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Abstract

In this paper we argue that the commonly employed exposure coefficient/beta is inadequate to capture the entire impact of exchange rate changes on firms' future operating cash flows. Instead, we employ the bivariate GJR-GARCH-M models to investigate four aspects of exchange rate exposure, including sensitivity of stock returns to exchange rate changes, sensitivity of stock returns to the volatility of exchange rate changes, sensitivity of conditional variance of returns to exchange rate volatility, and the dynamic conditional correlation between returns and exchange rate changes, respectively, using data from ten industrial sectors in Japan. We find significant evidence of such exchange rate exposure which is not captured by the conventional measure. The diagnostic statistics confirm the adequacy of our model, and hence the robustness of the results.

Key Words: exchange rate exposure; volatility spillovers; multivariate GARCH-M models; time-varying correlation

JEL Classification: C22; F31; F37; G12; G15

1. Introduction

In recent years the volatility of exchange rate exposure and its associated risk have become a hot issue in international financial management. Exchange rate exposure is empirically defined as the change in a firm's future operating cash-flows in response to changes in exchange rates. It is often assumed that a firm's future operating cash flows is proxied by its market value, and the exposure coefficient would be able to efficiently measure the impact of exchange rate changes on a firm's return and its sensitivity to the changes (see Adler and Dumas, 1984). More recently, researchers attempt to investigate whether exchange rate exposure is asymmetric in volatility of stock returns and between currency appreciations and depreciations (see, for instance, Kanas, 2000; Koutmos and Martin, 2003; Aloui, 2007). Raghavan and Dark (2008) use a Vector Autoregressive GARCH (VAR-GARCH) model to examine the return and volatility spillover effects between the US dollar/Australian dollar exchange rate and the Australian All Ordinaries Index (AOI). Jayashinghe and Tsui (2008) employ a bivariate GJR-GARCH model to examine exposed returns and its asymmetric conditional volatility of exchange rate exposure in the Japanese industries. Neely and Fawley (2012) use GARCH and CGARCH to investigate the persistence of capital flow shocks on Japanese yen foreign exchange volatility.

By far most existing studies on exchange rate exposure assume that the variances of a firm's returns and exchange rates changes are time-invariant. In this paper, we assess empirically the validity of this assumption, and argue that the conveniently defined exchange rate exposure is inadequate for measuring the entire impact of exchange rate changes on a firm's future operating cash flows in cases of time-varying variances. By extending the Jayashinghe and Tsui (2008) study, we postulate that there are at least four alternative routes through which a firm's returns are exposed to foreign exchange risks when the variances are time-variant, as illustrated in Figure 1.

[Insert Figure 1 about here]

The very first route is route [a] through which a firm's stock returns are exposed to the exchange rate changes either directly or indirectly through its business linkages with other firms. The second route, indicated by [b], captures the exposure to the volatility of exchange rate changes, namely, the sensitivity of a firm's value to the degree of fluctuations of exchange rates. If the degree of fluctuations is time-varying, the firm may react to change its marketing, production location and hedging strategies. The third level of exchange rate exposure measures the sensitivity of conditional variance of the returns to the volatility of exchange rate changes through Route [c]. Even if the relationship [b] is absent, as long as the conditional variances of returns are exposed to volatility of exchange rate changes and the returns are sensitive to its own volatility changes as represented by [e] in Figure 1, there still exists the possibility of an indirect impact of exchange rate volatility on returns. As a consequence, the firm may have to re-assess and even change its current business strategies which may in turn affect its profitability. Finally, route [d] indicates the time-varying conditional correlation between returns and exchange rate changes, through which the dynamics of a firm's exchange rate exposure will be captured.

In this paper, we employ a bivariate GARCH-type model to investigate the aforementioned sensitivities of exchange rate exposure by using daily industrial indexes of ten sectors in Japan during the period from 1992 to 2000. The results indicate that there are cases which are not exposed to currency risk under the conventional measure (exposure coefficient), but significantly exposed to currency risk through the alternative routes identified in Figure 1.

The rest of this paper is organized as follows. Section 2 discusses the theoretical framework and methodology, and provides a brief review of the empirical evidence of sensitivities of exchange rate exposure. In Section 3 we discuss briefly the datasets used in our study and analyze the estimation results. Some concluding remarks are given in Section 4.

2. Analytical Framework and the Model

The first moment of exchange rate exposure has been thoroughly discussed in the literature during the last two decades.[1] Most of the existing studies adopt the standard OLS or SUR method of estimation to assess the direct impact of exchange rate changes on the profits of the firms that are directly engaged in foreign currency denominated transactions as well as the indirect impact of exchange rate changes on firms' profits that can occur through their linkages with directly exposed firms. Such indirect impacts may come into being when a firm provides

[1] Among many others, see Adler and Dumas (1984), Jorion (1990), Bodnar and Gentry (1993), Bodnar and Wong (2003), Dominguez and Tesar (2006). See also Jayashinghe and Tsui (2008) for a review.

inputs to directly exposed firms, acts as an import competitor in the domestic market or uses internationally priced inputs, even if it does not have foreign currency denominated transactions in its accounts. For instance, Bodnar and Gentry (1993) employ the OLS to assess the monthly exchange rate exposure of industry portfolios, and find that 5 out of 20 Japanese industries are significantly exposed to exchange rate changes. In particular, an appreciation in the yen affects favourably both non-tradable goods sector and importers, and adversely on exporters and the value of their foreign operations. However, the major problem associated with the augmented market approach is that the variance of firm's return and changes of exchange rate are assumed to be time-invariant.

Recently there have been an increasing number of studies to accommodating the time-varying volatility in empirical studies of exchange rate changes by applying the GARCH-type models. Among others, Koutmos and Martin (2003) employ GARCH-type models to augment the mean equation with a time-varying variance structure in order to improve the precision of parameters, and Kanas (2000) uses bivariate asymmetric GARCH models to analyze the mutual impact of volatilities between equity and exchange rate markets. However, these studies examine only one or two aspects of exchange rate exposure and also at country level. The main drawback is that exchange rate exposure could be averaged out when a highly aggregated index is used[2], and similarly, the asymmetries associated with the exchange rate exposure of both the first and second moments of stock returns are also likely to be averaged out when highly aggregated indexes are used. Jayashinghe and Tsui (2008) is among the first few to employ a bivariate GJR-GARCH model to capture three aspects of daily exchange rate exposure simultaneously by using disaggregated industrial sectoral data from Japan. They find evidence of constant conditional correlation between return on seven Japanese sectoral indexes and exchange rate changes, and also report that the conditional correlations between return on some sectors and exchange rate changes are time-varying.

Koutmos and Martin (2003) and Jayashinghe and Tsui (2008) are among the first few to examine the second moment of exchange rate exposure and beyond. Exchange rate volatility can mainly affect the profits of firms through its impact on firms' international trade activities. Jayashinghe and Tsui (2008) find significant evidence of exposed returns, and its asymmetric

[2] As a matter of fact, this "averaged-out exposure" argument may also apply to sectoral analysis. We will discuss the selection issue regarding the optimal level of aggregation of our dataset in the data analysis section.

conditional volatility of exchange rate exposure as well as support for the "averaged-out exposure and asymmetries" argument. Unfortunately, there is no consensus on the direction of such an impact. Clark (1973) and Hooper and Kohlhagen (1978) present theoretical models in which risk averse producers reduce trade in the face of high exchange rate volatility periods. De Grauwe (1989) argues that this adverse effect of exchange risk is a direct result of the assumption of constant absolute risk aversion which usually eliminates the income effect of risk. If a certain producer is slightly risk averse, then one can expect the results suggested by Clarke (1973) and Hooper and Kolhagen (1978). However, if the producer is highly risk averse, then he may worry about the worst possible outcome and the income effect is most likely to dominate the substitution effect. As a result, the producer may export more in order to avoid heavy revenue losses that he expects high exchange rate risk to bring about.

Hysteretic models of trade, in which exporting firms are viewed as holders of options to exit or enter export markets, also have implications towards the relationship between the exports and exchange rate volatility. According to these models, the decision to enter or exit international markets is based not only on the relevant explicit fixed and variable costs, but also on the cost of exercising the option. The higher the volatility is, the higher the possibility that the exchange rates will be more favorable, and hence the higher the value of keeping the option unexercised (see, for instance, Baldwin and Krugman, 1989; Sercu and Vanhulle, 1992). Furthermore, high volatility in foreign exchange markets may motivate the firms to hedge against currency risk, thus affecting the profits through increased hedging costs (Koutmos and Martin, 2003). The impact of currency risk on profits may also be due to the positive relationship between the currency risk and the prices of hedging instruments. In this study, we make a further extension of the Jayashinghe and Tsui (2008) study to investigate the postulated multi-elements of exchange rate exposure by using daily industrial indexes of ten sectors in Japan.

In recent years, it has become common to use generalized autoregressive conditional heteroskedasticity (GARCH)-type models to accommodate the time-varying volatility in empirical studies of exchange rate changes. The GARCH model pioneered by Bollerslev (1986) and its subsequent extensions have been well-documented in the literature on modeling conditional volatility in empirical economics and finance. A few such extensions are noteworthy as we are going to capture those stylized facts in this study. First, many variants that are capable of capturing volatility asymmetry have been developed. A widely accepted variant is the GJR-

GARCH model of Glosten et al. (1993). Second, as Bollerslev (1987) and others emphasized, financial return series tend to be largely leptokurtic, and hence GARCH-type models with *t*-distributed residuals are often used to capture such features. Third, Tse (2000) find that the constant conditional correlation between volatilities of two financial time-series may be at odds with empirical evidence. As a remedy, Tse and Tsui (2002) and Engle (2002) suggest time-varying conditional correlation GARCH-type models. Finally, according to Engle et al. (1987), as the degree of risk associated with the returns on assets is likely to vary over time, the compensation required by risk averse investors for holding such assets must also be time-varying, which was hence incorporated into their asset pricing models with a GARCH-in-mean term. This provides some justification for our choice of the GJR-GARCH models.

We adopt a time-varying conditional correlation bivariate GJR-GARCH(1,1)-M model to capture the four elements of exchange rate exposure of sectoral returns. Residuals are assumed to be *t*-distributed. The mean, variance and correlation structures are specified as follows:

Mean equation for sectoral returns:

$$r_{i,t} = a_0 + a_m r_{m,t} + a_{x-1} r_{x,t-1} + \sum_{k=1}^{q} a_{j-k} r_{i,t-k} + a_g \left(h_{x,t-1}\right)^{1/2} + \varepsilon_{i,t}; \qquad i = 1,2,\ldots n \tag{1}$$

Mean equation for exchange rate changes:

$$r_{x,t} = b_0 + \sum_{l=1}^{s} b_{x-l} r_{x,t-l} + \varepsilon_{x,t} \tag{2}$$

Variance and covariance equations:

$$z_t = \varepsilon_t H_t^{-1/2} \tag{3}$$

$$\varepsilon_t \mid I_{t-1} = (\varepsilon_{i,t} \varepsilon_{x,t})' \mid I_{t-1} \sim f_v(\varepsilon_t \mid I_{t-1})$$

$$h_{i,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \gamma_i d_{i,t-1} \varepsilon_{i,t-1}^2 + \beta_i h_{i,t-1} + \alpha_{ix} \varepsilon_{x,t-1}^2 + \gamma_{ix} d_{x,t-1} \varepsilon_{x,t-1}^2 \tag{4}$$

$$h_{x,t} = \omega_x + \alpha_x \varepsilon_{x,t-1}^2 + \gamma_x d_{x,t-1} \varepsilon_{x,t-1}^2 + \beta_x h_{x,t-1} \tag{5}$$

$$h_{ix,t} = \rho_{ix,t} \left(h_{i,t} h_{x,t}\right)^{1/2} \tag{6}$$

Correlation equation:

$$\rho_{ix,t} = (1-\theta_1-\theta_2)\bar{\rho}_{ix} + \theta_1\rho_{ix,t-1} + \theta_2\psi_{ix,t-1} \quad (7)$$

where $r_{i,t}$ is returns on sectoral index *i* at time *t*; $r_{m,t}$ is returns on market index at time *t*; $r_{x,t}$ is the log difference in exchange rate at time *t*. In addition, ε_t is a 2 x 1 vector of the daily shocks of ($\varepsilon_{i,t} \quad \varepsilon_{x,t}$) at time *t* pair-wise with each sector *i*. And $\varepsilon_t \mid I_{t-1}$ denote the 2 x 1 vector of random shocks at time *t* given all available information at time (*t* – 1). We assume that it follows a bivariate *t*-distribution with ν degrees of freedom, zero mean and conditional variance H_t, which is a 2 x 2 variance-covariance matrix. For each sector, the main diagonal elements of H_t are the conditional variances of sectoral returns and changes in exchange rate, represented by $h_{i,t}$ and $h_{x,t}$, respectively. The two conditional variances are assumed to follow GJR-GARCH(1,1) structure given by equations (4) and (5), and $d_{u,t-1} = 1$ if $\varepsilon_{u,t-1} < 0$ and zero otherwise for $u = i, x$. Finally, z_t denotes the standardized errors which are assumed to be independently and identically distributed with mean *0* and variance *1*.

As regards mean equation (1) for sectoral returns, we follow Bartov and Bodnar (1994) and others to include lagged variables of exchange rate changes to capture the possible impact on stock returns. This is supported by Bartov et al. (1996) when they argue that "characterizing the exposures of firms on a timely basis may be difficult for the investors due to complexities associated with their determination. Without extensive knowledge of international pricing policies, strategic responses to exchange rate changes, foreign currency positions, or firm operations, investors may wait for the firm to release information about its actual performance before they adjust firm value in response to past exchange rate changes, resulting in a delayed rather than a contemporaneous relation. As such, the exposure coefficient a_{x-1} measures the sensitivity of sectoral returns at time *t* to the exchange rate changes at time (*t* – 1). This phenomenon is called the first moment exchange rate exposure[3]. Given that the exchange rate is

[3] Unlike the conventional augmented market model that is widely used to estimate exchange rate exposure, suggested bivariate GJR-GARCH model does not capture the impact of contemporaneous exchange rate changes in the mean equation. Apparently, there is a trade off here. Though the conventional augmented market model is able

expressed as local currency price of foreign currency, a positive coefficient implies that sectoral returns increase with a depreciation of the yen. This should be the case for those industrial sectors dominated by exporting firms. Following Bodner and Wong (2003) and others, market returns ($r_{m,t}$) are included in the equation to avoid the spurious correlation component between the sectoral returns and exchange rate changes. In order to capture the exposure of sectoral returns to the volatility changes in foreign exchange market, we include a cross GARCH-M term. In parallel with the use of the lagged exchange rate changes, we include a lagged volatility term $(h_{x,t-1})^{1/2}$ in the equation. The coefficient a_g measures the second moment exchange rate exposure. A negative sign of the coefficient would imply that trade flows are adversely affected by exchange rate volatility which, in turn, may have an adverse impact on firms' profits (for instance, exchange rate volatility may reduce the trade volume and profits of an exporter). A negative sign may also imply that increase in exchange rate volatility will reduce firm's profits through higher hedging costs. However, as mentioned earlier, the sign of a_g can be either negative or positive. We note in passing that based on the Ljung-Box statistics[4], the optimal lag order for q ranges from 1 to 3 across sectors.

In mean equation (2) for exchange rate changes, we follow closely the smooth transition autoregressive model (STAR), in particular, the generalized form of an exponential function (ESTAR), which implies that within each regime, the exchange rate reverts to a linear autoregressive representation, with different parameter values and asymmetric speeds of adjustment.[5] We do not include the sectoral returns as the explanatory variables in this equation. This is supported by the following observations. First, each industrial sector is sufficiently small as compared to the whole economy. It is therefore reasonably safe to assume that the exchange rates are almost entirely dependent on activities in the rest of the economy (see Bodner and Gentry, 1993). Hence, returns on a particular sector are assumed to have negligible effect on the

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to capture the contemporaneous exchange rate changes in the mean equation, it does not capture the other elements of exchange rate exposure of sectoral returns as specified in the conditional variance and correlation equations discussed in this paper. In this sense, this minor weakness of the model is the cost that is paid for its being able to successfully capture the other elements of exposure. Nevertheless, the use of lagged exchange rate changes may not be unrealistic in the context of daily data.

[4] We have also tried other procedures for picking the autoregressive lag structure, such as the information-based rules including the Akaike and Schwartz Bayesian information criterion. The results are consistent.

[5] The ESTAR model can be viewed as a generalization of the double-threshold TAR model. For details, please refer to Kilian and Taylor (2003), and Altavilla and De Grauwe (2010).

exchange rate. Second, we have conducted the Granger-causality tests for all sectors with changes in exchange rates, and the results show that none of the returns series Granger-causes exchange rate changes at industry level. For similar reason, we also exclude the returns of the market portfolio in the mean equation. Although the "stock-oriented approach" to the exchange rate determination provides some theoretical support for inclusion, we decide to exclude the market returns because they do not Granger-cause exchange rate changes.

We include in the variance equation in Equation (4) the GARCH(1,1) terms (represented by α_i and β_i) and the GJR term with coefficient γ_i. In order to measure the exchange rate exposure of the conditional variance of sectoral returns, a cross ARCH term is also included and its impact on sectoral volatility is captured by the coefficient α_{ix}. A positive and significant estimate of α_{ix} suggests that an increase in volatility in exchange rates will increase the volatility of sectoral returns. Moreover, a cross GJR term, the coefficient of which is γ_{ix}, is added to capture the possibly asymmetric exchange rate exposure of the second moment. A negative and statistically significant γ_{ix} implies that the volatility increase in sectoral returns caused by a depreciation of yen is greater than that caused by an appreciation of the same magnitude. However, in literature, there is no consensus on whether depreciation is good news or bad news to the stock markets. Based on their empirical findings, Ma and Kao (1990) argue that stock prices may be adversely affected by news of appreciation in an export-dominant economy whereas the opposite is the case for an import-dominant economy.

Similarly Equation (5) is assumed to follow a GARCH(1,1) process, together with a GJR term to capture the possibly asymmetric exchange rate volatility by parameter γ_x. The inclusion of the GJR term can be justified by the fact that exchange rate changes are often negatively skewed. For an asymmetric volatility associated with exchange rate changes, the estimated values of γ_x are expected to be statistically significant.

Finally, the conditional covariance of sectoral returns and exchange rate changes is defined by equation (6), specified as the product of conditional correlation coefficient and the square root of the conditional variance of returns and exchange rate changes. Following Tse and Tsui (2002), we assume that the conditional correlation between sectoral returns and exchange rate changes is time-varying, and follows the structure in equation (7). As such, the conditional correlation at time *t* ($\rho_{ix,t}$) is given by the weighted average of time-invariant component ($\overline{\rho}_{ix}$), its own lag term in previous period ($\rho_{ix,t-1}$) and $\psi_{ix,t-1}$ which is assumed to be a function of lagged observations of standardized error z_t. More specifically, $\psi_{ix,t-1} = \frac{\sum_{h=1}^{M} z_{i,t-h} z_{x,t-h}}{\sqrt{\left(\sum_{h=1}^{M} z_{i,t-h}^2\right)\left(\sum_{h=1}^{M} z_{x,t-h}^2\right)}}$, where M is set equal to the dimension of the GARCH model. Both θ_1 and θ_2 are assumed to be nonnegative and sum up to less than 1, namely, $(\theta_1 + \theta_2) \leq 1$.

Assuming that the standardized residuals of the suggested bivariate model are *t*-distributed, the conditional log-likelihood of residual vector ε_t at time *t* can be defined as follows:

$$\ell(\varphi)_t = \ln\Gamma\left(\frac{\nu+2}{2}\right) - \ln\Gamma\left(\frac{\nu}{2}\right) - \ln(\pi(\nu-2)) - \frac{1}{2}\ln|H_t| - \left(\frac{\nu+2}{2}\right)\ln\left(1 + \frac{\varepsilon_t'(D_t R_t D_t)^{-1}\varepsilon_t}{\nu-2}\right) \quad (8)$$

where φ is the vector of parameters to be estimated; $\Gamma(.)$ is the Gamma function; D_t is a 2 x 2 diagonal matrix whose diagonal elements are $h_{i,t}^{1/2}$ and $h_{x,t}^{1/2}$; R_t is the 2 x 2 conditional correlation matrix whose diagonal elements consist of ones and off-diagonal elements are represented by $\rho_{ix,t}$.

The log-likelihood function of the sample is obtained as: $L(\phi) = \sum_{t=1}^{T} \ell(\varphi)_t$, where T is the number of observations. The parameter vector φ of the bivariate GJR-GARCH-M model is estimated by maximizing L with respect to φ. All estimates of the parameters in this paper are obtained by the method of maximum likelihood using programs coded in GAUSS.

3. Empirical Analysis

3.1. Data description

Our dataset consists of ten industrial sectors of the Japanese economy during the period from June 1, 1992 to December 12, 2000, and contains 2240 observations. The choice of this sample is based on availability of data and the specific nature of this sample period[6]. In selecting the sectoral returns, we focus on level 4 industrial classification, which is based on FTSE actuaries system, available in Datastream.[7] We choose 10 out of the 39 sectors which are reasonably related to manufacturing goods, including automobile and parts (A&P), construction and building materials (C&BM), diversified industries (DI), electrical and electronic equipment (E&EE), engineering and machinery (E&M), information technology and hardware (IT&H), oil and gas (O&G), pharmaceuticals and biotechnology (P&B), software and computer services (S&CS) and steel and other metals (S&OM), respectively. Market portfolio is assumed to be represented by Nikkei 225, the overall stock index in Japan. And all sectoral returns and market returns are expressed in local currency.

To measure the exchange rate exposure, Adler and Dumas (1984) suggest to use a set of bilateral rates. However, it may cause the problem of multi-collinearity among the regressors as most currencies are related to one another and move in similar directions (see Jorion, 1990). A parsimonious rectification is to collapse a large number of bilateral rates into a single trade-weighted exchange rate. However, a common problem with the trade-weighted basket of currencies is that the nature of a sector's (or a firm's) exposure may not correspond to the exchange rates and the relevant weights included in the basket (Dominguez and Tesar, 2006). Alternatively, a single bilateral exchange rate with currency that is important in terms of trade and capital flows with respect to the country in question can also be selected. On balance, we measure the multi-elements of exchange rate exposure with respect to two exchange rates: (a) an effective exchange rate for Japanese yen compiled by the Bank of England (BOE) and; (b) a bilateral exchange rate between yen and the US dollar compiled by Morgan Stanley Capital International (MSCI). Weights of the BOE exchange rates are designed to represent the relative importance of each of the other countries as a competitor to the relevant country's manufacturing sector. Data for both rates are extracted from Datastream and are expressed as local currency

[6] During the sample period of study, the yen appreciated by 21.43% on average. More specifically, the sample period includes three main phases: appreciation of the yen by 38% between August 1992 and April 1995; depreciation by 65% between April 1995 and August 1998; and appreciation again by 34% between August 1998 and September 2000. Apparently, such trends including appreciation and depreciation of the yen on roughly 3-year intervals provide a relatively balanced period of study, as compared to other sample periods consisting of a single trend.

[7] Sectoral indexes included in both level 2 that comprises only 4 sectors and level 3 that comprises only 9 sectors were assumed to be too aggregated in nature to test for possible exposure to exchange rate changes. On the other hand, in order to keep the study within a manageable range, we did not use further disaggregated indexes in level 5 which comprises more than 100 sectors.

price of foreign currency. That is: an increase in the index indicates depreciation of local currency. Following most of the previous studies, we use changes in nominal exchange rate. And the continuously compounded daily returns and exchange rate changes are computed as follows:

$$r_{u,t} = \ln\left(R_{u,t} / R_{u,t-1} \right) * 100 \qquad u = i, x, m$$

where $R_{u,t}$ and $R_{u,t-1}$ are the closing values of stock prices/exchange rates for the trading days t and t-1, respectively.

We have done some preliminary analysis of the sectoral returns data and conducted the Augmented Dickey-Fuller (ADF) test to check for stationarity in order to ensure reliable statistical inference. The results are not reported, but available upon request from authors. It is found that, out of these 14 sectors, PC&H and P&B are the least volatile, while DI and S&CS are the most volatile, with the standard deviations for returns ranging from 1.086% (P&B) to 2.063% (S&CS). Returns of the market portfolio and those of 13 out of the 14 industrial sectors are positively skewed and highly leptokurtic with all values of kurtosis greater than 3, thereby exceeding the kurtosis of returns following a normal distribution. The ADF tests suggest that the returns of all the 10 industrial sectors and the market portfolio and changes in exchange rate of the yen are stationary at the 1% level of significance. However, the Jarque-Bera test for non-normality is highly significant in all ten sectors, thereby rejecting the null hypothesis that the daily returns in the industrial sectors are normally distributed. Moreover, the Ljung-Box statistics evaluated at 20 lags provide support for linear dependency in every sector. However, the Ljung-Box statistics of squared returns evaluated at 20 lags indicate evidence of non-linear dependence, which may be due to autoregressive heteroskedasticity.

3.2. Empirical Findings

We first assess the features of the data series used in our empirical study, and then discuss the estimation results of the bivariate GJR-GARCH-M model. This includes all four elements of exchange rate exposure of sectoral returns and diagnostic checks for adequacy of the proposed model. It is found that all the sectoral indexes, market index and exchange rates are $I(1)$ processes. As such, before using sectoral returns and changes in exchange rate (both being $I(0)$ processes) in a vector autoregressive form, one has to check whether each sectoral index is co-integrated with the exchange rate. Existence of such a long-run relationship will require the relevant model to be augmented with error correction terms. To this end, we carry out the Johansen cointegration test and the results are reported in Table 1[8]. As can be observed, we do not find support of co-integration between sectoral index and the exchange rate during the sample period, thereby suggesting that the error correction terms are not required in the mean equations.

[Insert Table 1 about here]

Table 2 reports the maximum likelihood estimates of the time-varying conditional correlation GJR-GARCH(1,1)-M model. The results indicate that over half of the 10 Japanese industries are significantly exposed to exchange rate changes in terms of their returns, implying the existence of the first moment of exchange rate exposure[9] (see row 1 in Table 2). The absolute value of estimated exposure coefficient represented by a_{x-1} ranges from 0.052 in C&BM to 0.152 in O&G, and there are four cases in which the exposure coefficients are greater than 0.1, which suggests that returns in those sectors are relatively highly sensitive to the changes in exchange rate.

[Insert Table 2 about here]

It is interesting to note that returns in some sectors such as A&P, E&EE and IT&H are positively related to the exchange rate changes, implying that returns on such sectors increase with the depreciation of the yen. This finding is consistent with our casual observation that devaluation of the currency would favour the exporting sectors. The negative relationship between O&G and exchange rate changes can be attributed to Japan's heavy import reliance in that sector. Although lack of all the natural resources, Japan is the world's third largest oil consumer and second largest energy importer (EIA, 2004). Our findings are also consistent with that by Bodnar and Gentry (1993), Dominguez (1998) and Jayasinghe and Tsui (2008), who

[8] We did not conduct panel cointegration test as our primary interest is to check whether each sectoral index is co-integrated with the exchange rate. We are grateful to the referee for pointing out this.
[9] Jaussaud and Rey (2012) find that real appreciation of the yen and greater uncertainty derived from increased exchange rate volatility have significantly reduced Japanese exports.

report that electrical machinery, precision instruments and industrial sectors are positively exposed to exchange rate changes while the energy and utilities sectors show the opposite result.[10]

Returns in the C&BM sector are also found negatively exposed. However, unlike the O&G sector, it is difficult to craft a clear-cut explanation for this in terms of imports and exports. The difficulty is partly due to the different classification systems used in sectoral stock indexes and import/export data.[11] On the other hand, it is not sensible to solely attribute exchange rate exposure of sectoral returns to the aggregated import/export trade statistics. Indeed, many studies have argued that the first moment of exchange rate exposure is determined by a number of other industry characteristics in addition to imports and exports[12] (among others, see Bodnar and Gentry, 1993).

Turning to the estimates of the GARCH-M term, we find evidence of volatility of exchange rate exposure in three out of the ten sectors (see row 2 of Table 2). The coefficient a_g is positive and significant in sectors IT&H and S&CS, and negative and significant in S&OM. The negative coefficient suggests that exchange rate volatility may increase the hedging costs and/or adversely affect the exports from this sector, while positive sign would indicate that the income effect dominates and firms may have to increase exports in order to avoid possible revenue losses that may stem from volatility of exchange rates. It is also interesting to note that, though S&CS and S&OM sectors are exposed to the volatility of exchange rate, they are not exposed to the exchange rate changes.

The estimated coefficient of own GJR term (γ_i) are significant at the 5% level and bear the expected positive sign in seven industrial sectors including A&P, C&BM, DI, E&M, O&G, P&B and S&OM (see row 4 in Table 2), suggesting that the leverage effect is at work when there is a reduction in sectoral returns. The results confirm the existence of asymmetric volatility in returns in these seven sectors. Volatility associated with exchange rate changes is also found to

[10] However, Bodnar and Gentry (1993), Dominguez (1998) and this study employ three different industry classification systems.

[11] For instance, the industrial sectors used in this study are due to the FTSE actuaries system whereas the data in Yearbook of International Trade Statistics are based on Standard International Trade Classification (SITC). Although sectors like oil and gas are common to both systems, in many other sectors, such a commonality does not exist.

[12] A detailed discussion of the "determinants" of the exposure of sectoral returns in terms of industrial characteristics and firm-specific factors such as hedging activities is beyond the scope of this study.

be asymmetric in five sectors (the results are not reported but available upon request from the authors).

We now turn to the empirical results relating to the sensitivity of the conditional variance of returns to the volatility of exchange rate changes. As it can be seen from Row 5 in Table 2, the cross squared error (α_{ix}) is positive and significant at the 5% significant level in sectors DI, E&M and S&OM, and significant at the 10% significant level in A&P, C&BM and S&CS. The estimated α_{ix} ranges from the highest value of 0.16 in the DI Sector to the lowest 0.018 in the E&M Sector. The results confirm the "meteoric shower" effect in these industrial sectors, and suggest that an increase in the volatility in exchange rates will raise the volatility of sectoral returns. Moreover, the coefficient of the cross GJR term (γ_{ix}) is found to be negative and significant in the sectors of DI, E&M and C&BM (row 6 in Table 2), and suggest the asymmetric exchange rate exposure of the conditional variance in these sectors. The implication is that the returns in these three sectors are not only highly sensitive to the volatility in foreign exchange market, but also vulnerable to the depreciation of yen. As discussed early, the negative and statistically significant γ_{ix} implies that the volatility increase in sectoral returns caused by a depreciation of yen would be greater than that caused by an appreciation of the same magnitude. This is because the depreciation of local currency always contains an element of uncertainty and hence acts as a "bad" news, which may result in program trading which has the potential of decreasing of stock prices through increased selling pressures.

We find that the time-varying conditional correlation model converges only in nine industrial sectors (i.e. all except the S&OM sector) in our estimations[13], of which the time-invariant component of the correlation ($\overline{\rho}_{ix}$) is significant only in four industrial sectors, namely, in E&EE at 1% significant level, in IT&H and O&G at 5% level and in A&P at 10% level. Moreover, out of those nine cases θ_1 is found highly significant in eight sectors with the exception of E&M (rows 9 in Table 2). These results suggest there exist two different patterns of time-varying conditional correlation between Japanese industrial sectors and the exchange rate changes. The first one is that, although the correlation between the returns and exchange rate changes are time-varying in these sectors, time varying correlation is more likely to be dependent

[13] The estimates of the tenth sector, namely S&OM, are based on the constant correlation counterpart of the suggested time-varying correlation GJR-GARCH model.

on its own past and less likely to be disturbed by the recent changes as reflected in the standardized residuals. The second one is that although the time-invariant component is not significant, time-variant component is significant, suggesting that the time-invariant component alone is not a reliable measure of the correlation between the two variables.

[Insert Table 3 about here]

In order to evaluate the robustness of the above findings, we further estimate the multi-elements of exchange rate exposure associated with a yen-US dollar bilateral exchange rate. The results are reported in Table 3. With the chosen bilateral exchange rate, the first moment exposure of exchange rate is present in six sectors (A&P, C&BM, E&EE, E&M, IT&H and O&G). However, the second moment exposure of returns is limited to only two (IT&H and S&CS). The exposure of the conditional variance of returns is also confined to two sectors, namely, DI and S&OM. As regards for the time-varying conditional correlation between sectoral returns, $\overline{\rho}_{ix}$ is significant in three sectors (E&EE, IT&H and O&G); θ_1 is significant in all nine sectors[14]; and θ_2 is not significant in any of those sectors. On average, the exposure of sectoral returns to the yen-US dollar bilateral exchange rate is very similar to their exposure to yen effective exchange rate.

[Insert Table 4 about here]

For a better exposition, we summarize all the main findings in Table 4. First, the results indicate that there is no sector whose return and variance are simultaneously exposed through all the four routes indicated in Figure 1. Then there are the four sectors, DI, E&M, P&B and S&CS, which have been found to be less likely exposed to the currency risk[15] given the insignificant estimates of the coefficient a_{x-1}.[16] We find evidence of asymmetric cross-volatility spillover

[14] As the suggested time-varying model did not converge for S&CS sector, the estimations reported in Table 3 are based on the constant correlation counterpart of the suggested model.

[15] Here, one may argue that the coefficient of the contemporaneous exchange rate change term might have been significant (if it was included in regression) though the coefficient of the lag term is not. As the results of univariate regressions reveal, in all these four cases, the coefficients of both contemporaneous and lag exchange rate changes are not significant.

[16] The coefficient of a_{x-1} is significant in the E&M sector for the yen-US dollar bilateral exchange rate.

between exchange rate exposure and sectoral returns in three sectors. The findings are consistent with our theoretical argument stated early. However, the returns and/or conditional variance of some of these sectors are statistically significantly exposed to the exchange rate volatility. Finally, we find evidence that in some sectors, the conditional correlation between returns and exchange rate changes are even time-varying. These findings imply that the commonly employed exposure coefficient/beta is inadequate to capture the entire impact of exchange rate changes on firms' future operating cash flows. For instance, there are cases which are not exposed to currency risk under the conventional measure (exposure coefficient in Column (a) of Table 4), but statistically significantly exposed to the currency risk through the alternative routes identified in this paper (refer to Columns (b), (c) and (d) in Table 4).

[Insert Table 5 about here]

Table 5 presents the diagnostics including the summary statistics of the standardized residuals obtained from the regressions based on the yen effective exchange rate.[17] Although there are still some non-normal features in the standardized residual series, we can see that the Jarque-Bera statistics and kurtosis in all the sectors have been remarkably reduced. The non-normality associated with the return series has largely been taken off by the Student *t*-distribution based model. In addition, as indicated by row 11 of Table 2 and row 10 of Table 3, the degrees of freedom values of the *t*-distribution (ν) for each sector is highly significant, ranging from 4.961 (A&P: yen effective exchange rate) to 6.325 (E&M: bilateral exchange rate), and the relevant *t*-statistic is always greater than 10. This justifies the selection of the Student *t*-distribution as the underlying stochastic structure of the time series for the sectoral returns and exchange rate changes. It is noted that the Ljung-Box statistics with 20 degrees of freedom for the standardized residuals ($Q_i(20)$) and for the squared standardized residuals ($Q_i^2(20)$) are significantly low as compared to those of the return series in the preliminary analysis of the sectoral returns data. Since we employ a multivariate model, two more tests have been employed to diagnose any remaining nonlinear dependencies in the cross product of the standardized residuals. We first conduct the Box-Pierce type test as suggested in Tse and Tsui (1999) by using

[17] The summary statistics of the standardized residuals based on the yen-US dollar bilateral exchange rate are not reported as they are very similar to the results based on the yen effective exchange rate.

the correlation coefficient-adjusted cross product of the standardized residuals ($z_{i,t} z_{x,t} - \rho_{ix,t}$), and then apply the Runs test to the cross product of the standardized residuals ($z_{i,t} z_{x,t}$). The test results confirm that the non-linear dependencies in almost all the sectoral indexes have been adequately captured by the proposed model, and the proposed bivariate GJR-GARCH(1,1)-M model is adequate for capturing all the four elements of exchange rate exposure of sectoral returns.[18]

4. Concluding Remarks

In this study a bivariate time-varying conditional correlation GJR-GARCH(1,1)-M model is employed to estimate the multi-elements of exchange rate exposure in ten Japanese industrial sectors. We find strong evidence for the existence of all the four elements of exchange rate exposure postulated in this paper in the Japanese sectoral returns. The results confirm the first moment exposure to exchange rate changes in the six sectors, namely, A&P, C&BM, E&EE, E&M, IT&H and O&G, and that the returns in three sectors (IT&H, S&CS and S&OM) are statistically significantly exposed to the volatility of exchange rate changes. The conditional variances of the returns in three sectors (DI, E&M and S&OM) are found to be significantly exposed to the volatility of exchange rate changes. The exchange rate exposure of the conditional variances of the returns in three sectors (DI, E&M and C&BM) are found asymmetric, implying that the volatility increase in sectoral returns caused by a depreciation of yen would be greater than that caused by an appreciation of the same magnitude. We find evidence that returns in nine sectors are significantly correlated with the exchange rate changes and the correlation is time-varying. In addition, the time-varying correlation between sectoral returns and exchange rate changes is more persistent and less likely to be disturbed by the recent changes. The finding, that in some sectors the time-varying correlation parameters are significant even though the time-invariant component is not, implies that the time-invariant component is a misleading measure of the correlation. Most importantly, the results show that returns in some sectors are statistically significantly exposed to "other" identified elements of the exchange rate changes even though

[18] Any other asymmetric GARCH specification could be chosen and would have been adequate for this task. But the focus of this paper is not on choosing the most suitable asymmetric GARCH model for estimating exchange rate exposure.

they are not exposed in terms of the conventional measure of exchange rate exposure, namely, the exchange rate exposure coefficient/beta.

This study provide strong evidence suggesting that the commonly employed exposure coefficient/beta is inadequate to capture the entire impact of exchange rate changes on firms' future operating cash flows. In the presence of those "other" elements of exchange rate exposure, the *entire currency risk* actually faced by a firm/sector is not fully captured by the "exchange rate exposure coefficient" alone. As such, taking the conventional exposure coefficient as the sole measure of exchange rate exposure of firms/sectors may provide us with misleading results. There are cases which are not exposed to currency risk under the conventional measure, but are found significantly exposed to the currency risk through the four alternative routes identified in this paper. The diagnostic statistics further confirm the adequacy of our model, and hence the robustness of the results.

REFERENCES

Adler, M. and B. Dumas (1984) "Exposure to Currency Risk: Definition and Measurement", *Financial Management*, 13, pp. 41-50.

Aloui, C. (2007), "Price and volatility spillovers between exchange rates and stock indexes for the pre- and post-euro period", *Quantitative Finance* 7(6), pp 669-685.

Altavilla, C. and P. De Grauwe (2010), "Forecasting and combining competing models of exchange rate determination", *Applied Economics*, 42, pp. 3455–3480.

Baldwin, R. and P. Krugman (1989) "Persistent Trade Effects of Large Exchange Rate Shocks", *Quarterly Journal of Economics*, 104(4), pp. 635-654.

Bartov, E., and G. M. Bodnar (1994) "Firm Valuation, Earnings Expectations and the Exchange Rate Exposure Effect, *Journal of Finance,* 49(5), pp. 1755-1785.

Bartov, E., G. M. Bodnar and A. Kaul (1996) "Exchange Rate Variability and the Riskiness of US Multinational Firms: Evidence from the Breakdown of the Bretton Woods System", *Journal of Financial Economics*, 42, pp. 105-132.

Bodnar, G. M. and W. M. Gentry (1993) "Exchange Rate Exposure and Industry Characteristics: Evidence from Canada, Japan and the USA", *Journal of International Money and Finance*, 12, pp. 29-45.

Bodnar, G. M. and M. F. H. Wong (2003) "Estimating Exchange Rate Exposures: Issues in Model Structure", Financial Management (Spring), 35-67.

Bollerslev, T. (1986) "A Generalized Conditional Autoregressive Heteroskedasticity", *Journal of Econometrics*, 31, pp. 307-327.

Bollerslev, T. (1987) "A Conditional Heteroskedastic Time Series Model for Speculative Prices and Rates of Returns", *Review of Economics and Statistics*, 69, pp.542-547.

Clarke, P. B. (1973) "Uncertainty, Exchange Rate and the Level of International Trade", *Western Economic Journal*, 11, pp. 302-313.

De Garuwe, P. (1988) "Exchange Rate Variability and the Slowdown in the Growth of International Trade", *IMF Staff Papers*, 35, pp. 63-84.

Dominguez, K. M. E. (1998) "The Dollar Exposure of Japanese Companies", *Journal of the Japanese and International Economies*, 12, pp. 388-405.

Dominguez, K. M. E. and L. L. Tesar (2006) "Exchange Rate Exposure", *Journal of International Economics*, 68, pp. 188 – 218.

EIA (2004) "Country Analysis Briefs: Japan", Energy Information Administration http://www.eia.doe.gov/emeu/cabs/japan.html.

Engle, R. F. (2002) "Dynamic Conditional Correlation – A New Simple Class of Multivariate GARCH Models", *Journal of Business and Economic Statistics*, 20, pp. 339-350.

Engle, R. F., D. M. Lilien and R. P. Robins (1987) "Estimating Time-Varying Risk Premia in the Time Structure: The ARCH-M Model", *Econometrica*, 55(2), pp. 391-407.

Glosten, L., R. Jegannathan and D. Runkle (1993) "On the Relation between the Expected Value and Volatility of Nominal Excess Return on Stock", *Journal of Finance*, 46, pp. 1779-1801.

Hooper, P. and S. W. Kohlhagen (1978) "The Effect of Exchange Rate Uncertainty on the Price and Volume of International Trade", *Journal of International Economics*, 8, pp. 483-511.

Jaussaud, J. and S. Rey (2012) "Long-Run Determinants of Japanese Exports to China and the United States: A Sectoral Analysis", *Pacific Economic Review*, 17, pp. 1-28.

Jayasinghe, P. and A. Tsui (2008) "Exchange Rate Exposure of Sectoral Returns and Volatilities: Evidence from Japanese Industrial Sectors", *Japan and the World Economy,* 20, pp. 639–660.

Jorion, P. (1990) "The Exchange Rate Exposure of U.S. Multinationals", *Journal of Business*, 63, pp. 331-345.

Kanas, A. (2000), "Volatility Spillovers between Stock Returns and Exchange Rate Changes", *Journal of Business and Finance and Accounting*, 27 (3), April/May, pp. 447-67.

Kilian, L. and M.P. Taylor, (2003), "Why is it so difficult to beat the random walk forecast of exchange rates?", *Journal of International Economics*, 60, pp. 85–107.

Koutmos, G. and A. D. Martin (2003) "First and Second Moment Exchange Rate Exposure: Evidence from U.S. Stock Returns", *The Financial Review*, 38, pp. 455-71.

Ma, C. and W. Kao (1990) "On Exchange Rates and Stock Price Reactions", *Journal of Business, Finance and Accounting*", 17(3), pp. 441-450.

Neely, C. and B. Fawley (2012) "Capital Flows and Japanese Asset Volatility", *Pacific Economic Review*, 17 (3), pp. 391-414.

Raghavan, M. and J. Dark (2008) "Return and Volatility Spillovers Between the Foreign Exchange Market and the Australian All Ordinaries Index", *The ICFAI Journal of Applied Finance* 14, pp. 41-48.

Sercu, P. and C. Vanhulle (1992) "Exchange Rate Volatility, International Trade and the Value of Exporting Firms", *Journal of Banking and Finance*, 16, pp. 155-182.

Tse, Y. K. (2000) "A Test for Constant Correlations in a Multivariate GARCH Model" *Journal of Econometrics*, 98, pp. 107-127

Tse, Y. K. and A. K. Tsui (2002) "A Multivariate GARCH Model with Time-Varying Correlations", *Journal of Business and Economic Statistics*, 20, pp. 351-62.

Tables:

Table 1: Johansen cointegration test results

Sectoral index	Hypothesized no. of cointegrated eqns	ER(tw)		ER(bi)	
		Trace	Max EV	Trace	Max EV
A&P	None	7.34	4.68	8.33	5.89
	At most one	2.65	2.65	2.44	2.44
C&BM	None	6.16	4.88	6.89	5.88
	At most one	1.28	1.28	1.01	1.01
DI	None	7.28	4.15	8.14	5.76
	At most one	3.13	3.13	2.38	2.38
E&E	None	7.71	5.15	6.56	3.86
	At most one	2.55	2.55	2.70	2.70
E&M	None	7.76	4.60	8.54	6.34
	At most one	3.04	3.04	2.20	2.20
IT&H	None	6.56	4.56	6.29	4.06
	At most one	2.00	2.00	2.23	2.23
O&G	None	4.87	4.28	5.31	4.76
	At most one	0.58	0.59	0.55	0.55
P&B	None	4.87	4.86	5.82	5.82
	At most one	0.01	0.01	1.26	1.26
S&CS	None	7.70	5.49	6.25	3.70
	At most one	2.21	2.21	2.55	2.55
S&OM	None	4.87	4.13	5.42	4.78
	At most one	0.74	0.74	0.64	0.64

Notes: Critical values for trace and maximum eigen value statistics at the 5% level of significance are 15.49 and 14.26, respectively; ER(tw): yen trade-weighted exchange rate; ER(bi): yen-US dollar bilateral exchange rate.

Table 2:
Maximum likelihood estimates for the time-varying conditional correlation GJR GARCH(1,1)–M model (yen effective exchange rate)

Parameter	A&P	C&BM	DI	E&EE	E&M	IT&H	O&G	P&B	S&CS	S&OM[§]
1. a_{x-1}	0.1405***	-0.0523***	0.0161	0.1175***	0.0277*	0.1500***	-0.1522***	-0.0239	-0.0295	0.0103
	(6.30)	(-3.18)	(0.45)	(6.57)	(1.84)	(5.80)	(-6.19)	(-1.26)	(-0.78)	(0.39)
2. a_g	-0.0356	0.0618	0.0957	0.0295	-0.0130	0.1646**	-0.0759	0.0266	0.2604**	-0.1635**
	(-0.51)	(1.26)	(0.95)	(0.54)	(-0.28)	(2.13)	(-1.11)	(0.49)	(2.35)	(-2.10)
3. α_i	0.0800***	0.0894***	0.0449***	0.0762***	0.0549***	0.0827***	0.0555***	0.0602***	0.1668***	0.0775***
	(4.13)	(3.91)	(3.62)	(4.08)	(3.25)	(3.90)	(3.09)	(2.90)	(6.17)	(4.27)
4. γ_i	0.0568**	0.0736***	0.0335**	0.0196	0.0690***	0.0279	0.0458**	0.0387**	0.0496	0.0555**
	(2.07)	(2.85)	(1.99)	(0.91)	(3.12)	(1.31)	(2.31)	(1.97)	(1.40)	(2.24)
5. α_{ix}	0.0352*	0.0171*	0.1597***	0.0142	0.0175**	0.0197	0.0112	0.0109	0.1112*	0.0678**
	(1.64)	(1.78)	(3.37)	(1.61)	(2.30)	(0.92)	(0.92)	(1.12)	(1.83)	(2.25)
6. γ_{ix}	-0.0213	-0.0189*	-0.1924***	-0.0142	-0.0175**	-0.0124	0.0013	-0.0068	-0.0867	-0.0513
	(-0.87)	(-1.67)	(3.51))	(-1.37)	(-2.05)	(-0.46)	(0.08)	(-0.54)	(1.17)	(-1.46)
7. β_i	0.8808***	0.8729***	0.9274***	0.9019***	0.9002***	0.8963***	0.9244***	0.9143***	0.8000***	0.8705***
	(36.32)	(35.60)	(67.64)	(42.28)	(46.04)	(39.89)	(60.33)	(39.70)	(29.08)	(42.47)
8. $\overline{\rho}_{ix}$	0.0539*	-0.0496	-0.0050	0.0848***	0.0246	0.0635**	-0.0582**	-0.0258	-0.0086	-0.0496**
	(1.75)	(-1.58)	(-0.16)	(3.13)	(1.03)	(2.44)	(-2.09)	(-0.91)	(-0.27)	(-2.13)
9. θ_1	0.9927***	0.9784***	0.9747***	0.9775***	0.7156	0.8780***	0.9671***	0.9770***	0.9979***	NA
	(63.76)	(35.21)	(24.96)	(24.44)	(1.40)	(5.61)	(20.35)	(47.85)	(139.51)	
10. θ_2	0.0012	0.0056	0.0064	0.0026	0.0083	0.0114	0.0049	0.0041	0.0003	NA
	(0.41)	(0.95)	(0.88)	(0.44)	(0.04)	(0.80)	(0.67)	(0.82)	(0.10)	
11. ν	4.9612***	5.4010***	5.2667***	5.8365***	6.2954***	5.4368***	5.4290***	5.2129***	5.8265***	5.3226***
	(12.87)	(12.17)	(12.27)	(11.80)	(10.87)	(11.83)	(12.08)	(12.18)	(11.33)	(12.58)

Notes: ***, ** and * indicate 1%, 5% and 10% levels of significance, respectively; Values mentioned within parentheses are relevant *t*-statistics; The estimated model consists of the Equations 1 through 8. [§] For S&OM, constant correlation model is used as the time-varying version of the suggested model did not converge. Except for the time-varying correlation parameters, the results from the two versions of the model are largely similar and available upon request; NA: Not available.

Table 3: Maximum likelihood estimates for the time-varying conditional correlation GJR GARCH(1,1)–M model (yen-US dollar bilateral exchange rate)

Parameter	A&P	C&BM	DI	E&EE	E&M	IT&H	O&G	P&B	S&CS[§]	S&OM
1. a_{x-1}	0.1322***	-0.0479***	0.0010	0.1218***	0.0261**	0.1415***	-0.1389***	-0.0202	-0.0114	0.0043
	(6.62)	(-3.13)	(0.45)	(7.66)	(2.00)	(6.29)	(-6.56)	(-1.09)	(-0.33)	(0.18)
2. a_g	-0.0764	0.0354	0.0846	0.0131	-0.0089	0.1638**	-0.0627	-0.0028	0.2718**	-0.1193
	(-1.14)	(0.76)	(0.84)	(0.24)	(-0.21)	(2.23)	(-0.96)	(-0.06)	(2.50)	(-1.56)
3. γ_i	0.0481**	0.0695***	0.0305*	0.0207	0.0663***	0.0287	0.0442**	0.0376**	0.0518	0.0556**
	(2.05)	(2.83)	(1.90)	(1.00)	(3.32)	(1.39)	(2.31)	(1.99)	(1.45)	(2.28)
4. α_{ix}	0.0047	0.0071	0.1049***	0.0068	0.0079*	0.0009	-0.0001	0.0055	0.0773	0.0385**
	(0.45)	(1.14)	(3.03)	(0.98)	(1.70)	(0.08)	(-0.01)	(0.95)	(1.54)	(1.96)
5. γ_{ix}	-0.0016	-0.0098	-0.1287***	-0.0076	-0.0082	0.0040	0.0080	-0.0011	-0.0684	-0.0296
	(-0.11)	(-1.23)	(3.17)	(-0.85)	(-1.38)	(0.20)	(0.67)	(-0.13)	(-1.11)	(-1.22)
6. γ_x	0.0267*	0.0223*	0.0275*	0.0264*	0.0275**	0.048*	0.0267**	0.0244*	0.0248*	0.0262*
	(1.81)	(1.68)	(1.87)	(1.89)	(1.96)	(1.83)	(1.99)	(1.75)	(1.80)	(1.80)
7. $\overline{\rho}_{ix}$	0.0700*	-0.0516*	-0.0033	0.1086***	0.0098	0.0855***	-0.0708**	-0.0170	-0.0045	-0.0524
	(1.91)	(-1.78)	(-0.10)	(4.08)	(0.18)	(3.02)	(-2.53)	(-0.49)	(-0.19)	(-1.29)
8. θ_1	0.9899***	0.9720***	0.9768***	0.9066***	0.9942***	0.8443***	0.9891***	0.9597***	NA	0.9894***
	(83.17)	(28.99)	(29.32)	(4.97)	(172.58)	(8.39)	(56.71)	(18.71)		(99.82)
9. θ_2	0.0030	0.0054	0.0071	0.0090	0.0032	0.0273	0.0016	0.0132	NA	0.0044
	(0.85)	(0.86)	(0.96)	(0.66)	(1.11)	(1.72)	(0.44)	(1.13)		(1.13)
10. ν	5.0443***	5.5653***	5.6159***	5.8226***	6.3251***	5.5893***	5.5779***	5.3889***	5.9548***	5.4112***
	(12.81)	(12.04)	(11.91)	(11.81)	(10.96)	(11.72)	(11.95)	(12.12)	(11.23)	(12.31)

Notes: ***, ** and * indicate 1%, 5% and 10% levels of significance, respectively; NA: Not available; Values mentioned within parentheses are relevant *t*-statistics; The estimated model consists of the Equations 1 through 8. [†] since the time-varying version of the suggested model did not converge, constant correlation model is used. Except for the time-varying correlation parameters, the results from the two versions of the model are largely similar and available upon request. [‡] Note α_i and β_i are not reported mainly because the results are entirely comparable to those from Table 2.

Table 4: Evidence for multi-elements of exchange rate exposure: a summary

Sector	(a) Exposure of returns to e.r. changes (a_{x-1})		(b) Exposure of returns to volty. of e.r. (a_g)		(c) Exposure of variance to volty of e.r. (α_{ix})		(d) Dynamic correlation					
	ER(eer)	ER(bi)	ER(eer)	ER(bi)	ER(eer)	ER(bi)	ER(eer) ($\bar{\rho}_{ix}$)	ER(eer) (θ_1)	ER(eer) (θ_2)	ER(bi) ($\bar{\rho}_{ix}$)	ER(bi) (θ_1)	ER(bi) (θ_2)
A&P	***	***	–	–	*	–	*	***	–	*	***	–
C&BM	***	***	–	–	*	–	–	***	–	*	***	–
DI	–	–	–	–	***	***	–	***	–	–	***	–
E&EE.	***	***	–	–	–	–	***	***	–	***	***	–
E&M	*	**		–	**	*	*	–	–	–	***	–
IT&H	***	***	**	**	–	–	**	***	–	***	***	–
Oil&G	***	***	–	–	–	–	**	***	–	**	***	–
P&B	–	–	–	–	–	–	–	***	–	–	***	–
S&CS	–	–	**	**	*	–	–	***	–	–	dnc	dnc
S&OM	–	–	**	–	**	**	**	dnc	dnc	–	***	–

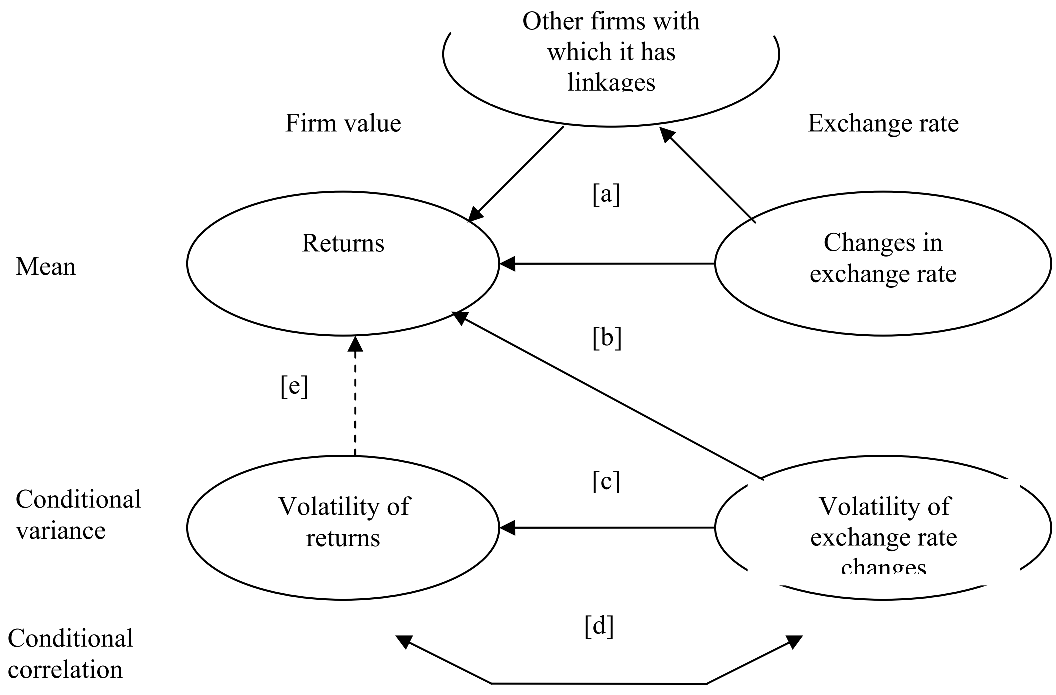
Notes: ***, ** and * indicate that the relevant coefficient is significant at least at the 1%, 5% and 10% level significance, respectively; The relevant coefficients are a_x, a_g, $\bar{\rho}_{ix}, \alpha_{ix}$, θ_1 and θ_2 in Equations 1, 4 and 7 respectively; dnc: time-varying correlation version of the suggested model did not converge; ER(eer): yen effective exchange rate; ER(bi): yen-US dollar bilateral exchange rate.

Table 5: Diagnostics: sectoral returns (trade-weighted exchange rate) [§]

Sector	A&P	C&BM	DI	E&EE	E&M	IT&H	O&G*	P&B	S&CS	S&OM*#
Mean	0.0143	0.0329	0.0113	0.0086	0.0181	0.0147	0.0116	0.0334	0.0230	0.0202
Maximum	5.295	7.1825	6.0302	5.7326	5.511	4.4874	5.7243	6.0521	7.4237	5.5578
Minimum	-4.2696	-4.3904	-4.1056	-4.4358	-5.4343	-5.0839	-3.7878	-4.6357	-4.5838	-3.9618
SD	0.9776	0.9813	0.9743	0.9774	0.9711	0.9660	0.9604	0.9737	0.9736	0.9737
Skewness	0.3133	0.6586	0.2003	0.0843	0.1274	0.1151	0.2643	0.3603	0.3264	0.3436
Kurtosis	5.4441	6.3093	5.2082	5.2728	4.4954	4.4226	4.9450	5.3726	5.4504	4.9731
Jarque-Bera stat	593.69	1183.00	469.68	484.35	214.51	193.66	378.80	573.32	599.66	406.35
$Q_i(20)$	22.90	34.09	12.92	27.24	28.37	39.80	22.22	21.21	27.97	27.58
$Q_x(20)$	30.08	28.31	28.97	28.46	27.86	28.28	29.11	28.08	27.43	28.91
$Q_i^2(20)$	21.95	45.73	27.92	21.51	21.88	20.53	8.49	14.40	19.11	6.60
$Q_x^2(20)$	18.59	19.06	17.97	18.41	18.32	18.43	18.71	18.60	18.61	18.83
$TTQ_{ix}(20)$	18.00	29.46	14.57	15.31	10.35	23.69	33.29	22.13	16.16	18.10
$Runs_{ix}$	-1.41	-1.87	0.24	-1.19	-0.34	-0.78	-0.36	1.08	-1.92	0.47

Notes: $Q_i(20)$, $Q_x(20)$, $Q_i^2(20)$ and $Q_x^2(20)$ are Ljung-Box statistics of residuals and squared residuals from equations 1 (returns) and 2 (exchange rate changes) for 20 lags. $TTQ_{ix}(20)$ is the Box-Pierce type test for cross product of the residuals suggested in Tse and Tsui (1999). The test statistics associated with $Q(.)$, $Q^2(.)$ and $TTQ(.)$ tests are assumed to follow a χ^2 distribution and the critical value at the 5% level of significance with 20 degrees of freedom is 31.41. $Runs_{ix}$ is the runs test statistic for cross product of the residuals from equations 1 and 2. For samples greater than 30, it is assumed to follow a standard normal distribution. *A remarkable outlier which has not been filtered is removed to get these summary statistics in sectors O&G and S&OM; # Residuals are obtained from the constant correlation version of the suggested model.

Figures:



(a) Sensitivity of stock returns to exchange rate changes (first moment exchange rate exposure of returns)
(b) Sensitivity of stock returns to the volatility of exchange rate changes (second moment exchange rate exposure of returns)
(c) Sensitivity of the conditional variance of returns to the volatility of exchange rate changes (exchange rate exposure of conditional variance)
(d) Dynamic conditional correlation between stock returns and exchange rate changes

Figure 1
Multi-elements of exchange rate exposure