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VOLATILITY TRANSMISSION BETWEEN STOCK RETURNS AND EXCHANGE RATES: Evidence from a Frontier Market through a BEKK-GARCH Approach

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Abstract: The proliferate advancements in modern market economies created profuse global interlinks among international capital markets. Hence, the fluctuations in the foreign exchange rates have become very crucial in determining the stock returns. Thus, the purpose of this study is to examine the impact of exchange rate volatility on stock return volatility from a frontier market's perspective. The study analyzes the volatilities of daily market returns of All Share Price Index (ASPI) of Colombo Stock Exchange (CSE) against the exchange rates of US Dollars (USD) and Euros (EUR) over the period of January 2010 to December 2018. A trivariate BEKK-GARCH (1, 1) model employs to examine the transmission of volatilities between stock returns and exchange rates. The empirical evidence reveals the presence of a statistically significant spillover effect from USD to stock returns in the Sri Lankan context. Although the empirical results reject the existence of a spillover effect from EUR to stock returns,with respect to the overall shock spillovers, the estimated results indicate a statistically significant transmission of shocks from USD as well as EUR to ASPI.This indicates the impact of globalization and the introduction of open market economic policies on the Sri Lankan capital markets and it provides interesting insights for the policy makers when outlining the future monetary strategies.

Keywords: Exchange rates; GARCH model; Sri Lanka; Stock returns

JEL Classification: C 22, G 15, F 31

1. INTRODUCTION

International interactions have been motivated through the market liberalization at global scale; financial markets are contacted with each other through various links at a global level and resulted in an unprecedented

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growth in the financial markets[15]. Nevertheless, due to these numerous interlinks among international financial markets, nowadays countries are highly vulnerable to movements in the global capital markets [29]. Therefore, it is crucial to examine these inter connections in the financial markets due to growth in international trade and financial liberalization. More importantly, a well-functioning capital market is an integral part of a rapidly growing economy [21].

[10], depicts that the stock return fluctuations are commonly considered as a tool to capture the risk; these movements in stock returns are widely documented in relation to the studies on hedging, asset pricing and portfolio selection. In addition to that, [24] demonstrate that the existence of miss priced securities in the market lead to heavy market fluctuations and thereby the investors incline to interpret them as market disturbances. Thus, in the finance literature, the fluctuations in the stock returns are given special reference as it has long been an area of significant interest.

Unlike in the past, heavy fluctuations in the exchange rates can be observed in nowadays due to many uncertainties around the world. In fact, the volatilities of both stock returns and exchange rates may get affected as a result of a sudden adverse event which could create a negative outlook on a particular market [14]. This may also occur due to 'flight to quality' [11] where [13] notes that the exchange rate is an important factor in determining the performance of a firm in the international arena. In addition to that, recent changes in the global financial markets due to numerous events such as COVID-19 pandemic, global financial crisis and terrorism resulted in aggressive fluctuations in the exchange rates. Being a frontier market with US $1,433 million worth foreign investments in its equity market, Sri Lanka has exposed severely to the fluctuations in the foreign exchange rates.

However, the previous research findings on the impact of exchange rate volatility on volatility of stock returns are inconclusive. For instance, portfolio balanced model [7, 9] asserts the existence of a connection between the movements of stock prices and exchange rates. Furthermore, [23] notes that the changes in the exchange rates have a direct impact on a firm's operations and profitability. Moreover, based on the previous findings of [17], [19] and [27], it is identified that exchange rates have a direct influence on the market capitalization and competitiveness of a firm. [1] report that the currency movements may have an impact on stock price volatility as the comparative changes in the exchange rates have a critical impact on the monetary resources of a firm.

The finance literature uncovers a fundamental association between foreign currency and stock return volatilities with the Asian financial crisis occurred in 1997. [4] report that due to global presence of a firm, its business operations and profitability are widely affected by the fluctuations in the foreign currency rates. Moreover, [2], [26] and [28] note that when estimating the equity return of a firm a due consideration needs to be given to the risks involved with the fluctuations in the foreign currency rates as the cost of equity of a firms directly links with the development of external sector development of a country.

As in the stock oriented model, the comparative fluctuations in the exchange rates transmit a significant impact over the financial assets of a firm [1]. Hence, this indicates that the stock price volatility is influenced by the changes in the foreign currency rates. Similarly, the portfolio balanced model notes that when the fall in domestic wealth is coupled with a reduction in share prices and an increment in the interest rates due to capital outlays, a negative connection can be observed between the fluctuations of the foreign currencies and stock returns [7, 9]. However, on the empirical grounds, some early studies failed to build a reliable association between the fluctuation of foreign currencies and stock returns [12].

Nevertheless, [22] record that foreign currency rates are positively influenced by the absolute changes in the stock returns while [19] empirically show that exchange rate is a vital determinant of stock returns. Moreover, [5] note that rise in the stock returns locally tend to create a positive impact on the local currency value in the long run while [3] shows that exchange rate volatilities positively influence the stock returns in the United States.

On the other hand, [25] discovers an inverse nexus between the volatilities of exchange rates and stock returns in the US context with the use ARIMA models. He further reveals that hedging tools are less successful in mitigating the negative impact of foreign currency rates on the stock returns. With the use Johansen cointegration test, [23] demonstrates that stock market returns are inversely associated with exchange rates in the long run whilst [16], depicts that S&P's common stock price negatively result with the exchange rate.

Thus, it is quite evident that the extant evidence provides inconsistent inferenceson the influence of exchange rate volatility on volatility in stock returns. Moreover, [6] and [20] admit that further studies in the area of impact of exchange rate volatility on share market volatility are essential. Accordingly, the current study attempts to shed light on this inconclusive connection from a frontier market point of view using a multivariate GARCH approach. Further, as per the best of knowledge of the authors, there is no previously published study on the volatility transmission between stock returns and exchange rates using a multivariate GARCH approach. The rest of the paper is organized as follows; Section 2 discusses the data and methodology, while the data analysis and discussion of results presented in Section 3. Section 4 provides the conclusion of the study.

2. METHODS

In order to serve the underlying research objective of the study, daily market returns of All Share Price Index (ASPI) and exchange rates of US Dollars (USD) and Euros (EUR) gathered from www.yahoofinance.com and www.quandl.com over the period of January 2010 to December 2018. By taking the difference of natural logarithm of closed prices of ASPI, USD and EUR, the daily market returns are calculated as follows;

The return for country i on day t is calculated and is denoted as $c\_c\_i_t$ where i = *ASPI (All Share Price Index), USD, and EUR (Euro).*

$$c\_c\_i_t = \ln\left(P_{i,t}^{Close}\right) - \ln\left(P_{i,t-1}^{Close}\right)$$

To estimate the volatility transmission between stock returns and exchange rates, the following trivariate BEKK-GARCH (1, 1) model is employed.

$$R_t = \mu + \varepsilon$$

$$\varepsilon_t = z_t H_t^{1/2}$$

$$\varepsilon_t \mid I_{t-1} \sim N(0.H_t)$$

$$H_t = \Omega\Omega' + A\ \varepsilon_{t-1}\,\varepsilon'_{t-1}\,A' + B\ H_{t-1}\,B'$$

where R_t is daily stock returns and exchange rate movements; μ_t is the conditional mean vector; ε_t is 3 x 1 vector of daily shocks; $H_t^{1/2}$ is a 3 x 3 variance-covariance matrix; Ω is a 3 x 3 lower triangular matrix of constants; A and B are lower triangular parameter matrices. Further, matrix A and B respectively measure the impact of shocks on the conditional variances and how persistent the conditional variances between the markets are. The parameters that reveal whether there are volatility transmission between ASPI and the two exchange rates are contained in matrices A and B.

3. RESULTS AND DISCUSSION

Estimation results are summarized in the Table 1. Given the objective of exploring the existence of volatility spillovers from reported exchange rates to ASPI, the estimated results are reported in order to identify their significances. However, due to the nature of the parameterization of BEKK model, the square value of the parameters has to be computed to obtain the magnitude of the spillover effect.

Table 1
Empirical results on spillovers

	From the exchanges to ASPI	
	Volatility spillover effect	*Overall shock spillover effect*
USD	0.034159***	-0.096656*
	(0.0024)	(0.0601)
EUR	0.003389	-0.027557*
	(0.4783)	(0.0554)

Note: ***; **; and* show 1 percent, 5 percent and 10 percent level of significance respectively. Probability values are indicated within parenthesis.

According to the above estimation results, it can be identified that there is a significant spillover effect from USD to ASPI whereas there is no spillover effect from EUR to ASPI. However, with respect to the overall shock spillovers, the estimated results indicate that the transmission of shocks from USD as well as EUR to ASPI is statistically significant.

This statistically significant volatility spillovers show the impact of globalisation and the introduction of open market economic policies on the Sri Lankan capital markets. Though the Sri Lankan capital market turned out to be a potential destination for foreign investors, it has created an intense exposure to the foreign currency risk. As [8] highlights, portfolio investments in equity recorded a marginal net outflow in the year 2018 particularly due to the negative outlook of the global investors on the capital markets of the emerging economies. [8] further notes that recorded net outflow of portfolio investments in equity amounts to US dollars four million in the year 2018.

Moreover,the statistically significant volatility spillovers report in the present study might be further fueled due to lack of developed derivatives market in Sri Lanka to mitigate any potential exchange rate risks exposures. According to [8], Sri Lankan rupee has depreciated against the USD by 16.4 percent in the year 2018 particularly due to an excessive volatility of exchange rates reported in the latter part of the year 2018.

4. CONCLUSION

The empirical findings of the present study revealed that there is an overall shock spillover effect from the exchange rates to stock returns in Sri Lanka and it is also found to be statistically significant. Further, in terms of individual currencies, US dollars is found to be having a statistically significant spillover effect over stock returns in Sri Lanka while it is found to be statistically insignificant with the Euros. Accordingly, the present study provides strong evidence on the presence of volatility spillover effects from exchange rates to stock returns in the Sri Lankan context.

Overall, the empirical findings of the study are robust for a financial market such as Sri Lanka which lacks a greatly developed infrastructure to facilitate derivative products in order to provide more opportunities to mitigate the exposure to the foreign exchange risks. Hence, the empirical findings of this study provide timely insights for both local and foreign investors on their equity investments as the stock market returns are vulnerable to fluctuations in the foreign exchange rates. The empirical findings also provide interesting insights for the policy makers when outlining the monetary strategies as they need to extend a greater emphasis on the exchange rate policy when devising the overall monetary policy of the economy. This is because, the capital market development is crucial for a sound financial system coupled with a higher economic growth.

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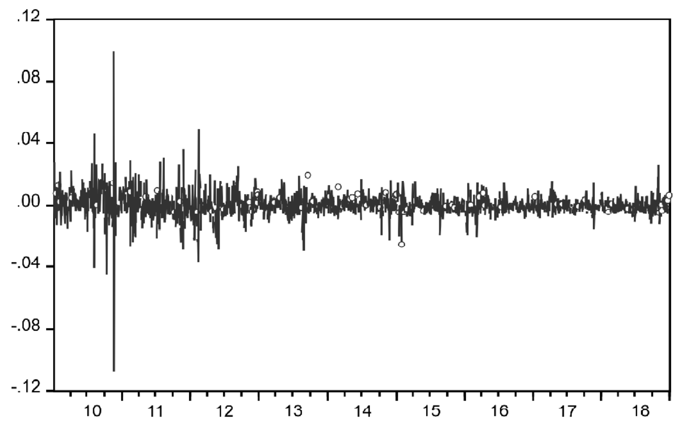
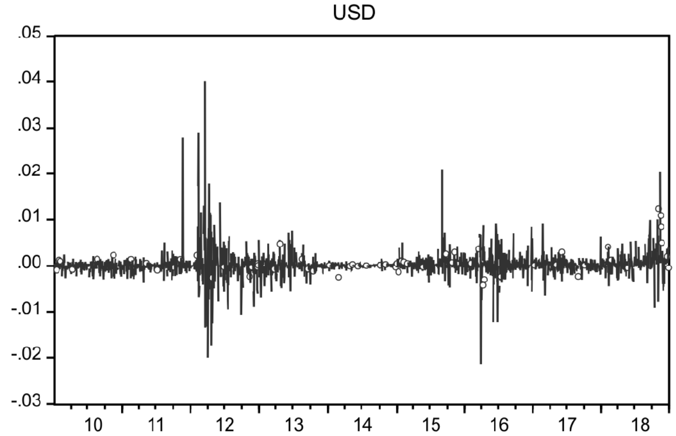
Annexure

Behavior of data series

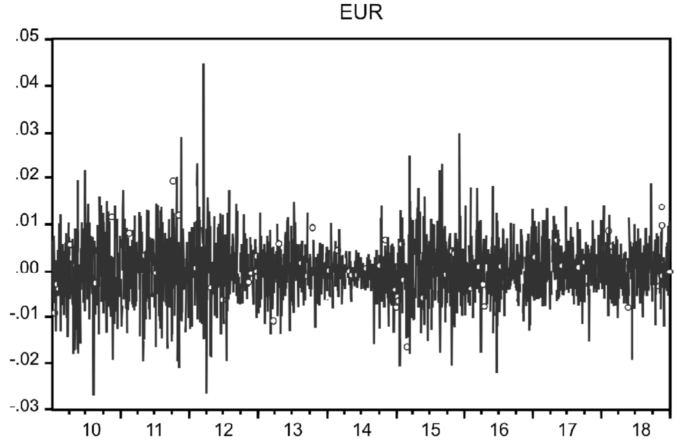
ASPI



USD



EUR



Mean Structures

ASPI (All Share Price Index)

$c\_c\_sl_t = 0.0000763 + 0.185382\ c\_c\_sl_{t-1} + 0.102775\ c\_c\_sl_{t-2} + 0.066623\ c\_c\_sl_{t-4} + 0.077015\ c\_c\_sl_{t-5}$

USD (US Dollars)

$c\_c\_usd_t = -9.87\ e^{-8} - 0.035355\ c\_c\_usd_{t-1} - 0.038204\ c\_c\_usd_{t-2}$

EUR

$c\_c\_eur_t = 0.000108$

where $c\_c\_i_t$ represents log return of *i* on day *t*; *i = sl (ASPI), usd (USD) and eur (Euro).*

ASPI

Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)
Included observations: 2160 after adjustments
Convergence achieved after 25 iterations
Coefficient covariance computed using outer product of gradients
Presample variance: backcast (parameter = 0.7)
GARCH = C(6) + C(7)*RESID(-1)^2 + C(8)*GARCH(-1)

Variable	*Coefficient*	*Std. Error*	*z-Statistic*	*Prob.*
C	7.63E-05	0.000104	0.735002	0.4623
ASPI(-1)	0.185382	0.024770	7.484119	0.0000
ASPI(-2)	0.102775	0.021895	4.694011	0.0000
ASPI(-4)	0.066623	0.020108	3.313240	0.0009
ASPI(-5)	0.077015	0.021756	3.539927	0.0004
		Variance Equation		
C	1.47E-06	2.12E-07	6.928756	0.0000
RESID(-1)^2	0.237460	0.012207	19.45332	0.0000
GARCH(-1)	0.761399	0.011725	64.93725	0.0000
R-squared	0.004070	Mean dependent var		0.000252
Adjusted R-squared	0.002222	S.D. dependent var		0.007711
S.E. of regression	0.007702	Akaike info criterion		-7.439681
Sum squared resid	0.127835	Schwarz criterion		-7.418652
Log likelihood	8042.856	Hannan-Quinn criter.		-7.431990
Durbin-Watson stat	2.150331			

Included observations: 2160
Q-statistic probabilities adjusted for 4 dynamic regressors

Autocorrelation	*Partial Correlation*		*AC*	*PAC*	*Q-Stat*	*Prob**
| |	| |	1	0.028	0.028	1.7125	0.191
| |	| |	2	-0.027	-0.028	3.3469	0.188
| |	| |	3	0.002	0.004	3.3564	0.340
| |	| |	4	0.021	0.020	4.3490	0.361
| |	| |	5	0.001	-0.000	4.3497	0.500
| |	| |	6	-0.039	-0.038	7.6309	0.266
| |	| |	7	-0.006	-0.004	7.7124	0.359
| |	| |	8	0.047	0.045	12.506	0.130
|* |	|* |	9	0.077	0.074	25.290	0.003
| |	| |	10	-0.030	-0.030	27.209	0.002
| |	| |	11	-0.010	-0.005	27.429	0.004
| |	| |	12	-0.001	-0.006	27.431	0.007
| |	| |	13	-0.006	-0.009	27.511	0.011
| |	| |	14	0.007	0.012	27.614	0.016
| |	| |	15	0.028	0.034	29.269	0.015
| |	| |	16	-0.007	-0.012	29.381	0.021
| |	| |	17	-0.007	-0.013	29.485	0.030
| |	| |	18	-0.018	-0.023	30.220	0.035
| |	| |	19	0.031	0.036	32.287	0.029
| |	| |	20	-0.013	-0.015	32.670	0.037

*Probabilities may not be valid for this equation specification.

USD
Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)
Included observations: 2163 after adjustments
Failure to improve likelihood (non-zero gradients) after 29 iterations
Coefficient covariance computed using outer product of gradients
Presample variance: backcast (parameter = 0.7)
GARCH = C(4) + C(5)*RESID(-1)^2 + C(6)*GARCH(-1)

Variable	*Coefficient*	*Std. Error*	*z-Statistic*	*Prob.*
C	-9.87E-08	1.26E-05	-0.007848	0.9937
USD(-1)	-0.035355	0.019189	-1.842461	0.0654
USD(-2)	-0.038204	0.020327	-1.879451	0.0602
		Variance Equation		
C	6.32E-09	1.89E-09	3.345238	0.0008
RESID(-1)^2	0.425425	0.008020	53.04711	0.0000
GARCH(-1)	0.779313	0.002857	272.8017	0.0000

R-squared	-0.024148	Mean dependent var	0.000252
Adjusted R-squared	-0.025097	S.D. dependent var	0.002628
S.E. of regression	0.002660	Akaike info criterion	-9.949752
Sum squared resid	0.015288	Schwarz criterion	-9.933998
Log likelihood	10766.66	Hannan-Quinn criter.	-9.943990
Durbin-Watson stat	1.765183		

Included observations: 2163
Q-statistic probabilities adjusted for 2 dynamic regressors

Autocorrelation	*Partial Correlation*		*AC*	*PAC*	*Q-Stat*	*Prob**
| |	| |	1	0.004	0.004	0.0324	0.857
| |	| |	2	0.031	0.031	2.1819	0.336
| |	| |	3	0.026	0.026	3.6996	0.296
| |	| |	4	0.035	0.034	6.4074	0.171
| |	| |	5	0.021	0.019	7.3823	0.194
| |	| |	6	-0.000	-0.003	7.3826	0.287
| |	| |	7	0.019	0.016	8.1618	0.319
| |	| |	8	0.010	0.007	8.3606	0.399
| |	| |	9	0.011	0.009	8.6200	0.473
| |	| |	10	0.011	0.009	8.8701	0.544
| |	| |	11	0.008	0.006	9.0240	0.620
| |	| |	12	0.040	0.038	12.461	0.409
| |	| |	13	0.008	0.006	12.587	0.480
| |	| |	14	0.016	0.012	13.117	0.517
| |	| |	15	0.065	0.062	22.451	0.097
| |	| |	16	-0.002	-0.007	22.464	0.129
| |	| |	17	0.003	-0.004	22.485	0.167
| |	| |	18	0.012	0.008	22.782	0.199
| |	| |	19	0.051	0.046	28.558	0.073
| |	| |	20	0.016	0.013	29.114	0.086

* Probabilities may not be valid for this equation specification.

EUR

Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)
Included observations: 2165
Convergence achieved after 30 iterations
Coefficient covariance computed using outer product of gradients
Presample variance: backcast (parameter = 0.7)
GARCH = C(2) + C(3)*RESID(-1)^2 + C(4)*GARCH(-1)

Variable	*Coefficient*	*Std. Error*	*z-Statistic*	*Prob.*
C	0.000108	0.000120	0.899597	0.3683
		Variance Equation		
C	1.39E-07	3.40E-08	4.107631	0.0000
RESID(-1)^2	0.033155	0.004686	7.075980	0.0000
GARCH(-1)	0.963748	0.004870	197.9107	0.0000

R-squared	-0.000038	Mean dependent var	0.000147
Adjusted R-squared	-0.000038	S.D. dependent var	0.006303
S.E. of regression	0.006303	Akaike info criterion	-7.411776
Sum squared resid	0.085980	Schwarz criterion	-7.401281
Log likelihood	8027.248	Hannan-Quinn criter.	-7.407938
Durbin-Watson stat	2.022667		

Included observations: 2165

Autocorrelation	*Partial Correlation*		*AC*	*PAC*	*Q-Stat*	*Prob**
| |	| |	1	-0.011	-0.011	0.2816	0.596
| |	| |	2	0.011	0.011	0.5324	0.766
| |	| |	3	-0.019	-0.018	1.2754	0.735
| |	| |	4	0.011	0.011	1.5416	0.819
| |	| |	5	0.033	0.033	3.8782	0.567
| |	| |	6	-0.034	-0.034	6.4213	0.378
| |	| |	7	-0.005	-0.006	6.4719	0.486
| |	| |	8	-0.011	-0.010	6.7525	0.564
| |	| |	9	-0.013	-0.016	7.1446	0.622
| |	| |	10	-0.015	-0.015	7.6059	0.667
| |	| |	11	0.018	0.020	8.3186	0.685
| |	| |	12	-0.003	-0.004	8.3450	0.758
| |	| |	13	-0.013	-0.014	8.7217	0.794
| |	| |	14	-0.005	-0.004	8.7716	0.845
| |	| |	15	-0.007	-0.008	8.8815	0.884
| |	| |	16	0.006	0.003	8.9712	0.915
| |	| |	17	0.027	0.029	10.568	0.878
| |	| |	18	0.029	0.029	12.351	0.829
| |	| |	19	0.010	0.010	12.569	0.860
| |	| |	20	0.045	0.047	17.082	0.648

*Probabilities may not be valid for this equation specification.

To explore the spillovers from other markets towards Sri Lanka, the parameters of the following volatility equation is analyzed. In reading the variables of the equation, the numbers 1, 2 and 3 represents USD, EUR and ASPI respectively.

The trivariate GARCH (1, 1) BEKK parameterization is as follows;

$$H_t = \begin{bmatrix} \omega_{11} & 0 & 0 \\ \omega_{21} & \omega_{22} & 0 \\ \omega_{31} & \omega_{32} & \omega_{33} \end{bmatrix} \times \begin{bmatrix} \omega_{11} & \omega_{21} & \omega_{31} \\ 0 & \omega_{22} & \omega_{32} \\ 0 & 0 & \omega_{33} \end{bmatrix} +$$

$$\begin{bmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} \times \begin{bmatrix} \varepsilon_{1,t-1} \\ \varepsilon_{2,t-1} \\ \varepsilon_{3,t-1} \end{bmatrix} \times [\varepsilon_{1,t-1} \quad \varepsilon_{2,t-1} \quad \varepsilon_{3,t-1}] \times \begin{bmatrix} \alpha_{11} & \alpha_{21} & \alpha_{31} \\ 0 & \alpha_{22} & \alpha_{32} \\ 0 & 0 & \alpha_{33} \end{bmatrix} +$$

$$\begin{bmatrix} \beta_{11} & 0 & 0 \\ \beta_{21} & \beta_{22} & 0 \\ \beta_{31} & \beta_{32} & \beta_{33} \end{bmatrix} \times \begin{bmatrix} h_{11,t-1} & h_{12,t-1} & h_{13,t-1} \\ h_{21,t-1} & h_{22,t-1} & h_{23,t-1} \\ h_{31,t-1} & h_{32,t-1} & h_{33,t-1} \end{bmatrix} \times \begin{bmatrix} \beta_{11} & \beta_{21} & \beta_{31} \\ 0 & \beta_{22} & \beta_{32} \\ 0 & 0 & \beta_{33} \end{bmatrix}$$

where $H_t = \begin{bmatrix} h_{11,t} & h_{12,t} & h_{13,t} \\ h_{21,t} & h_{22,t} & h_{23,t} \\ h_{31,t} & h_{32,t} & h_{33,t} \end{bmatrix}$ is a symmetric matrix.

(i. e. $h_{12,t} = h_{21,t}$, $h_{13,t} = h_{31,t}$, and $h_{23,t} = h_{32,t}$)

To serve our objective, we are interested only on the following equation;

$$\begin{aligned} h_{33,t} = {} & \left(\omega_{31}^2 + \omega_{32}^2 + \omega_{33}^2\right) + \alpha_{31}^2 \varepsilon_{1,t-1}^2 + \alpha_{32}^2 \varepsilon_{2,t-1}^2 + \alpha_{33}^2 \varepsilon_{3,t-1}^2 \\ & + 2\alpha_{31}\alpha_{32}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 2\alpha_{31}\alpha_{33}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2\alpha_{32}\alpha_{33}\varepsilon_{2,t-1}\varepsilon_{3,t-1} \\ & + \beta_{31}^2 h_{11,t-1} + \beta_{32}^2 h_{22,t-1} + \beta_{33}^2 h_{33,t-1} + 2\beta_{31}\beta_{32} h_{12,t-1} \\ & + 2\beta_{31}\beta_{33} h_{13,t-1} + 2\beta_{32}\beta_{33} h_{32,t-1} \end{aligned}$$

In analyzing the volatility transmission from USD and EUR towards ASPI, we focus on the off diagonal parameters of matrix *A* and *B* which are listed in the above equation. The estimation results are shown below.

Volatility Spillovers from USD and EUR to ASPI

	Coefficient	*Std. Error*	*z-Statistic*	*Prob.*
ω_{11}	9.48E-05	1.20E-05	7.869860	0.0000
β_{11}	0.883464	0.001736	508.8633	0.0000
α_{11}	0.668290	0.006410	104.2612	0.0000
ω_{21}	0.000274	0.000136	2.016145	0.0438
ω_{22}	0.000263	0.000109	2.409296	0.0160
β_{21}	-0.093271	0.011727	-7.953645	0.0000
α_{21}	0.465402	0.036491	12.75400	0.0000
β_{22}	0.990399	0.001327	746.1750	0.0000
α_{21}	0.126601	0.008605	14.71165	0.0000
β_{22}	-0.000102	0.000194	-0.526506	0.5985
α_{22}	-0.000123	0.000474	-0.259561	0.7952
ω_{31}	0.000921	9.80E-05	9.401341	0.0000
ω_{32}	**0.034159**	**0.011247**	**3.037023**	**0.0024**
ω_{33}	0.003389	0.004780	0.709080	0.4783
β_{31}	0.923337	0.004669	197.7512	0.0000
β_{32}	**-0.096656**	**0.051414**	**-1.879936**	**0.0601**
α_{32}	-0.027557	0.014387	-1.915355	0.0554
α_{33}	0.388091	0.012931	30.01345	0.0000
Log likelihood	26835.90	Akaike info criterion		-24.83455
Avg. log likelihood	12.42978	Schwarz criterion		-24.76355
Number of Coefs.	27	Hannan-Quinn criter.		-24.80859

Note: Parameter estimation method is Maximum Likelihood (Marquardt) method and convergence achieved after 118 iterations.