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The Wavelet Multi-Scale Analysis of Exchange Rate Exposure: An Application to Malaysian Consumer Products and Services Sector

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ABSTRACT

Objective – Past efforts in assessing foreign exchange rate exposure assume homogeneity in the level of exposure across time horizons which seems to be impractical due to the dynamic nature of comovement between firm value and exchange rate.

Methodology – Given this, the study aimed to investigate the multi-scale relationships between changes in exchange rates and firm values of 56 multinational corporations in the consumer products and services sector from January 2000 to December 2020.

Findings – The novelty of the study lies upon the application of Maximal Overlap Discrete Wavelet Transformation (MODWT) method which allows decomposition of a single time series domain into different time domains. The fragmentation into multiple time domains allows the measurement of scale-dependent foreign exchange exposure. As a result, the study discovered a non-monotonic trend for wavelet scale *j* of currency exposure across time scales. In particular, there was a gradual increase in the magnitude of beta exchange exposure and the proportion of exposed firms from low to high time scales. This finding suggested that firm value is more sensitive to changes in the exchange rate within a widened time domain.

Novelty – The study demonstrated on how the wavelet technique can be used to measure foreign exchange risk and aided firm managers and market participants in managing foreign exchange risk for a specific time interval.

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1. Introduction

According to Adler and Dumas (1984), currency exposure is the risk where a company's value is susceptible to changes in foreign exchange movement. Any change in the value of a foreign currency has a significant impact on a company's profitability and operations.

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For businesses with active worldwide networking involving sales, resources, subsidiaries, facilities, and operations, the influence is considerably more pervasive. Multinational corporations (MNCs) with a variety of overseas activities are not exempted from currency risk, even though it has emerged as a major risk for businesses engaging in cross-border transactions. As time interval expands, the sensitivity of firm value to exchange rate movement increases. Under regression analysis, the currency beta (proxy for currency exposure) changes with the time interval because asset return's covariance with the exchange rate change and the exchange rate variance do not change proportionately as time domain increases (Handa et al., 1989). Given this, the traditional single time domain of foreign currency exposure under regression estimation with its arbitrary time interval results in a large loss of beta dynamics information across multiple time frequencies. One method for addressing the information loss is with the aid of a wavelet analysis. Measurement of foreign currency risk is significantly impacted by the knowledge on scale-dependent foreign exchange exposure. Foreign exchange exposure can be divided into two categories: short-term (transaction exposure) and long-term (economic exposure). The exposure to short-term foreign exchange could be easily controlled and hedged utilizing a variety of financial tools and organic hedging techniques. On the other hand, it is challenging to monitor and manage the unanticipated long-term foreign exchange risk. Through the analysis of the paper, the information on a multi-scale foreign currency exposure could assist business managers in making prompt decisions for controlling a particular type of foreign exchange risk at a specific time period.

This study, which evaluates the currency exposure of corporations under consumer goods and services sector in Malaysia, is motivated by a number of issues. Firstly, Malaysia's economy is small and open, and it is heavily dependent on foreign trade which lends to an interesting case study. Despite declining global demand, many economic sectors must compete with other developing nations. Multinational companies in Malaysia are particularly vulnerable to currency risk because of the frequent cross-border operations and trades. According to Abdul Wahab et al. (2022), the majority of businesses in developing nations still lack in the knowledge and competence necessary to manage exchange rate risk. Malaysia was not immune to the 1997 Asian Financial Crisis and the 2008 Global Financial Crisis, which had a negative impact on corporate profitability due to unfavourable exchange rate fluctuations (Bacha et al., 2013; Hadian & Adaoglu, 2020). While there has been a growing interest in examining foreign exchange risk incidence under Malaysia market, however limited studies have been concentrated on a single sector of consumer products and services in Malaysia. Under Bursa Malaysia, the sector consists of several sub-fields, including agricultural products, automotive, food and beverages, household goods, personal goods, retailers, and travel and leisure services. Given the wide range of products and services, the corporations under the sector have been involved in vigorous cross-border trading activities. The consumer products and services equities become the second largest sector in Bursa Malaysia which constitutes 15.89% of total stocks in main market of Bursa Malaysia in July 2021 with a 265.02 billion of total market capitalization. Since then, this industry has grown to be one of Malaysia's key industries and is exposed to increased levels of foreign exchange risk as a result of heightened active cross-border transactions.

Secondly, the study is motivated to address methodological issue on the bias in exchange risk pricing found in previous studies. Specifically, majority of past studies assumed homogeneity of exchange risk across time domains which seems to be unrealistic. Traditional exposure models (Adler & Dumas, 1984; Jorion, 1990) made the assumption that the level of foreign exchange exposure is constant over a range of time horizons. In practice, different time horizons, however, necessitate varied hedging techniques in managing foreign exchange risk. The standard model of currency exposure is unable to accurately predict the level of exchange risk since each time interval implies a distinct set of hedging strategies. The bias issue appears when there is a mixture of foreign exchange exposure over several time scales and has a propensity

to offset the actual level of foreign exchange exposure. Because standard models of exchange rate exposure employ a single time domain, earlier attempts to price exchange risk in the Malaysian market specifically failed to the dynamics of scale-dependent currency exposure level (Bacha et al., 2013; Parsley & Popper, 2006; Verschoor & Muller, 2007). Additionally, a number of research (Bartram & Bodnar, 2012; Bodnar & Wong, 2003) that focused on developed economies found minimal level in the currency exposure due to bias in estimation. Specifically, aggregate foreign exchange exposure was employed in earlier models ignored the effects of hedging practices and time-variation in currency risk evaluation. A single time domain analysis gives inaccurate forecasts of exposure levels, whereby businesses might use the wrong hedges. Risk managers in the financial industry need to be exposed to several time dimensions because they are often under-informed and prone to making biased decisions. Additionally, it would appear unrealistic to have information on a single time domain currency exposure given the diversity of players in the capital market and their varied investment holdings and expectations. In light of this, the objective of the study is to assess the extent of exposure of Malaysia's consumer goods and services industry throughout the period of January 2000 to December 2020. The study used maximal overlap discrete wavelet transformation (MODWT) in foreign exchange risk pricing to break down a single time domain series into numerous time domains in order to mitigate time scale bias as explained earlier.

In order to fill in the gap in understanding the true amount of foreign exchange exposure while taking into consideration various time horizons, multi scale estimation of foreign exchange exposure based on the wavelet approach is conducted in this study. The significance of the study highlighted the novelty of the wavelet approach in measuring scale-dependent currency exposure. The output from the wavelet analysis could assist firm manager to make timely, optimal decisions on risk management techniques. The study is in line with ‘Safeguarding the Stability of the Financial System’ as stated in the Bank Negara Malaysia Financial Sector Blueprint (2011-2020). Evidently, the study documented that Malaysia's consumer goods and services corporations were exposed to currency risk differently across varied time domains from January 2000 till December 2020. Accordingly, the study found that a significant amount of exposure to exchange rates is concentrated in longer time periods of data as opposed to shorter time periods. The study established the heterogeneity of exchange risk and showed that long-term international transactions required more intensive risk management procedures. There are a number of ways to manage long-term foreign exchange exposure, including diversifying businesses and operations across various countries and regions, engaging in trade with nations that have offsetting effects on the value of the currency, setting up a lead-lag arrangement, borrowing and lending in traded currencies (natural hedging), and many more.

There are five sections in this study. The summary and major conclusions from the previous literature are thoroughly reviewed in Section 2. The details of the study's models and data characteristics are covered in detail in Section 3. All of the estimated findings are shown in Section 4. The results are integrated, and emphasis is placed on the importance of the multi-scale link between firm value and exchange rate changes for Malaysian companies operating in the consumer products and services sector. The final Section 5 is important for highlighting key results and implications for market participants and firm managers.

2. Literature Review

Fundamentally, there is a close connection between firm cash flows and exchange rate movements. Under the international asset pricing paradigm, this comovement between the currency rate and firm value becomes a prominent factor (Bartram & Bodnar, 2012; Suhaimi et al., 2019a). Accordingly, exchange rate volatility can be a significant source of unsystematic risk for international trade enterprises depending on the length of the investment horizon. Currency exposure, according to Adler & Dumas (1984), is the sensitivity of

business value to changes in exchange rates. The existing and anticipated cash flow from international businesses are significantly impacted by exchange rate uncertainties. Furthermore, such unanticipated exchange rate changes can have an impact on the relative prices of foreign assets and liabilities in addition to the competitiveness of businesses in both domestic and international markets (Chou et al., 2017; Sikarwar & Gupta, 2019). Depending on the nature of importing and exporting activities, the appreciation and depreciation of domestic (foreign) currency have opposing outcomes for business revenues and input costs (Bartram & Bodnar, 2012; Suhaimi et al., 2019b). Past studies have been unable to accurately measure the exchange rate exposure with respect to different time-scales due to a lack of appropriate methodology. The differing investment time horizons of the investors create a special relationship between the stock market and the foreign exchange market at various frequencies (Dar et al., 2014). A better measurement of currency exposure across various timescales has become possible and viable because of recent advancements in methodological research and the applicability of wavelet techniques. The next paragraph focuses on the empirical evidences of foreign exchange exposure for both developed nations and Malaysia setting within a single time domain analysis before critically assessing the specification problem relating to the single time domain analysis.

In developed economies, there has been extensive research on the relationship between the exchange rate exposure and corporate performance by using a single time domain estimator (Bartov et al., 1996; Bartov & Bodnar, 1994; Choi & Prasad, 1995; Sikarwar & Gupta, 2019). Adler & Dumas (1984) introduced the total exposure model, which incorporates both firm-specific and macroeconomic variables, and this is where the measurement of exchange rate exposure first emerged. The firm cash flow as dependent variable is regressed against currency changes. Then, residual exposure model was proposed by Jorion (1990), and it used the residual market exposure slope (M) on the right side of the equation to control market factor in the regression model. However, the study found that only a small percentage of the sample of US enterprises (15 out of 287) had a significant exposure to changes in the trade-weighted exchange rate from 1971 to 1987. In a similar fashion, a body of literature (Boudt et al., 2019; Sikarwar & Gupta, 2019) illustrated how minimal exchange exposure of corporations in developed nations have, which is mostly due to the extensive use of hedging instruments and time scale effects.

Besides, several studies have shed some lights on the extent of foreign exchange rate exposure under Malaysia context with a single time interval estimation. Parsley & Popper (2006) conducted a study on the widespread of foreign exchange exposure among Asian Firms. Specifically, 3% to 13% of Malaysian firms had significant exposure to the Euro and Japanese Yen. Bacha et al. (2013) documented that Malaysian firms were largely affected by the USD, whereby 70% of the sample firms had significant exposures to the USD. In the same vein, the recent study by Abdul Wahab et al. (2022) reported that 40% of sample Malaysian firms had significant exposures to the USD under stock returns approach, while cash flow approach displayed 23% of exposed firms to the USD. Verschoor & Muller (2007) also reported higher incidence of the USD exposure to the Malaysian firm value. In terms of time-varying foreign exchange exposure, Suhaimi et al. (2019b) found that the extent of foreign exchange risk was event specific, whereby a large number of sample firms were highly susceptible to foreign exchange movements during the Asian financial crisis 1997. The same finding was documented by Abdul Wahab et al. (2022), whereby majority of sample firms of ASEAN-4 had significant exposures to exchange rate movements during the Asian financial crisis (AFC) in 1997 and the Global financial crisis (GFC) in 2008.

In terms of specification, previous assessments of the level of exchange rate vulnerability in western economies found lower levels of exposure (Adler & Dumas, 1984; Jorion, 1990). The extensive adoption of hedging strategies by multinational corporations is one of the main causes of minimal exchange rate exposure, but few research have examined the potential impact of time scales on the measurement of exchange exposure. As most previous studies primarily examined one particular time series domain, they

neglected the potential bias of time scale. Results from a single time period may be skewed since the degree of exchange rate exposure may vary over time, which has a significant impact on how a firm manages its risk. In terms of risk management, treatment of risk is different for varied participants. For instance, under banking sector, the way that banks manage risks are different due to different expectations, capital requirements, regulations, market segments and operations (Abdul-Wahab, 2018) (H Abdul Wahab, 2018). In the same vein, the financial market with a diverse range of market participants need to manage foreign risk with various hedging strategies that are subjected to their varied investment holding periods and expectations. For less experienced risk managers, knowing about the multi-time dimensional exchange rate exposure is crucial to avoid making bad decisions on risk management. There are two types of exchange risk under the financial risk management: short term and long term. Different time spans have varying levels of risk, necessitating various hedging techniques. In order to provide timely and accurate level exchange risk for a given time domain, it is necessary to split a given single time domain series into a multi-scale series. Given this, the study is motivated to use the wavelet technique with a focus on currency risk since it can reveal multi-scale correlations across time intervals. In the methodology section, more details on the wavelet technique utilized in the study will be provided.

To date, several studies have been conducted to explain scale-dependent financial relationships by using the wavelet techniques, such as capital asset pricing model (CAPM) (Masih et al., 2010), time frequency diversification benefits (Abdullah et al., 2022; Abdullah et al. 2023), multi-scale relationship between futures and spot prices (Alzahrani et al., 2014) and many more. Wavelet techniques which have been widely applied, specifically in empirical finance studies is basically an extension from the Fourier transform analysis. The technique provides several advantages in terms of methodological specification. Firstly, wavelet technique assists in explaining multi-scale relationship between financial variables due to its ability to locate wavelet crystals on both time and frequency domains. Secondly, wavelet technique does not require priori distributional assumption of data in comparison to traditional regression method which is beneficial for handling irregular observations. Thirdly, the method can effectively handle noises in high frequency data. Despite of its practical benefits, wavelet technique has not been widely applied in explaining scale dependent exchange rate exposure. This study is motivated from the fact that the covariances between stock returns and foreign exchange returns do not change proportionately as return interval changes which has significant implications on firm's profitability and risk management routine. The value of standard deviation tends to rise as return interval lengthens. So far, limited number of studies have been devoted to explain multi-scale foreign exchange exposure. The recent study by (Suhaimi et al., 2019a) found that the high level of foreign exchange beta exposure is highly concentrated at higher time scale corroborating the notion that the level of risk is greater within a widened investment holding period. Handa et al. (1989) argued that larger beta values were recorded for high-risk stocks as a result of the increase in return interval, but lower beta values were recorded for low-risk securities. The beta values throughout the scales were tied to the riskiness of the securities and the size of the operational firms because the study also associated high-risk securities with small firms and low-risk securities with big firms. To put it another way, the relationship between stock return and exchange rates fluctuated dynamically throughout a range of scales and frequencies. To adequately accommodate the financial market traders' varied time scales, the standard time-domain method in this regard needed to integrate different frequencies forms.

In conclusion, it is important to remember that the majority of earlier studies concentrating on Malaysia revealed a higher degree of currency exposure in comparison to developed economies, and in particular, a very significant exposure to the USD. Furthermore, previous research concentrated on a single time domain, which lowers estimating power due to the effect of time scales. To reveal the time scale component of exchange rate exposure, this study employed a relatively novel method called the wavelet analysis. Wavelet technique enabled to study the actual dynamic relationship over a range of time periods without running the

danger of information loss and confirming the series stationary assumption. Additionally, wavelet analysis enabled to more accurately and swiftly capture how sensitive stock returns are to changes in exchange rates. Given this benefit, wavelets may be able to offer crucial details regarding the level of exposure at a given time interval that can be matched with the ideal hedging strategy.

3. Research Methodology

3.1 Data

In terms of population, currently there are more than 100 active stocks listed under the consumer products and services sector in Bursa Malaysia. A number of factors were taken into consideration when choosing the sample companies. First, the study took into account the companies that were continually listed during the study period. In order to make the filtering process easier, listed companies were chosen. Each stock was inspected and was rejected when it contained aspects of suspension, insolvency, and trade halts. The availability of the financial data, which included daily stock returns from January 2000 to December 2022, was used to further select these listed companies. This process is essential because it lessens the issue of missing and unbalanced data, which can have an impact on how results are generally interpreted. The overseas trading activities of the chosen firms were then scrutinized based on foreign sales information extracted from the companies' geographical or segmental business information in the consolidated annual reports. For the final sample, the study collected 56 stock prices of listed consumer products and services corporations in Bursa Malaysia through Compustat Database. For bilateral exchange rates, the study selected 5 major trading currencies in Malaysia comprising the United States Dollar (USD), the European currency (EUR), the Japanese Yen (JPY), the Great Britain Pound (GBP) and the Chinese Yuan (CNY). To control the market effect, the study opted FTSE Bursa Malaysia Kuala Lumpur Composite Index (FBM-KLCI) as the control variable. It should be noted that all the data were extracted from the Compustat Database from S&P Global Market Intelligence. To avoid spurious regression, each variable needed to satisfy stationarity property by transforming original data into log differences as below;

Stock returns, $R_t = ln\left(\frac{P_t}{P_{t-1}}\right)$ (1)

Market returns, $R_{m,t} = ln\left(\frac{P_{m,t}}{P_{m,t-1}}\right)$ (2)

Foreign exchange returns, $R_{x,t} = ln\left(\frac{S(MYR/X)_t}{S(MYR/X)_{t-1}}\right)$ (3)

where, P_t stands for closing stock price at time t, $P_{m,t}$ represents market index at time t and X_t refers to specific foreign currency explained in direct quotation $S(MYR/X)_t$ at time t.

3.2 Methods

The two-stage analysis was conducted, whereby the first stage involved the decomposition of each variable under maximal overlap discrete wavelet transformation (MODWT) method. The study focused on discrete wavelet transformation to address firm manager's interest in finite length of duration (Masih et al., 2010). The MODWT routine produced a smooth information (father wavelet) and detailed information (mother wavelet). For the second stage, the study used the decomposed time series that produced in stage 1 to measure the scale dependent foreign exchange exposure under multiple regression models.

Stage 1: MODWT

Previous foreign exchange exposure studies had difficulties in explaining foreign exchange exposure due to hedging endogeneity and specification problems. One of major concerns under specification problems was the simplistic assumption of identical level of foreign exchange risk across different time domains. To cater for specification bias, the study adopted the maximal overlap discrete wavelet transformation (MODWT) in decomposing a single time domain series into different wavelet crystals. To effectively fragment the series, MODWT adopted a special wavelet filter called Daubechies least asymmetric of length 8, LA (8). The study highlighted on discrete wavelet transformation relative to continuous wavelet transformation was due to the fact that finite discrete time interval provides more meaningful information for managerial decision-making process. The decomposition of low-resolution information of original return series involved the production father wavelet and mother wavelet. Father wavelet (sk) part represented the smooth part, while the detailed part was explained by mother wavelet (dk). MODWT had zero phasing property in its process where the wavelet scale could be perfectly matched with the original series without the needs to down-sampling the filtered output at each wavelet scale. The decomposition process of wavelet scale j=1 involved the filtering of Rt into s1 and d1, by using the Daubechies wavelet filter. In subsequent process, the finer resolutions functions of s2 and d2 would be produced. The filtering process continued until reaching a maximum scale of 2J, whereby J was the maximum wavelet scale of 7 (128-256 days). The mother wavelet could be further split in 7 wavelet scales namely, d1 (2-4 days), d2 (4-8 days), d3 (8-16 days), d4 (16-32 days), d5 (32-64 days), d6 (64-128 days) and d7 (128-256 days). The details of father and mother wavelet coefficients under MODWT could be explained as follows;

$$s_{J,k} \approx \int \phi_{J,k}(t) R_t \, dt \tag{4}$$

$$d_{j,k} \approx \int \psi_{j,k}(t) R_t \, dt \tag{5}$$

To simplify, the original return series could be approximated as a summation of mother wavelet coefficients ($d_{j,k}$) and father wavelet coefficients($s_{j,k}$) as follows;

$$R_t \approx \sum_k s_{J,k}\phi_{J,k}(t) + \sum_k d_{J,k}\psi_{J,k}(t) + \sum_k d_{J-1,k}\psi_{J-1,k}(t) + \cdots + \sum_k d_{1,k}\psi_{1,k}(t) \tag{6}$$

where, father wavelet part is sum of product between father wavelet coefficients $s_{J,k}$, and father wavelet scaling functions $\phi_{J,k}$ is presented as below;

$$S_{J,k} = \sum_k s_{J,k}\phi_{J,k}(t) \tag{7}$$

Mother wavelet part is sum of product between mother wavelet coefficients $d_{J,k}$, and mother wavelet scaling functions $\psi_{J,k}$ is presented as below;

$$D_{J,k} = \sum_k d_{J,k}\psi_{J,k}(t) \tag{8}$$

The father scaling function and mother scaling functions could be further explained as ;

$$\phi_{j,k}(t) = 2^{-\frac{j}{2}}\phi\left(\frac{t-2^j k}{2^j}\right) for\ j = 1\ to\ J \tag{9}$$

$$\psi_{j,k}(t) = 2^{-j/2}\psi\left(\frac{t-2^j k}{2^j}\right) for\ j = 1\ to\ J \tag{10}$$

To ensure that basic functions (9) and (10) remained within unity (less than 1), the term 2-j/2 was introduced in both equations. The term 2jk was referred to the shift parameter. An increase in scale j caused

2j factor became greater and scaling functions to be reduced and more spread out. All the MODWT processes ran by using a special RStudio library called waveslim. All the series were decomposed by using waveslim library plus a loop programming coding that allowed the repetition of sequence of instructions for all series.

Stage 2: Cross sectional regression

After all MODWT scale-dependent series were successfully produced, the scale dependent exchange rate exposure using augmented version of Jorion (1990) was calculated as;

$$R_t^j = a_t^j + \beta_M^j R_M^j + \beta_{USD}^j R_{USD}^j + \beta_{EUR}^j R_{EUR}^j + \beta_{GBP}^j R_{GBP}^j + \beta_{JPY}^j R_{JPY}^j + e_t^j \quad j = 1,2,\ldots,7 \qquad (11)$$

Equation 11 gauged multihorizon exchange rate exposure which was depicted by the term β_X^j. The significance of coefficient β_X^j implies the rejection of null hypothesis that the extent of beta is homogenous across time scales. In terms of sign of beta exposure, the positive or negative sign of β_X^j implies an increase or decrease of firm value by β_X^j% when there is 1% increase in exchange rate. To ensure the robustness of the estimates, GARCH(1,1) was embedded in Equation 11 to correct for any potential heteroscedasticity (non-constant variance) problem. The equation for GARCH(1,1) process is explained in the following equation:

Mean equation,

$$R_t^j = a_t^j + \beta_M^j R_M^j + \beta_{USD}^j R_{USD}^j + \beta_{EUR}^j R_{EUR}^j + \beta_{GBP}^j R_{GBP}^j + \beta_{JPY}^j R_{JPY}^j + e_t^j \quad j = 1,2,\ldots,7 \qquad (12)$$

Conditional variance equation,

$$h_t = \alpha_0 + \alpha_1 h_{t-1} + \alpha_2 e_{t-1}^2 + \upsilon_t \qquad (13)$$

Where

α_0 constitutes the intercept, α_1 and α_2 are GARCH (1,1) parameters
h_t stands for conditional variance at time *t*
e_{t-1}^2 denotes squared error term at time *t-1*
υ_t stands for residual.

By using wavelet analysis, the degree of currency exposure was examined in relation to various time scales. The multi-scale relationship between scale dependent exchange rate returns and stock returns is summarized in the following conceptual framework diagram.

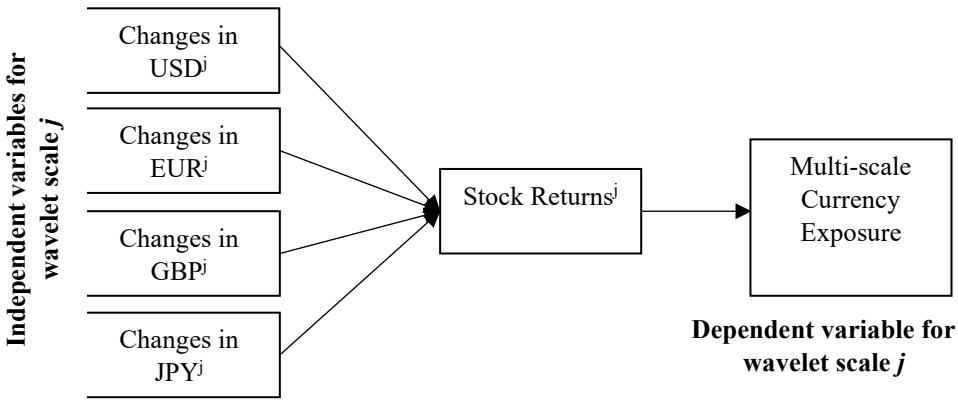


Figure 1: Conceptual framework of the study

4. Results and Discussions

This section explains the results of estimated foreign exchange beta coefficient β_X^j generated from the individual regression of stock returns on each exchange rate changes and market returns at scale crystal j. Before proceeding to the scale dependent beta currency exposure estimates, the distribution properties of all variables as showcased in Table 1.

Table 1: Descriptive statistics and stationarity test of independent variables

Series	Mean	Max	Min	SD	Skewness	Kurtosis	ADF test	PP test
rKLCI	0.0001	0.0663	-0.0998	0.00797	-0.7662	14.2931	-65.4508 ***	-65.6789 ***
rUSD	0.0000	0.0234	-0.0256	0.00349	-0.1947	10.3644	-73.0858 ***	-73.1427 ***
rEUR	0.0000	0.0359	-0.0403	0.00585	0.0010	6.3812	-75.4521 ***	-75.4856 ***
rGBP	0.0000	0.0294	-0.0727	0.00564	-0.5911	11.0838	-71.5224 ***	-71.4970 ***
rJPY	0.0000	0.0605	-0.0476	0.00691	0.2726	8.7201	-77.5507 ***	-77.6012 ***
rCNY	0.0001	0.0207	-0.0354	0.00346	-0.4288	11.2489	-74.8878 ***	-74.8901 ***

Note: Max, Min, SD, ADF-test and PP-test denote maximum data, minimum data, standard deviation, Augmented Dickey Fuller test and Phillips Perron test respectively. *** denotes the variable is significant at 1% respectively.

It could be observed that the Japanese Yen (JPY) and European currency (EUR) returns exhibited the highest volatilities, while Chinese Yuan (CNY) returns showed the least volatility. This finding inferred that the JPY and EUR could be important source of foreign exchange risk to the corporations in consumer products and services sector. However, this priori findings need to be validated in wavelet and regression analysis. In terms of stationary properties, all return series were stationary at 5% significance level I(0) at level form. In general, regression models for stationary series avoid spurious results and this finding could help the analysis in producing robust estimates. Further test required to test for multicollinearity problem on the variables by using variance inflation factor (VIF) analysis. Based on Table 2, it could be clearly seen that all the series showcased VIF values less than 10, signifying the absence of multicollinearity problem in the variables across time scales.

Table 2: Variance inflation factor *(VIF)* test

Time Scales	VIF					
	KLCI	USD	EUR	GBP	JPY	CNY
Overall	1.11	1.89	1.60	1.55	1.44	1.56
D1	1.10	1.55	1.58	1.54	1.44	1.23
D2	1.11	2.22	1.56	1.52	1.46	1.88
D3	1.12	3.74	1.69	1.58	1.46	3.47
D4	1.17	4.67	1.67	1.58	1.45	4.44
D5	1.18	7.10	1.77	1.67	1.50	6.86
D6	1.19	6.14	1.76	1.79	1.48	5.81
D7	1.26	4.26	1.95	2.19	1.44	4.35
S7	1.63	3.90	2.45	2.79	1.42	3.46

For the exchange rate exposure estimation, Table 3 provides beta estimates without decomposition. The extent of foreign exchange exposure could be seen through the magnitude and the significance of beta at 5% significance level. It was observed that the currency EUR and JPY displayed the highest average betas at BEUR=-0.0463 and BJPY=-0.0424, indicating that 1% increase in currency EUR and JPY decreases stock returns by 0.0463% and 0.0424%, respectively. This finding is economically sensible since the finding

corroborated the result from the descriptive statistics. In terms of fraction of exposed firms, it could be seen that the consumer products and services firms were highly susceptible to the JPY and EUR with negative sign, whereby 18% of sample firms had significant exposures to the JPY and 16% of sample firms had significant exposures to the Euro. This meets the priori expectation as the Japan and European countries are amongst major trading partners of Malaysia. This finding is also in line with Lily et al. (2018) study which demonstrated that Malaysia firms were significantly benefited from the depreciation of JPY. On the other hand, the US Dollar (USD) and the Great Britain Pound (GBP) exhibited a positive sign of exposure with mean beta BUSD=0.0183 and BGBP=0.0387, implying that 1% increment on those currencies increases firm values by 0.0183% and 0.0387%, respectively.

Table 3: Descriptive statistics of exchange rate exposure coefficient (Overall, No time scale)

Descriptive Statistics	β_{USD}	β_{EUR}	β_{GBP}	β_{JPY}	β_{CNY}
Mean	0.0183	-0.0463	0.0387	-0.0424	-0.0028
Median	0.0115	-0.0403	0.0310	-0.0388	-0.0292
Max	0.5265	0.1814	0.3169	0.1030	0.8446
Min	-0.5868	-0.3119	-0.2211	-0.2954	-0.4420
SD	0.2071	0.0979	0.0935	0.0829	0.2101
(+ sign) Significant : Number of firms	6 : 31	0 : 15	6 : 36	0 : 16	6 : 24
(– sign) Significant : Number of firms	2 : 25	9 : 41	1 : 20	10 : 40	3 : 32
Percentage of exposed firms (+ sign significant)	11%	0%	11%	0%	11%
Percentage of exposed firms (– sign significant)	4%	16%	2%	18%	5%
Percentage of total exposed firms significantly	14%	16%	13%	18%	16%

Note: This table shows the distribution of exchange rate exposure(beta coefficient) using OLS with GARCH (1,1) specification by employing the following below regression model equation:

$$R_{it} = \beta_0 + \beta_{mt}R_{mt} + \beta_{USDt}R_{USDt} + \beta_{EURt}R_{EURt} + \beta_{GBPt}R_{GBPt} + \beta_{JPYt}R_{JPYt} + \beta_{CNYt}R_{CNYt} + \varepsilon_t$$

+ sign and – sign denote as positive coefficient and negative coefficient respectively.

Table 4 provides the summary of mean currency exposure (positive and negative signs) and percentage of exposed firms at 5% significance level across different time scales. A close observation to Table 4 shows that there is a multi-scale trend of foreign exchange exposure. Specifically, there is a gradual increase of exchange rate exposure from low time scale to high time scale, indicating the enhanced firm's sensitivity to foreign exchange fluctuations in widened time horizon. There is a gradual increase in coefficient of determination (R2 values) from low time scale to high time scale, implying the increase of explanatory power in explaining foreign exchange exposure at higher time scale. For illustration, the identical fashion of gradual increase in the level of foreign exchange exposure could be observed in Figure 2 (which displays fraction of exposed firms) and Figure 3 and Figure 4 which demonstrate the high concentration of magnitude of exchange rate exposures (positive and negative signs) at higher time intervals.

Table 4: Exchange rate exposure by different time scales

	Scale	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**S7**	**No scale**
β_{USD}	f	13	9	21	36	46	54	56	56	8
	%	23%	16%	38%	64%	82%	96%	100%	100%	14%
	Mean (+)	0.1661	0.2498	0.2516	0.5472	0.5064	0.6698	0.9638	0.9080	0.1451
	Mean (-)	-0.2058	-0.1640	-0.3318	-0.5248	-1.0262	-1.1149	-0.7492	-0.9198	-0.1498
β_{EUR}	f	9	17	22	37	43	53	54	56	9
	%	16%	30%	39%	66%	77%	95%	96%	100%	16%
	Mean (+)	0.1226	0.1050	0.1591	0.1545	0.1709	0.2644	0.2815	0.5474	0.0664
	Mean (-)	-0.0955	-0.1262	-0.1267	-0.2932	-0.3217	-0.3520	-0.5967	-0.4890	-0.0868
β_{GBP}	f	13	13	23	36	48	50	55	54	7
	%	23%	23%	41%	64%	86%	89%	98%	96%	13%

	Mean (+)	0.1061	0.1145	0.1419	0.2370	0.2704	0.3863	0.8585	0.5605	0.0868
	Mean (-)	-0.1190	-0.0960	-0.1211	-0.1676	-0.1819	-0.2122	-0.3785	-0.5832	-0.0502
β_{JPY}	f	13	15	27	36	45	51	55	56	10
	%	23%	27%	48%	64%	80%	91%	98%	100%	18%
	Mean (+)	0.0632	0.0696	0.0797	0.1716	0.1780	0.2849	0.4538	0.4353	0.0435
	Mean (-)	-0.1073	-0.1079	-0.1585	-0.1309	-0.1578	-0.2422	-0.2815	-0.4684	-0.0793
β_{CNY}	f	14	13	20	37	41	53	55	56	9
	%	25%	23%	36%	66%	73%	95%	98%	100%	16%
	Mean (+)	0.1985	0.2166	0.3084	0.5513	0.9119	1.0829	0.7468	1.2559	0.1712
	Mean (-)	-0.2096	-0.1636	-0.2351	-0.4271	-0.4740	-0.6079	-1.3487	-0.9848	-0.1317
R-Squared		0.0619	0.0791	0.1058	0.1511	0.1685	0.1664	0.1888	0.2820	0.0791

Note: This table shows the estimation results of exchange rate exposure using OLS with GARCH (1,1) specification by employing the following regression models:

i. Regression model from equation - overall time interval (No scale).
$$R_{it} = \beta_0 + \beta_{mt}R_{mt} + \beta_{USDt}R_{USDt} + \beta_{EURt}R_{EURt} + \beta_{GBPt}R_{GBPt} + \beta_{JPYt}R_{JPYt} + \beta_{CNYt}R_{CNYt} + \varepsilon_t$$

ii. Regression model from equation - different wavelet crystal scales (D1, D2, D3, D4, D5, D6, D7, S7).
$$R_i^j = \beta_0^j + \beta_m^j R_m^j + \beta_{USD}^j R_{USD}^j + \beta_{EUR}^j R_{EUR}^j + \beta_{GBP}^j R_{GBP}^j + \beta_{JPY}^j R_{JPY}^j + \beta_{CNY}^j R_{CNY}^j + \varepsilon_t^j$$

f, %, Mean (+) and Mean (-) denote the number of significant exposed firms at 5% significant level, percentage of exposed firm, mean positive coefficient, and mean negative coefficient respectively.

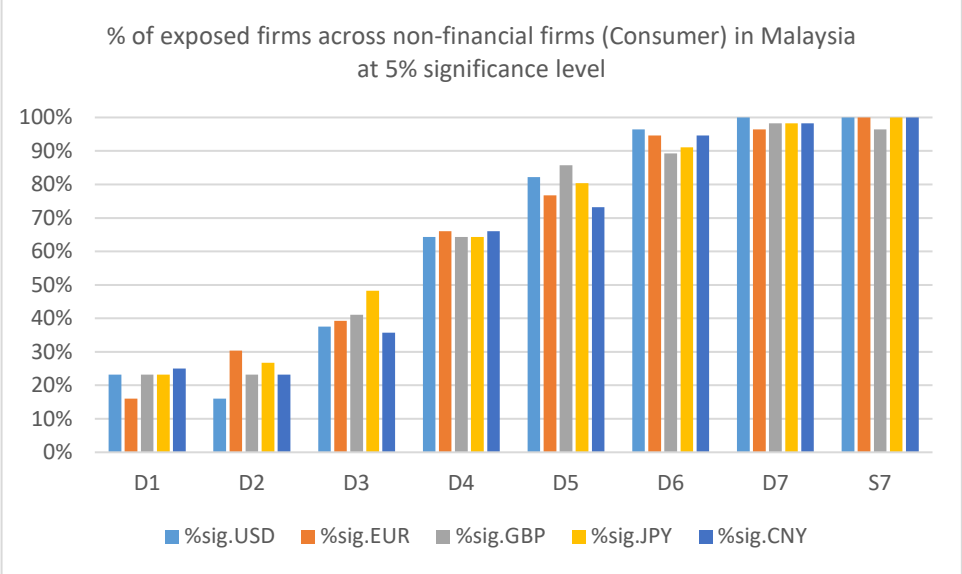


Figure 1. Percentage of exposed firms across consumer product and services firms in Malaysia at different time horizons at 5% significance level

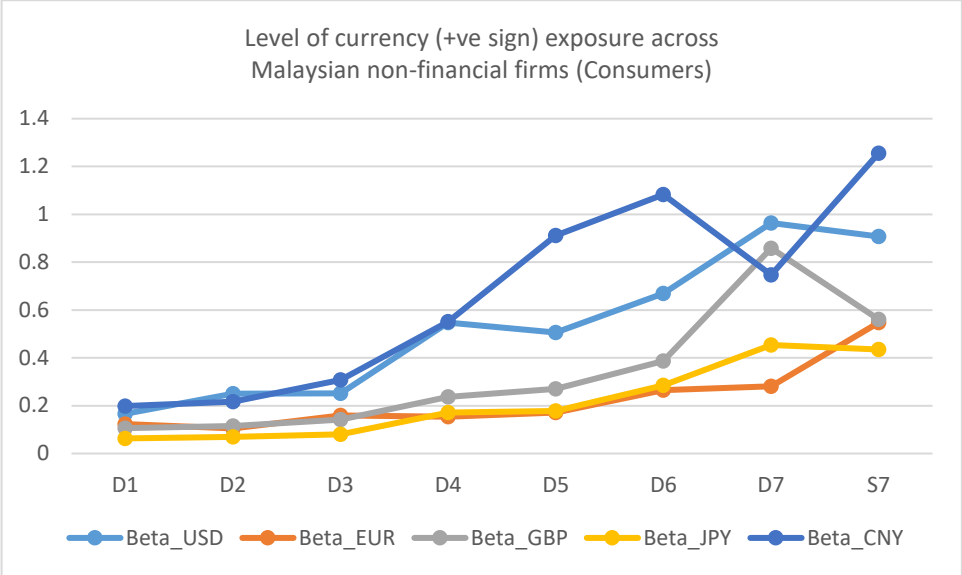


Figure 2. Time-scales currency exposure (positive coefficient) among consumer product and services firms in Malaysia.

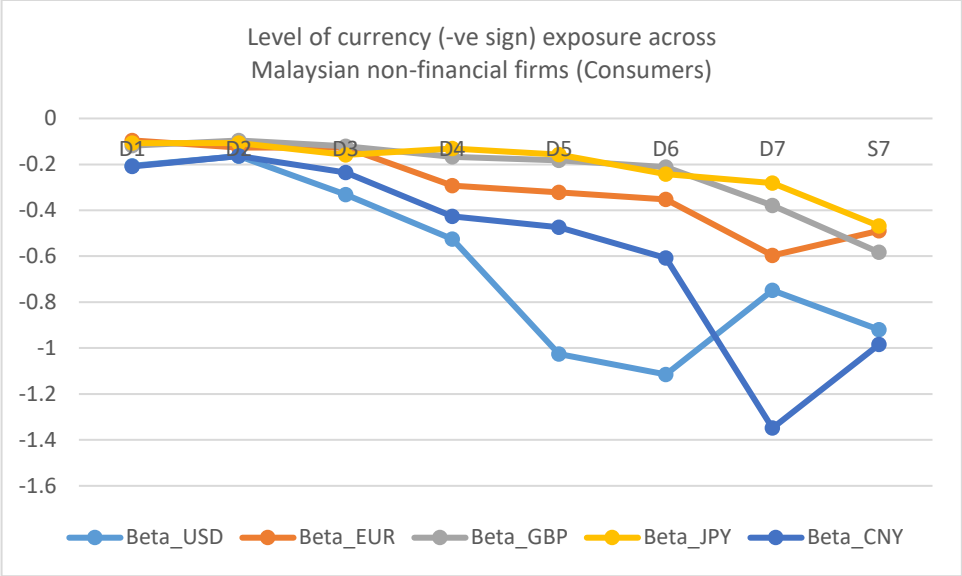


Figure 3. Time-scales currency exposure (negative coefficient) among consumer product and services firms in Malaysia.

6. Conclusion

The study aimed to unveil multi-scale foreign exchange exposure of corporations under the consumer products and services through the application of maximal overlap discrete wavelet transformation (MODWT). Accordingly, the study rejected the null hypothesis of identical level of foreign exchange risk across different time horizons at 5% significance level. Specifically, there was high concentration of exchange risk at high time scale in comparison to low time scale. The study contributed to the mainstream foreign exchange risk literature through many ways. First, the study offers new application of wavelet teachnique (i.e. Maximal overlap discrete wavelet transformation) in foreign exchange pricing. Second, with respect to consumer products and services sector, the study exerts that the widened investment length entails a greater exchange risk, while short time scale exhibits negligible effect of exchange risk. The finding has significant implications to foreign exchange risk management routine, whereby the firm manager should put

close monitoring and oversight on long-term foreign transactions. The long-term foreign exchange exposure could be managed through a variety of financial tools, as well as the right operational hedging practices.

The study is subjected to several limitations. Firstly, the study is solely focused on a single industry (i.e., the consumer products and services) which does not reflect the overall nature of scale dependent foreign exchange exposure in Malaysia. Secondly, the study highlighted on discrete wavelet transformation (DWT) only. The future study should expand the study by examining multihorizon foreign exchange exposure across different sectors by using continuous wavelet transformation (CWT) so that more generalized results could be discerned in future.

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