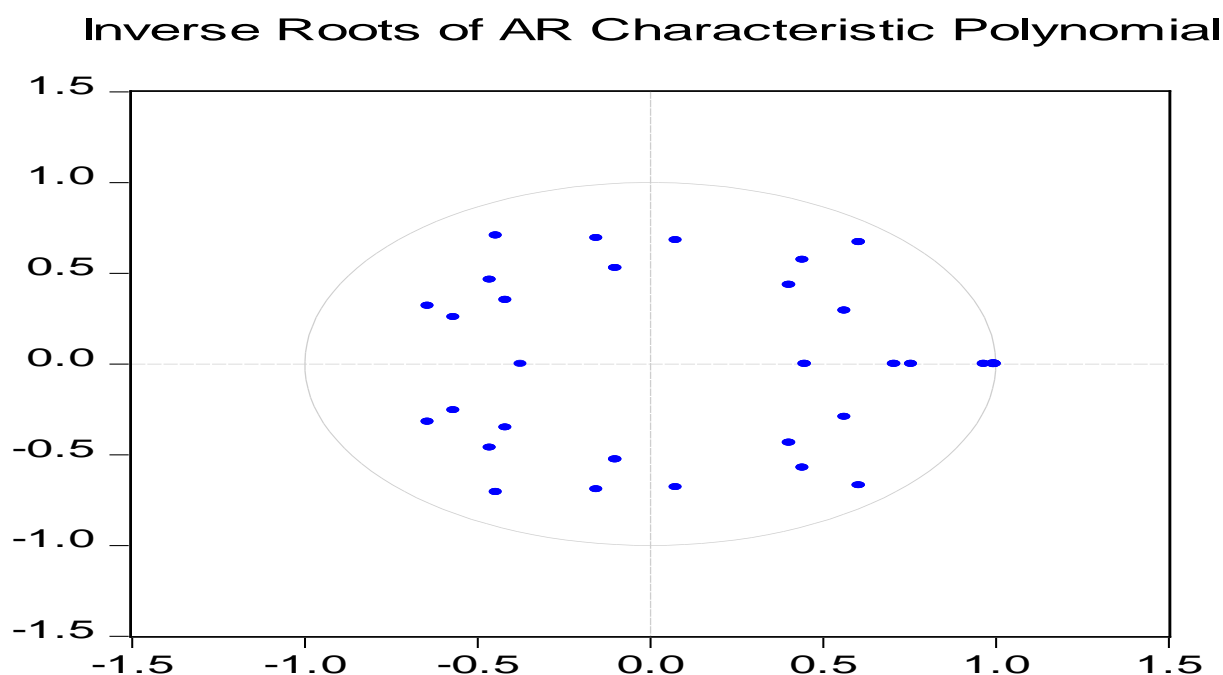**Exhibit IV. Variance decomposition, July 1996 to June 2016**

Variance Decomposition

Percent LEXPO variance due to LEXPO	Percent LEXPO variance due to LCPI	Percent LEXPO variance due to LNTD	Percent LEXPO variance due to TI	Percent LEXPO variance due to LMS	Percent LEXPO variance due to LTWSE
Percent LCPI variance due to LEXPO	Percent LCPI variance due to LCPI	Percent LCPI variance due to LNTD	Percent LCPI variance due to TI	Percent LCPI variance due to LMS	Percent LCPI variance due to LTWSE
Percent LNTD variance due to LEXPO	Percent LNTD variance due to LCPI	Percent LNTD variance due to LNTD	Percent LNTD variance due to TI	Percent LNTD variance due to LMS	Percent LNTD variance due to LTWSE
Percent TI variance due to LEXPO	Percent TI variance due to LCPI	Percent TI variance due to LNTD	Percent TI variance due to TI	Percent TI variance due to LMS	Percent TI variance due to LTWSE
Percent LMS variance due to LEXPO	Percent LMS variance due to LCPI	Percent LMS variance due to LNTD	Percent LMS variance due to TI	Percent LMS variance due to LMS	Percent LMS variance due to LTWSE
Percent LTWSE variance due to LEXPO	Percent LTWSE variance due to LCPI	Percent LTWSE variance due to LNTD	Percent LTWSE variance due to TI	Percent LTWSE variance due to LMS	Percent LTWSE variance due to LTWSE

Exhibit V. Stationary test for daily frequency VAR model with TSVOL shock

Inverse Roots of AR Characteristic Polynomial

No root lies outside the unit circle.
VAR satisfies the stability condition.

Exhibit VI. Granger Causality for daily frequency VAR model with TSVOL shock

Pairwise Granger Causality Tests
Date: 10/01/16   Time: 10:54
Sample: 1 2845
Lags: 8

Null Hypothesis:	Obs	F-Statistic	Prob.
TSVOL does not Granger Cause LNTD	2837	1.78379	0.0755
LNTD does not Granger Cause TSVOL		0.84355	0.5641
TONI does not Granger Cause LNTD	2828	1.17547	0.3098
LNTD does not Granger Cause TONI		0.14433	0.9971
LTB does not Granger Cause LNTD	2837	1.27084	0.2540
LNTD does not Granger Cause LTB		1.47638	0.1604
TONI does not Granger Cause TSVOL	2828	1.27261	0.2531
TSVOL does not Granger Cause TONI		0.93516	0.4859
LTB does not Granger Cause TSVOL	2837	3.25971	0.0011
TSVOL does not Granger Cause LTB		2.44834	0.0122
LTB does not Granger Cause TONI	2828	2.68581	0.0061
TONI does not Granger Cause LTB		4.98904	4.E-06

Exhibit VII. Impulse response to TSVOL, 4th January, 2005 to 29th July, 2016

Response to Cholesky One S.D. Innovations ± 2 S.E.
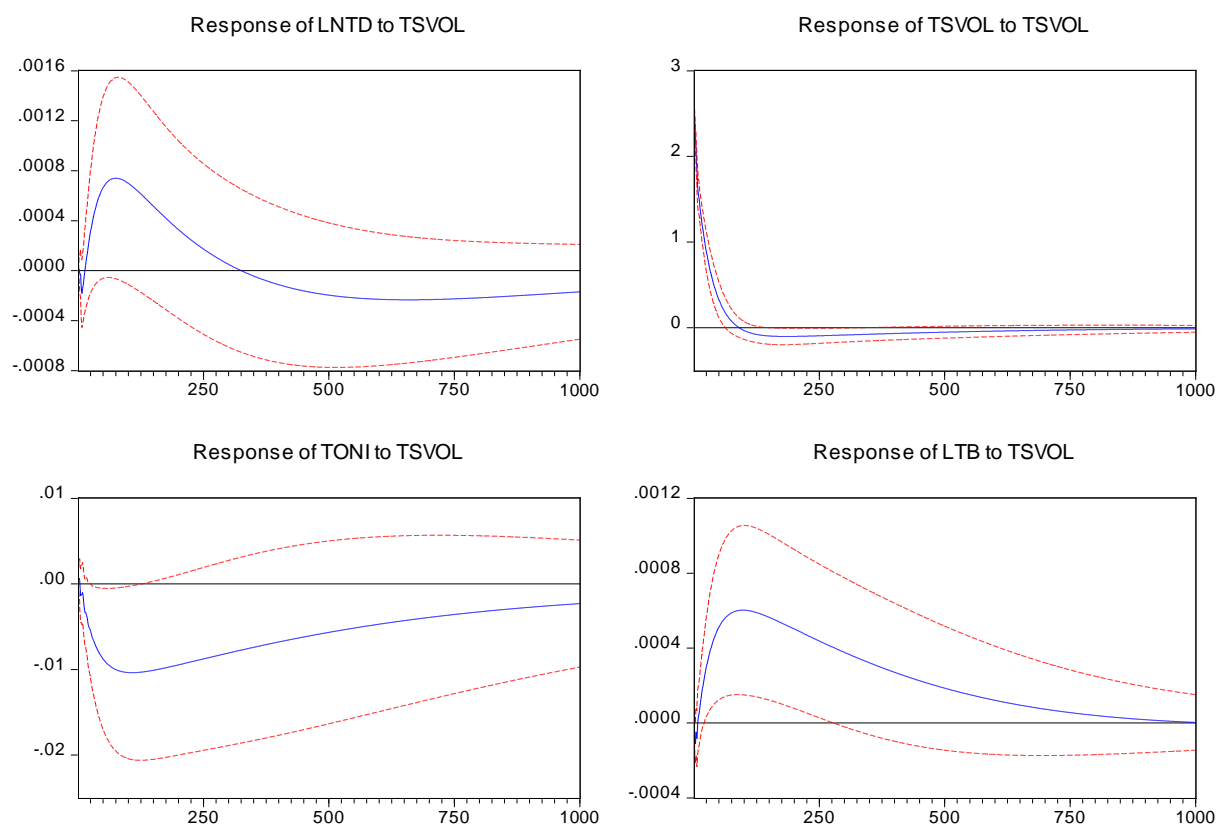
Where: LNTD denotes log(USD/NTD), TSVOL denotes TWSE volatility, TONI denotes overnight interbank loan rate, and LTB denotes log(TGBI).

Exhibit VIII. Variance decomposition, 4th January, 2005 to 29th July, 2016
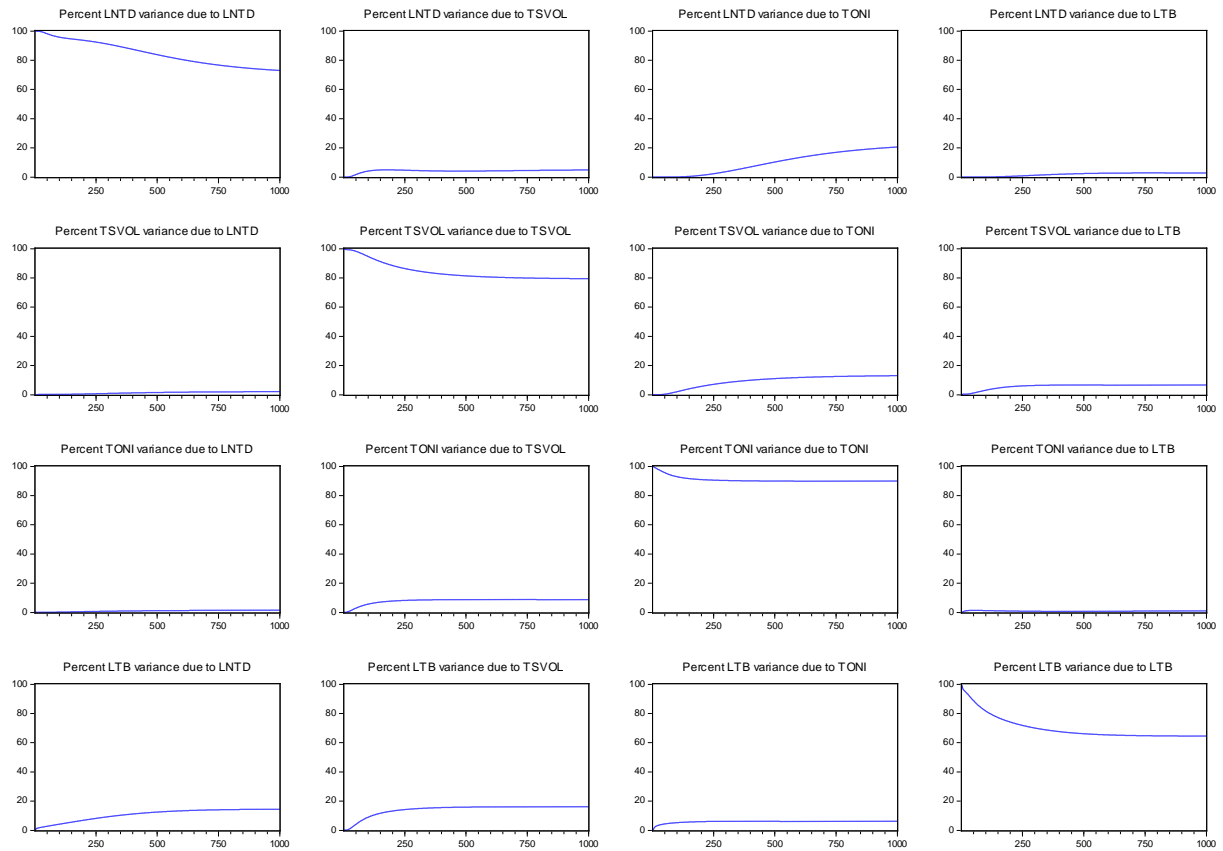
Variance Decomposition

Exhibit IX. GARCH 1.1 estimation

Summary statistics					
	Returns r(t)	Standardized z(t)			
mean	0.0001327		0.0188	Parameter	Estimate
standard deviation	0.012151		1.0415		
skewness	-0.494		-0.495	mu	0.0000126
kurtosis	7.224		4.647	omega	0.00000249
lag 1 correlation	0.0502		0.0649	alpha	0.0000
				alpha minus	0.2108
min	-0.0830		-4.99	beta	0.8782
max	0.0652		3.77		
				persistence	0.9836
Days in one year	250			variance*10000	1.5193
				log L	8962.255

Where: alpha determines reaction of volatility, beta determines the persistence of volatility, alpha + beta determines the rate of convergence of the conditional volatility to long-term volatility, and omega determines the unconditional volatility.

Volatility (GARCH 1.1)
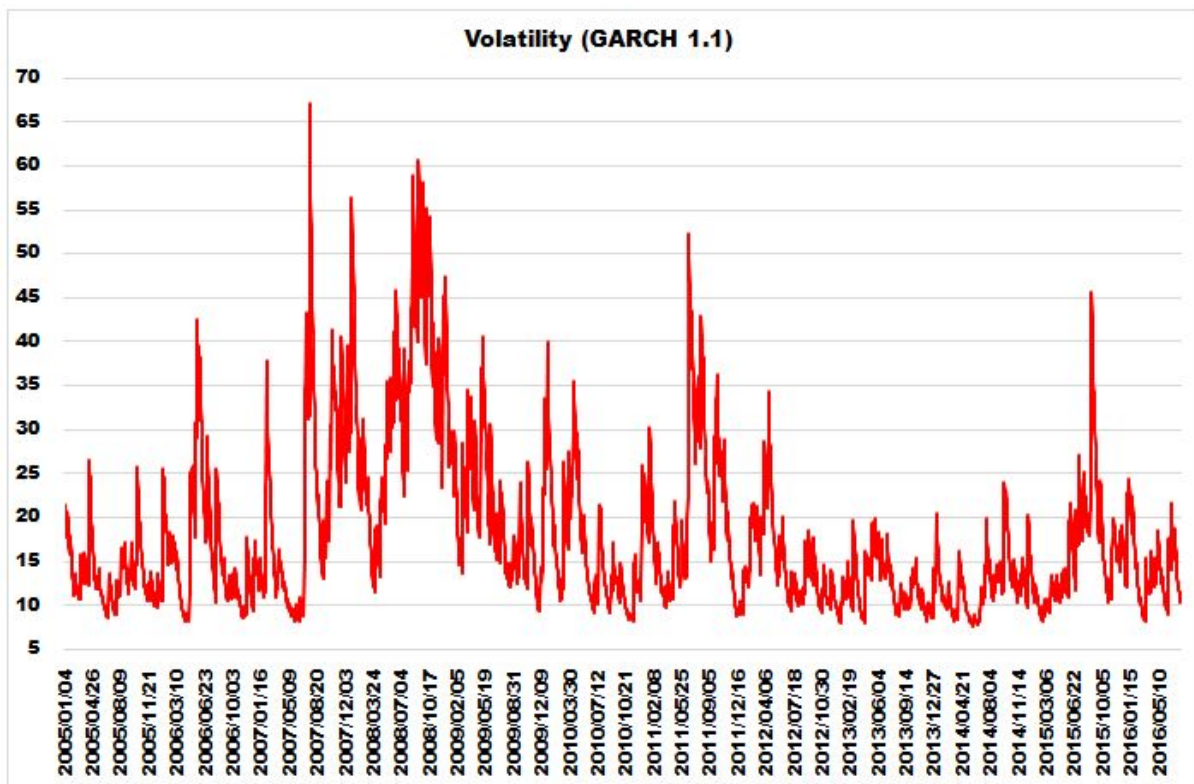
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