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## **Abstract**

Most studies of exchange rate exposure of stock returns do not address three relevant aspects simultaneously. They are, namely: sensitivity of stock returns to exchange rate changes; sensitivity of volatility of stock returns to volatility of changes in foreign exchange market; and the correlation between volatilities of stock returns and exchange rate changes. In this paper, we employ a bivariate GJR-GARCH model to examine all such aspects of exchange rate exposure of sectoral indexes in Japanese industries. Based on a sample data of fourteen sectors, we find significant evidence of exposed returns and its asymmetric conditional volatility of exchange rate exposure. In addition, returns in many sectors are correlated with those of exchange rate changes. We also find support for the “averaged-out exposure and asymmetries” argument. Our findings have direct implications for practitioners in formulating investment decisions and currency hedging strategies.

*Key Words:* exchange rate exposure; asymmetric volatility spillovers; GARCH-type models; conditional correlation

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

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# **Exchange Rate Exposure of Sectoral Returns and Volatilities: Evidence from Japanese Industrial Sectors**

## **1. Introduction**

Modeling exchange rate exposure has been an important growing area of research in the last decade. The literature of exchange rate exposure dates back to early 1940's. Initially, a firm's actual rather than future cash flows are used to analyze the exposure. However, such an approach is inappropriate for practical reasons. For instance, realized cash-flows do not capture a firm's operating exposure. Changes in exchange rates may also influence the future activities of the firm. And, it is not operationally easy to obtain a significant amount of firm-specific information, especially when the study is focused on a large number of firms. Adler and Dumas (1984) give a lucid review of the definition and measurement of exposure to currency risk. More recently, Bodner and Wong (2003) provide an excellent account of issues in estimating exchange rate exposures.

In this paper we propose a unified approach to address the exchange rate exposure of stock returns. To the best of our knowledge, our approach is the first direct investigation that simultaneously captures three relevant aspects exchange rate exposures including time-varying risk of 14 sectoral returns in Japanese industries. Bivariate GJR-GARCH models are employed to achieve such purposes.

We follow the well-documented approach of Adler and Dumas (1984) and others to take a firm's market value as reasonable proxy to its future operating cash flows. Based on the efficient market hypothesis, exchange rate exposure of a firm is defined as "the sensitivity of [its] economic value, or stock price, to exchange rate changes" (Heckman, 1983). Adler and Dumas (1984) show that exchange rate exposure can be obtained by regressing a firm's value on exchange rate. The following augmented market model is often used to estimate exposure coefficients:

$$r_{i,t} = \delta_{0,i} + \delta_m r_{m,t} + \delta_x r_{x,t} + \xi_{i,t} \quad i = 1, 2, \dots, n, \quad (1)$$

and  $\xi_{i,t} \sim N(0, \sigma^2)$

where  $r_{i,t}$  is returns on firm  $i$ 's stock at time  $t$ ;  $r_{m,t}$  is returns on market portfolio at time  $t$ ;  $r_{x,t}$  is changes in exchange rate at time  $t$ . Here exchange rate is expressed as local currency price of foreign currency;  $\delta_m$  is firm  $i$ 's exposure to market returns;  $\delta_x$  is firm  $i$ 's exchange rate exposure coefficient which measures the sensitivity of a firm's returns to the exchange rate movements; and  $\xi_{i,t}$  is the regression residual which is assumed to follow a normal distribution with zero mean and constant variance.

Many earlier studies rely heavily on the standard OLS or SUR method of estimation, with emphasis on the sensitivity of stock returns to changes in exchange rate. Among others, such studies include Jorion (1990), Bodnar and Gentry (1993), Chamberlain et al. (1997), Chow and Chen (1998), Dominguez (1998), He and Ng (1998), and Dominguez and Tesar (2001a, 2001b and 2006), respectively. Among many studies that focus on Japan, Bodnar and Gentry (1993)<sup>1</sup> obtain OLS estimates of monthly exchange rate exposure of industry portfolios<sup>2</sup>, and find that 5 out of 20 Japanese industries are significantly exposed to exchange rate changes. They find that an appreciation in the yen affects favourably on both non-traded goods sector producers and importers, and adversely on exporters and the value of their foreign operations. Dominguez (1998) classifies a sample of 275 Japanese firms into 18 portfolios distinguished by industry type, firm size and degree of internationalization. She finds that 7 out of 18 portfolios are significantly exposed to weekly exchange rate changes. At the firm level, He and Ng (1998) find that most of the 171 firm-returns are positively exposed to depreciation of the yen. They observe that significantly exposed firms are mostly concentrated in three sectors: electric machinery; precision instruments; and transport equipment. Contrary to the findings of He and Ng (1998), Chow and Chen (1998) find that Japanese firms are adversely affected by depreciation of the yen. One plausible explanation is that these firms may have anticipated the unavoidable appreciation of the yen and are actually able to respond to it efficiently.

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<sup>1</sup> Besides Japan, they focus on industrial sectors in the US and Canada as well.

<sup>2</sup> The industries are selected from the two-digit level of the Standard Industrial Classification (SIC).

The major problem of the augmented market approach is the questionable assumption of time-invariance in the variance of firm's return and in changes of exchange rate. In recent years, it has been common to use generalized autoregressive conditional heteroskedasticity (GARCH)-type models to accommodate the time-varying volatility in empirical studies of exchange rate changes. There are two main categories. The first group employs GARCH-type models to augment the mean equation with a time-varying variance structure in order to improve the precision of parameters. For instances, they include Patro et al. (2002) and Koutmos and Martin, (2003a). However, all such studies are confined to either one or two aspects of exchange rate exposure.

The second group assigns a more active role to the GARCH structure. For example, Kanas (2000), Apergis and Resitiz (2001) and Yang and Doong (2004) employ bivariate asymmetric GARCH models to analyze the mutual impact of volatilities between equity and exchange rate markets<sup>3</sup>. Koutmos and Martin (2003b) examine the first- and second-moment exchange rate exposure. However, most of these studies take the country as the unit of analysis. And the main defect of a country study is that exchange rate exposure could be averaged out when a highly aggregated index is used<sup>4</sup>. The reason is that various industries or sectors may be exposed negatively/positively to the exchange rate changes depending on whether they are import/export dominant. By the same token, the asymmetries associated with the exchange rate exposure of both first and second moments of stock returns are also likely to be averaged out when highly aggregated indexes are used. On the other hand, there are cases where estimation of overall market's exchange rate exposure may not largely help in hedging and investment decisions. For instance, a local investor who wants to invest in equities which bear low currency risk may find the exposure estimates of industrial sectors much useful, though the overall market's exposure does not appear to be so. As such, there is a need to focus our study on exchange rate exposure of Japanese industries at the sector level.

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<sup>3</sup> As Apergis and Rezitis (2001), Kanas (2000) and Yang and Ding (2004) are basically interested in estimating the possible spillovers between stock and foreign exchange markets, they do not explicitly use the term exchange rate exposure. The first two studies exclusively focus on volatility spillovers between two markets while the third one examines mean spillovers in addition to volatility spillovers.

<sup>4</sup> More realistically, to a lesser degree, this "averaged-out exposure" argument may also apply to sectoral analysis. However, we have been careful in selecting the optimal level of aggregation that might affect the results. See 'Data and Preliminary Analysis' in section 2 of this paper.

There are several reasons why we think this paper's emphasis on time-varying volatility at the sector level is relevant. First, as volatilities of exchange rate and stock returns are vital for currency hedging and investment decisions, exchange rate exposure of sectoral returns should not be confined to the exposure coefficient ( $\delta_x$ ) in the mean equation as specified in the augmented market model. Second, there are at least two other aspects of exchange rate exposure of stock returns which are worth investigating: (a) sensitivity of volatility of stock returns to the volatility in foreign exchange market; and (b) conditional correlation between stock returns and exchange rate changes. Hence, we intend to fill this gap by engaging a bivariate GJR-GARCH model to capture all three aspects of daily exchange rate exposure simultaneously in 14 Japanese industrial sectors.

We find evidence of all three aspects of exchange rate exposure of sectoral returns, thereby supporting our argument that the entire currency risk actually faced by a firm/sector is not fully captured by the exposure coefficient alone in the traditional augmented market model. Moreover, we find evidence to support the "averaged-out exposure" argument, in which exchange rate exposure of sectoral returns can be averaged out when highly aggregated indexes are employed at the market level. We also find support for extending such an argument to asymmetries associated with exchange rate exposure.

The rest of this paper is organized as follows. Section 2 briefly describes the datasets used in our study and reports the preliminary analysis of the returns series. Section 3 highlights the gist of the model used to capture the three aspects of exchange exposure of sectoral returns. Section 4 is divided into two parts. The first part reports estimation results and provides some discussions. The second part examines the dynamic properties of exchange rate exposure of returns and their conditional volatility by simulations. We also demonstrate that an indirect effect of the volatility of exchange rate exposure on returns could still be possible even if the sectoral returns are not directly exposed to the exchange rate changes in the mean equation. Some concluding remarks are given in Section 5.

## 2. Data and Preliminary Analysis

Our datasets comprise the daily industrial indexes of fourteen sectors in Japan. They are culled from Datastream, consisting of 2240 observations for each sector from 1 June 1992 to 29 December 2000<sup>5</sup>. We focus on the level 04 industrial classification under the FTSE actuaries system<sup>6</sup>. It comprises 39 industrial sectors. After excluding those obviously insignificant ones, we have selected fourteen sectors which are possibly exposed to exchange rate changes. They include: automobile and parts (A&P), chemicals (C), construction and building materials (C&BM), diversified industries (DI), electrical and electronic equipment (E&EE), engineering and machinery (E&M), household goods and textiles (HH&T), information technology and hardware (IT&H), oil and gas (O&G), personal care and household products (PC&H), pharmaceuticals and biotechnology (P&B), software and computer services (S&CS), steel and other metals (S&OM), and telecom (T), respectively. In addition, we assume that the market portfolio is reasonably proxied by Nikkei 225, an overall stock index in Japan.

Moreover, we extract from Datastream a daily trade-weighted index (base year 1990) compiled by the Bank of England (BOE) to measure the nominal exchange rate of the yen. These weights are designed to represent the relative importance of other countries as a competitor to Japan's manufacturing industries. The exchange rate is expressed as local currency price of foreign currency. An increase (decrease) in the index indicates depreciation (appreciation) of the yen. Following most of the previous studies, we use nominal exchange rates in this paper<sup>7</sup>.

The daily returns (as a percentage) of various industrial sectors ( $i$ ), market portfolio ( $m$ ) and nominal exchange rate ( $x$ ) on a continuously compounding basis are computed as follows:

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<sup>5</sup> Our initial attempt to extend the study to two more Asia-Pacific countries, namely Australia and Taiwan, was hindered by the limited availability of sectoral data.

<sup>6</sup> Sectoral indexes included in both level 02 that comprises only 4 sectors and level 03 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 05 which comprises more than 100 sectors.

<sup>7</sup> There are at least two reasons to justify the use of nominal rates. First, the use of real exchange rates implies that participants in financial markets instantaneously observe the inflation rates that are needed to obtain the real exchange rate. Second, it is well established that there exists a high correlation between the changes in nominal and real exchange rates (Bodnar and Gentry, 1993).

$$r_{v,t} = \ln\left(\frac{R_{v,t}}{R_{v,t-1}}\right) * 100 \quad v = i, x, m$$

where  $R_{v,t}$  and  $R_{v,t-1}$  are the closing values for the trading days  $t$  and  $t-1$ , respectively.

== Insert Table 1 here ==

During the 9-year 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. As can be observed from Table 1, the average daily change in exchange rates of the yen is about -0.01%, thereby indicating a very mild appreciation of the yen during the entire study period. Moreover, the distribution of daily returns of the yen is negatively skewed and highly leptokurtic. This is consistent with findings in the literature of exchange rates.

Table 1 also displays the summary statistics of returns from industrial sectors and the market portfolio represented by Nikkei 225. The highest two daily returns are in IT&H and S&CS, averaging 0.036% and 0.061%, respectively. The lowest two daily returns are in E&M and S&OM, with negative averages at 0.13% and 0.04%, respectively. The mean daily return of the market portfolio is at a loss of 0.013%, with a maximum gain at 7.66% and a loss at 7.23%, respectively. The standard deviations for returns from these industrial sectors range from 1.086% (P&B) to 2.063% (S&CS). Out of these 14 sectors, PC&H and P&B are the least volatile, while DI and S&CS are the most volatile. Moreover, returns of the market portfolio and those of 13 out of the 14 industrial sectors are positively skewed and highly leptokurtic.

We now turn to various test statistics for the preliminary returns series. As evidenced by the augmented Dickey-Fuller test, returns of all 14 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 fourteen sectors, thereby rejecting the null hypothesis that the daily returns in the industrial sectors are normally distributed. In addition, the Ljung-Box statistics evaluated at 20 lags provide support for linear dependency in every sector. Except for A&P and C, the runs tests for the remaining 13 sectors also provide evidence of some dependency. Moreover, the Ljung-Box statistics of squared returns evaluated at 20 lags indicate evidence of non-linear dependence. It may be due to autoregressive heteroskedasticity. In the next section, we shall investigate all three aspects of exchange rate exposure of sectoral returns in tandem.

### 3. The GJR-GARCH Model

The GARCH model pioneered by Bollerslev (1986) and its subsequent extension are well-documented in the literature on modeling conditional volatility in empirical economics and finance. One stylized fact is that asset returns are found to exhibit strong asymmetric conditional volatility, thereby indicating that negative return shocks induce greater future volatilities compared with positive shocks of the same magnitude. As such, many variants of GARCH-type models that are capable of capturing volatility asymmetry have been developed. A widely accepted variant of such models that allows for asymmetric effects is the GJR-GARCH model of Glosten et al. (1993). In this paper, we adopt a bivariate GJR-GARCH(1,1) model to capture the three aspects of exchange rate exposure of sectoral returns. The mean and variance structures are specified as follows:

Mean equation for sectoral returns:

$$r_{i,t} = a_0 + a_m r_{m,t} + a_{x-1} r_{x,t-1} + \sum_{k=1}^q a_{i-k} r_{i,t-k} + \varepsilon_{i,t}; \quad i = 1, 2, \dots, n \quad (2)$$

Mean equation for changes in exchange rate of the yen:

$$r_{x,t} = b_0 + \sum_{l=1}^s b_{x,t-l} r_{x,t-l} + \varepsilon_{x,t} \quad (3)$$

Variance equations:

$$\varepsilon_t = z_t H_t^{1/2} \quad \varepsilon_t | I_{t-1} = (\varepsilon_{i,t} \varepsilon_{x,t})' | I_{t-1} \sim N(0, H_t) \quad (4)$$

$$h_{i,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \gamma_i d_{i,t-1} \varepsilon_{i,t-1}^2 + \beta_i h_{i,t-1} + \alpha_{ix} \varepsilon_{x,t-1}^2 + \gamma_{ix} d_{x,t-1} \varepsilon_{x,t-1}^2 \quad (5)$$

$$h_{x,t} = \omega_x + \alpha_x \varepsilon_{x,t-1}^2 + \gamma_x d_{x,t-1} \varepsilon_{x,t-1}^2 + \beta_x h_{x,t-1} \quad (6)$$

$$h_{ix,t} = \rho_{ix} (h_{i,t} h_{x,t})^{1/2} \quad (7)$$

where  $r_{i,t}$  is the daily return of industrial sector  $i$  at time  $t$ ;  $r_{m,t}$  is the return of market portfolio at time  $t$ ;  $r_{x,t}$  is the change in exchange rates of the yen at time  $t$ . In addition,  $\varepsilon_t$  is a 2 x 1 vector of the daily shocks of  $\varepsilon_{i,t} \varepsilon_{x,t}$  at time  $t$  pair-wise with each sector  $i$ . And  $\varepsilon_t | I_{t-1}$  denotes 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 normal distribution with 0 mean and variance given by  $H_t$ , which is a 2 x 2 variance-covariance matrix. For each sector, the main-diagonal elements of  $H_t$  are the conditional variance of sectoral returns and changes in exchange rate of the yen captured by the GJR-GARCH (1,1) models in equations (5)-(6), respectively. Here,  $d_{u,t-1} = 1$  if  $\varepsilon_{u,t-1} < 0$  and zero otherwise, for  $u = i, x$ . The off-diagonal element of  $H_t$  is the conditional covariance of sectoral returns and changes in exchange rate of the yen. Finally  $z_t$  denote the standardized errors which are assumed to be independently and identically distributed with mean 0 and variance 1.

Some discussions on the model setup are in order. As regards the mean equation (2) 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<sup>8</sup>. As such, the exposure coefficient  $a_{x-1}$  measures the sensitivity of sectoral returns at time  $t$  to the exchange rate changes at time  $(t - 1)$ . Given that the exchange rate is expressed as local currency price of foreign currency, a positive

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<sup>8</sup> We are grateful to one referee for pointing out that the suggested bivariate GJR-GARCH model no longer captures the contemporaneous exchange rate changes in the mean equation. This is due to the time series structures in the reduced form. While the conventional augmented market model is able to capture the contemporaneous exchange rate changes in the mean equation, however, it does not capture the other aspects of exchange rate exposure of sectoral returns as specified in the variance equation discussed in this paper. Apparently, there is a trade off here.

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. We note in passing that based on the Ljung-Box statistics<sup>9</sup>, the optimal lag order for  $q$  ranges from 1 to 3 across sectors.

Turning to the mean equation in (3) for changes in exchange rate of the yen, we assume that it follows an autoregressive process of order  $s$ . However, sectoral returns are not included as explanatory variables in this equation. There are two main reasons. 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 exchange rate. Second, we have performed the Granger-causality tests for all sectors with changes in exchange rates and we find that none of the returns series Granger-causes exchange rate changes. Similarly, returns of the market portfolio are not included in the mean equation either. Although the “stock-oriented approach” to determining exchange rates provides some theoretical support for such an inclusion, we exclude the market returns because they do not Granger-cause exchange rate changes. Furthermore, as revealed by results of preliminary regressions, the corresponding coefficient of market returns in the mean equation is insignificant at the 5% level for all 14 sectors. And, based on the Ljung-Box statistics, we find that the optimal lag order of  $s$  is 1 across sectors.

The variance equation in (5) for returns of the  $i^{th}$  sector includes the GARCH (1, 1) terms ( $\alpha_i$  and  $\beta_i$ ) and the GJR term with coefficient  $\gamma_i$ . In order to measure the exchange rate exposure of the volatility of sectoral returns, a cross ARCH term is included and its impact on volatility of returns is captured by parameter  $\alpha_{ix}$ . In other words, a positive and significant estimate indicates that volatility of changes in exchange rates may increase the volatility of sectoral returns. Moreover, a cross GJR term is added to capture the possibly asymmetric volatility of exchange rate changes

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<sup>9</sup> 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.

by parameter  $\gamma_{ix}$ . A negative and significant coefficient implies that a depreciation shock of the yen induces even greater volatility in sectoral returns than an appreciation shock of the yen of the same magnitude.

Similarly, the variance equation in (6) for changes of exchange rate of the yen is assumed to follow a GARCH(1,1) process, together with an GJR term to capture the possibly asymmetric exchange rate volatility by parameter  $\gamma_x$ . The justification is that exchange rate changes are often negatively skewed. See the summary statistics reported in Table 1 of Section 2. As such, we will find some support for asymmetric volatility associated with exchange rate changes provided that the estimated values of  $\gamma_x$  are statistically significant.

The conditional covariance of sectoral returns and exchange rate changes equation in (7) is written as the product of time-invariant correlation coefficient ( $\rho_{ix}$ ) and square root of the conditional variance of returns and exchange rate changes. The constancy of  $\rho_{ix}$  is proposed by Bollerslev (1990) to ensure that the variance and covariance matrix is positive definite. We also relax such an assumption by using a time-varying correlation counterpart proposed by Tse and Tsui (2002). By doing so, we introduce a time-varying correlation matrix of sectoral returns  $i$  and exchange rate changes  $x$  at time  $t$ , which is assumed to be dependent on its term at time  $(t - 1)$  and the sample correlation matrix at time  $(t - 1)$  as indicated below:

$$\Gamma_{ix,t} = (1 - \theta_1 - \theta_2)\Gamma_{ix} + \theta_1\Gamma_{ix,t-1} + \theta_2\psi_{ix,t-1} \quad (8)$$

where  $\Gamma_{ix,t}$  is 2 x 2 time-varying correlation matrix at time  $t$ , which includes time-varying correlation coefficients between sectoral returns and exchange rate changes as off diagonal elements;  $\Gamma_{ix}$  is 2 x 2 matrix that includes the Bollerslev (1990) time-invariant component as off diagonal elements;  $\psi_{ix,t-1}$  is the sample correlation matrix of  $z$  at time  $t-1$ .

Assuming normality and ignoring the constant term, one can define the conditional log-likelihood of  $\varepsilon_t$  as follows:

$$\ell(\varphi)_t = -\frac{1}{2} \ln |H_t| - \frac{1}{2} \varepsilon_t' H_t^{-1} \varepsilon_t \quad (9)$$

$$= -\frac{1}{2} \ln |D_t \Gamma D_t| - \frac{1}{2} \varepsilon_t' (D_t \Gamma D_t)^{-1} \varepsilon_t \quad (10)$$

where  $\varphi$  is the vector of parameters to be estimated;  $\varepsilon_t$  is the 2 x 1 vector of residuals from equations (2) and (3) at time  $t$ ;  $D_t$  is a 2 x 2 diagonal matrix whose diagonal elements are  $h_{i,t}^{1/2}$  and  $h_{x,t}^{1/2}$ ;  $\Gamma$  is the 2 x 2 time-invariant correlation matrix whose diagonal elements are 1's and off-diagonal elements are represented by  $\rho_{ix}$ . The log-likelihood function of the sample is obtained as:  $L(\varphi) = \sum_{t=1}^T \ell(\varphi)_t$ , where  $T$  is the number of observations. All estimates of parameters  $\varphi$  in this paper are obtained by the method of maximum likelihood using programs coded in GAUSS.

#### 4. Results and Discussions

In this section, we will first report and discuss estimation results of the bivariate GJR-GARCH model. This includes all three aspects of exchange rate exposure of sectoral returns and diagnostic checks for adequacy of the proposed model. Then we move on to examine some dynamic properties of exchange rate exposure of sectoral returns and their conditional volatilities through simulation. The simulated impulse responses of nine sectors will be discussed accordingly. We also demonstrate by simulation that a possible indirect effect of the volatility of exchange rate exposure on sectoral returns could still be possible even if such returns are not directly exposed to changes of the exchange rate of the yen in the mean equation.

== Insert Tables 2 & 3 here ==

#### 4.1 Estimation Results

Tables 2-3 reports the maximum likelihood estimation of parameters of the bivariate GJR-GARCH model for returns of the 14 Japanese industrial sectors. Six sectors are significantly exposed to exchange rate changes of the yen (see row 1 of Tables 2 & 3). They include: A&P (automobile and parts), C&BM (construction and building materials), E&EE (electrical and electronic equipment), HH&T (household goods and textiles), IT&H (information technology and hardware), and O&G (oil and gas), respectively. The estimates of  $a_{x-1}$  (exposure coefficient) across these sectors range from -0.0403 ( $t$ -statistic: -2.4) in C&BM to 0.1759 ( $t$ -statistic: 6.45) in IT&H. And five of such estimates are greater than 0.1, indicating that returns in these sectors are relatively more sensitive to changes in exchange rate of the yen.

Regarding signs of the exposure coefficient, sectors like A&P, E&EE, HH&T and IT&H are expected to be positively related to exchange rate changes. This implies that returns on these sectors increase with depreciation of the yen. Our finding is consistent with the economic theory as these industrial sectors are mainly engaged in exporting goods or services. The negative relationship between O&G and exchange rate changes can be attributed to Japan's heavy import reliance in that sector. Although she does not have significant domestic resources of crude oil, natural gas and other energy, Japan is the world's third largest oil consumer and second largest energy importer (EIA, 2004). Our results are also consistent with the findings of Bodnar and Gentry (1993) and Dominguez (1998). They report that electrical machinery, precision instruments and industrial sectors are positively exposed to exchange rate changes while oil and coal and energy and utilities sectors show the opposite result<sup>10</sup>. However, we note that C&BM (construction and building materials) sector is negatively exposed. Unlike the O&G sector, it is difficult to craft a clear-cut explanation 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<sup>11</sup>. On the other hand, it is inappropriate to solely attribute the exchange rate

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<sup>10</sup> However, Bodnar and Gentry (1993), Dominguez (1998) and our study employ three different industry classification systems.

<sup>11</sup> For instance, the industrial sectors used in this study are due to the FTSE acturaries 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.

exposure of sectoral returns to the aggregate import/export trade statistics. Indeed, we have mentioned in Section 1 that exposure of sectoral indexes is determined by other industry characteristics besides imports and exports<sup>12</sup>.

In addition, there is support for asymmetric volatility in the GJR-GARCH model, as evidenced by the estimated coefficient of own GJR term ( $\gamma_i$ ) for four sectors (see row 6 in Tables 2 & 3). They include: C (chemicals), C&B (constructions and building), E&M (engineering and machinery), and P&B (pharmaceuticals and biotechnology). All four estimates are significant at the 5% level and bear the expected positive sign, suggesting that the leverage effect is at work when there is a reduction in sectoral returns. We also find evidence of asymmetric volatility associated with exchange rate changes. Indeed, all the estimated values of  $\gamma_x$  are significant at the 1% level in the variance equation. See row 9 in Tables 2 & 3.

Moreover, there are evidence of cross-volatility spillover ( $\alpha_{ix}$ ) between exchange rate changes and sectoral returns in six industrial sectors. They include: A&P (automobile and parts), DI (diversified industries), E&EE (electrical and electronics equipment), E&M (engineering and machinery), HH&T (household goods and textiles) and S&CS (software and computer services), respectively. See row 7 in Tables 2 & 3. The estimates of  $\alpha_{ix}$  range from 0.0164 ( $t$ -statistic: 2.46) in HH&T to 0.1360 ( $t$ -statistic: 4.17) in DI. In addition, the sign of  $\alpha_{ix}$  is positive in all significant cases, suggesting that an increase in the volatility in foreign exchange market may spillover as an increase in the volatility of sectoral returns.

Furthermore, we find evidence of asymmetric cross-volatility spillover between exchange rate exposure and sectoral returns in six sectors (see row 8 in Tables 2 & 3). They are: DI (diversified industries), E&EE (electrical and electronics equipment), E&M (engineering and machinery), HH&T (household goods and textiles), O&G (oil and gas), and S&CS (software and computer services). Except for

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<sup>12</sup> Apparently, 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.

O&G, signs of the estimates of the cross GJR term ( $\gamma_{ix}$ ) are all negative in all significant cases, ranging from -0.1708 ( $t$ -statistic: -4.39) in DI to -0.0195 ( $t$ -statistic: -2.18) in E&EE. This implies that the returns in these sectors are not only highly sensitive to the volatility in foreign exchange market but also highly vulnerable to depreciation of the yen. Given that the exchange rate is expressed as local currency price of foreign currency and that an increase in the exchange rate indicates depreciation, depreciation shocks in the exchange rate of the yen tend to spark off higher fluctuations in the sectoral returns than appreciation shocks. One explanation is that the depreciation of local currency is always regarded as ‘bad’ news, regardless of the magnitude, thereby signaling the imminent arrival of larger and persistent depreciations. This may result in program trading which has the potential of decreasing of stock prices through increased selling pressures (see Maghrebi et al., 2004). However, O&G sector emerges as a somewhat surprising case as it not only displays a positive cross GJR term, which is at odds with the previous argument, but also possesses a statistically insignificant cross ARCH term. This abnormality may be partly due to Japan’s unusually higher import dependence for energy and partly due to the other industry- and firm-specific factors like hedging practices.

We next discuss estimates of the constant correlation coefficient ( $\rho_{ix}$ ) in the bivariate GJR-GARCH model. As can be observed from row 10 of Tables 2 & 3, 8 out of 14 sectors show statistically significant contemporaneous relationship of the volatility of sectoral returns with that of exchange rate changes at the 5% level. These 8 sectors include: A&P (automobile and parts), C&BM (construction and building materials), E&EE (electrical and electronic equipment), HH&T (household goods and textiles), IT&H (information technology and hardware), O&G (oil and gas), S&OM (steel and other metals), and T (telecom), respectively. Six out of these 8 sectors are also significantly exposed to exchange rate changes as reflected by estimates of  $\alpha_{x-1}$  (exposure coefficient). We note in passing that our estimates of sectoral correlation coefficients are relatively smaller in magnitude as compared to those based on national stock index returns. For instance, Kanas (2000), reports estimates of constant correlation coefficient ranging from 0.25 to 0.61 in a similar study that employs national stock indexes of US, Japan Canada, France, UK, and Germany.

In addition, as can be observed from row 10 of Tables 2 & 3, returns on 4 sectors (A&P, E&EE, HH&T and IT&H) are positively correlated with exchange rate changes. Our findings are also consistent with the sign of the estimated exposure coefficient ( $a_{x-1}$ ). As expected, these 4 sectors are basically export-dominant sectors. In contrast, returns on the remaining 4 sectors (C&BM, O&G, S&OM and T), display a negative correlation with exchange rate changes. Again, 2 of these 4 sectors display negative exposure coefficients in the mean equation. However, the negative correlation between exchange rate changes and returns on S&OM and on T sectors is a bit puzzling, as these two sectors mainly consist of exporting firms instead of importing firms. A possible explanation due to Chow and Chen (1998) is related to Japan's lack of natural resources and heavy import dependence for production for local usage and exports. Besides the constant correlation between exchange rate changes and sectoral returns, estimation results for the time-varying correlation are worth mentioning<sup>13</sup>. The estimated coefficient of its own lag ( $\theta_1$ ) is significant at the 5% level in 9 out of 14 sectors. But the estimated sample correlation coefficient ( $\theta_2$ ) is significant only in two sectors, and A&P (automobile and parts) is the only sector that enjoys significance in both parameters. As such, we do not report the estimation in detail. The results are available from the authors upon request.

A comparison of our results with those of Kanas (2000) and Yang and Doong (2004) are in order. This is to enhance further understanding of the argument of “averaged-out exposure” as discussed in Section 1. First, Yang and Doong (2004) do not find strong evidence of the exchange rate exposure of the national stock indexes in question. More specifically, they report that only 1 out of 6 cases that shows the exposure of market returns. Second, both Kanas (2000) and Yang and Doong (2004) do not cite evidence of the exposure of the volatility of market returns. We conjecture that this may be partly due to the use of highly aggregated stock indexes at the country level. As can be observed from Table 4, exchange rate exposures of both market returns and its volatility are not statistically significant even at the 10% level. This implies that both the exchange rate exposure itself and asymmetries associated with exposure may also be averaged out when highly aggregated indexes are used.

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<sup>13</sup> Due to convergence problems, we have omitted the cross ARCH and GJR terms in the variance equation (6) when we tested for the suitability of the time-varying correlation counterpart of the model.

Our finding not only supports the “averaged-out exposure” argument, but also corroborates the use of ‘sector’ as the unit of analysis.

== Insert Tables 4 and 5 here ==

Table 5 summarizes findings of various aspects of exchange rate exposure that are significant at the 5% level for each sector. They include: exposure in returns ( $a_{x-1}$ ), exposure in volatility ( $\alpha_{ix}$ ), asymmetric exposure in volatility ( $\gamma_{ix}$ ), and correlation between exchange rate changes and sectoral returns ( $\rho_{ix}$ ), respectively. Firstly, A&P (auto and parts), E&EE (electronics and electrical equipment) and HH&T (household goods and textiles) are the only 3 out of 14 sectors significantly exposed to all three aspects of exchange rate exposure represented by  $a_{x-1}$ ,  $\alpha_{ix}$  and  $\rho_{ix}$ . Secondly, C&BM, (construction and building materials), IT&H (information technology and hardware) and O&G (oil and gas) are significantly exposed in terms of  $a_{x-1}$  and  $\rho_{ix}$ , but not in terms of  $\alpha_{ix}$ . Thirdly, the sectors PC&H (personal care and household products), P&B (pharmaceuticals and biotechnology) and C (chemicals) are not exposed to exchange rate changes through any of these aspects. We attempt to offer three explanations in line with the fact that they are traded goods sectors and are likely to be dominated by firms with a high degree of internationalization. First, exchange rate exposure may be simply averaged out by the existence of both importing and exporting firms in the same industry. Second, the exporters in these sectors may be highly import dependent for inputs and therefore gains and losses of depreciation/appreciation may be averaged out. Particularly, it is highly possible as our study period includes both appreciation and depreciation phases of the yen. Third, firms in these industries may be heavily engaged in hedging activities in order to mitigate the currency risk.

Fourthly, DI (diversified industries), E&M (engineering and machinery) and S&CS (software and computer services) are observed to be having an insignificant exposure coefficient  $a_{x-1}$  at the 5% level. According to the conventional measure of exchange rate exposure based on the augmented market model, these 3 sectors are not exposed to currency risk at all. However, as can be observed from columns 3 and 4

of Table 5, conditional volatility of these three sectoral returns are significantly exposed to the volatility of exchange rate changes, thereby suggesting that the currency risk faced by a firm/sector is not fully captured by the conventional “exchange rate exposure coefficient” alone. The shortcomings in the conventional measure of exchange rate exposure are further corroborated by two more sectors. They include S&OM (steel and other metals) and T (telecom) with insignificant  $a_{x-1}$ , but significant correlation between volatility of returns and exchange rate changes.

== Insert Table 6 here ==

Table 6 shows the diagnostics including the summary statistics of the standardized residuals. Except for S&OM, kurtosis in all the other sectors has decreased<sup>14</sup>. Note that the Ljung-Box statistics for standardized residuals ( $Q$ ) and for squared standardized residuals ( $Q^2$ ) at 20 lags are significantly low as compared to those of the return series in Table 1. In addition, the runs test statistics for the residuals are insignificant for 12 out of 14 sectors. This implies that the proposed bivariate GJR-GARCH model is adequate<sup>15</sup> for capturing the three aspects of exchange rate exposure of sectoral returns.

## 4.2 Simulation Results

In order to better understand the dynamic properties of the exchange rate exposure of sectoral returns and their conditional volatilities, we simulate impulse responses to a unit shock in exchange rate changes through nine selected sectors using estimates of the bivariate GIR-GARCH model. The remaining five sectors are not picked because neither their returns nor conditional volatilities are exposed to exchange rate changes. The selected sectors can be further divided into three groups. Group A comprises sectors where only returns are exposed to foreign exchange rates. They include C&BM (construction and building materials), IT&H (information technology and hardware) and O&G (oil and gas). Group B consists of sectors whose

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<sup>14</sup> This result associated with the standardized residuals in the ‘steel and other metals’ sector is mainly due to a remarkable outlier which has not been filtered through the process. Kurtosis and Jarque-Bera statistic without that outlier are 4.77 and 325.66 respectively.

<sup>15</sup> Surely other asymmetric GARCH models may also be adequate. But the focus of this paper is not on choosing a most suitable asymmetric GARCH model for the exchange rate exposure.

returns and volatility are exposed to exchange rate changes. They include A&P (automobile and parts), E&EE (electronics and electrical equipment) and HH&T (household goods and textiles). In the sectors classified under group C, only the conditional volatility of returns is exposed to that of exchange rate changes. The sectors in this group are: D&I (diversified industries), E&M (engineering and machinery) and S&CS (software and computer services), respectively.

== Insert Figures 1, 2 and 3 here ==

Columns 1-3 of Figures 1-3 display the corresponding impulse responses of each group of the selected industrial sectors to an exchange rate shock respectively, along with their 95 percent confidence bands indicated with dotted lines. For each figure, the first column indicates the responses of stock returns. The middle column indicates the responses of the volatility of stock returns. And the third column shows the responses of volatility of exchange rate changes.

As can be observed in Figure 1, although the volatility of returns of sectors in group A is not exposed to that of the exchange rate changes, their returns are exposed to such a shock. In all three sectors, the response of returns to the shock comes to its peak on the second day, dies down quickly and then becomes negligible within 5 days since the shock starts. Nevertheless, the short-lived impact of exchange rate shock is relatively larger in IT&H and O&G sectors. For instance, on the second day, the lower confidence band in the IT&H sector and the upper confidence band in the O&G sector lie above 0.1 and below -0.1, respectively.

Figure 2 shows the impulse responses for sectors in group B where both returns and conditional variances are exposed to the exchange rates. The pattern of the impulse responses of returns to an exchange rate shock is very similar to those observed in group A. As can be expected, the impact on volatility is more persistent than the impact on returns. The lower confidence band of the response of volatility does not become zero even after 20 days. However, the impact of an exchange rate shock on the volatility of returns is relatively smaller. Even the upper confidence band does not exceed 0.05 in E&EE and HH&T sectors. Moreover, the impact on volatility

of returns is smaller than the impact on the volatility of exchange rate changes for all three sectors.

The pattern of impulse responses of the sectors in group C is shown in Figure 3. It can be observed that only the conditional variances are exposed while the returns are not. Again, the impact of an exchange rate shock on the conditional variance is relatively more persistent. The effect of the exchange rate shock on the volatility of returns in DI and S&CS sectors are even greater than the impact on its own volatility.

== Insert Figure 4 here ==

== Insert Figure 5 here ==

Figure 4, which depicts the percentage changes in the relevant exchange rate during the sample period, exemplifies that exchange rate shocks of this nature and size are not uncommon. Overall, we observe that the patterns indicated by simulated impulse responses corroborate the findings reported in Sub-section 4.1. Particularly, sectors in group C support the main argument of this paper that exposure coefficient alone does not adequately capture the entire currency risk faced by firms. To further elaborate on this issue, we perform a simple simulation experiment using the DI sector from group C to demonstrate a possible indirect effect of the volatility of exchange rate exposure on returns. We first add a GARCH in the mean (GARCH-M) term in equation (2) to measure the sensitivity of the returns to its own volatility. The estimate of this new parameter is 0.1315 and is statistically significant at 10% with a  $t$ -statistic value of 1.85. We then simulate the returns by initiating a unit shock in exchange rate changes for the DI sector with the added GARCH-M term in the mean equation. Results are shown in Figure 5. As can be observed from the left panel, a somewhat persistent indirect impact could still affect the returns via the GARCH-M term, even if the returns are not directly exposed to the exchange rate changes. More importantly, there would be no such impact if the conditional volatility of the returns is not exposed to exchange rate volatility or the returns are not sensitive to its own volatility.

## 5. Concluding Remarks

We have employed a bivariate GJR-GARCH model to capture the exchange rate exposure of fourteen Japanese industrial sectors, with emphasis on three aspects of exchange rate exposure: sensitivity of sectoral returns to changes in exchange rate of the yen; sensitivity of the conditional volatility of sectoral returns to that of changes in the exchange rate of the yen and its possibly asymmetric effect; and the correlation between sectoral returns and exchange rate changes. In general, we find strong evidence of exchange rate exposure in all three aspects. This implies that the entire currency risk actually faced by firms is not fully captured by the traditional “exchange rate exposure coefficient” alone.

We find that returns on sectors A&P (automobile and parts), E&EE (electrical and electronic equipment), HH&T (household goods and textiles) and IT&H (information technology and hardware) show positive exposure to changes in exchange rate of the yen. And returns in sectors O&G (oil and gas) and C&BM (construction and building materials) are negatively exposed to exchange rate changes. Our results are consistent with the previous studies of Japanese industries at the sector level.

In addition, volatility of returns in each of these six sectors is also significantly correlated with that of the exchange rate changes, and the sign of correlation coefficient is largely consistent with that of the exposure coefficient. Moreover, conditional volatility of returns in six sectors including A&P (automobile and parts), DI (diversified industries), E&EE (electrical and electronic equipment), E&M (engineering and machinery), HH&T (household goods and textiles) and S&CS (software and computer services) are positively exposed to that of exchange rate changes, suggesting that volatility in these sectors increases with an increase in volatility of exchange rate changes.

Furthermore, we find evidence of asymmetric exposure of the volatility of returns in six sectors (DI, E&EE, E&M, HH&T, O&G and S&CS). In five sectors, volatility of sectoral returns caused by a depreciation of the yen is greater than that

caused by an appreciation of the yen of the same magnitude. On the contrary, returns in O&G sector are more vulnerable to appreciation of the yen<sup>16</sup>.

The simulation exercise reveals some interesting patterns of the dynamics of exchange rate exposure of sectoral returns. First, the impact of an exchange rate shock on returns, though large in magnitude, may die down relatively quickly. Second, even if the returns are not directly exposed to the exchange rate changes, as long as they are sensitive to its own volatility, there could be a persistent indirect impact via the exposure of conditional volatility of the returns to the volatility in foreign exchange markets. Finally, if the volatility of sectoral returns is significantly exposed to the volatility of changes in exchange rate with sufficiently large magnitude, the impact of an exchange rate shock on the conditional volatility of the returns may be even higher than the impact on its own volatility.

We also check the empirical validity of the argument that exchange rate exposure of stock returns is averaged out when highly aggregated stock indexes are used. Our findings not only support the “averaged-out exposure” argument, but also provide new evidence that asymmetries associated with exchange rate exposure are also likely to be averaged out with highly aggregated indexes.

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<sup>16</sup> No comparisons can be made in the case of findings related to correlations and exposure of the second moment as there are no prior studies of these aspects of Japan at the sector level.

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**Table 1****Preliminary statistics of sectoral returns, market returns and the exchange rate changes**

Sector	A&P	C	C&BM	DI	E&E	E&M	HH&T	IT&H	O&G	PC&H	P&B	S&CS	S&OM	T	Nikkei 225	Exchange Rate
Mean	0.0232	-0.0035	-0.0333	0.0176	0.0197	-0.1301	0.0096	0.0359	-0.0323	0.0213	0.0289	0.0614	-0.0367	0.0284	-0.0128	-0.0109
Maximum	9.3574	8.3060	9.5442	12.2568	7.0290	6.6456	6.2798	9.4960	11.0045	5.7487	9.2439	14.5879	10.4532	11.9031	7.6605	3.4259
Minimum	-9.3680	-6.4607	-7.4895	-7.1448	-6.3572	-7.4734	-8.1787	-7.7137	-10.4589	-5.8682	-4.4810	-10.8411	-7.2041	-11.5578	-7.2340	-5.7790
S D	1.3832	1.3298	1.2744	1.7504	1.2285	1.2441	1.3696	1.5712	1.6440	1.1692	1.0863	2.0631	1.5686	2.0183	1.3953	0.6828
Skewness	0.0643	0.2045	0.6663	0.4379	0.0150	0.0424	-0.0627	0.0887	0.1817	0.1113	0.3903	0.0412	0.5998	0.2545	0.1421	-0.6916
Kurtosis	6.9657	6.8230	8.6346	6.5645	5.9163	6.2023	6.7550	5.9194	6.8827	5.3942	7.1528	7.5041	7.2939	7.7830	5.8218	8.4413
Jarque-Bera stat	1469.39	1379.69	3128.97	1257.48	793.86	957.79	1317.51	798.41	1419.36	539.63	1666.44	1894.11	1855.10	2159.38	750.69	2942.02
Q (20)	46.76	26.16	50.40	31.68	69.37	36.96	53.00	111.92	28.44	23.99	23.94	277.01	62.82	64.48	22.48	28.62
Q <sup>2</sup> (20)	774.19	587.11	495.79	293.29	358.87	412.70	900.08	623.27	595.27	280.67	349.45	2010.50	463.97	397.68	402.39	366.81
Runs Test	0.15	-1.39	4.02	2.14	-3.24	-3.13	-3.99	-5.53	2.12	-2.00	2.12	-7.44	-3.29	-3.62	2.76	-1.53
ADF stat (4)	-47.87	-44.05	-41.90	-49.61	-41.14	-42.72	-42.28	-39.27	-49.19	-46.06	-47.26	-34.91	-41.84	-42.63	-49.41	-44.80

Notes: Q (20) and Q<sup>2</sup> (20) are Ljung-Box statistics of returns and squared returns respectively for 20 lags. They follow a  $\chi^2$  distribution and the critical value at the 5% level of significance with 20 degrees of freedom is 31.41.

**Table 2**  
**Exchange rate exposure of sectoral returns and volatilities in Japan: maximum likelihood estimates**

Parameter	A&P	C	C&BM	DI	E&EE	E&M	HH&T
1. $a_{x,t-1}$	0.1746*** (7.13)	-0.0248 (-1.47)	-0.0403** (-2.40)	-0.0112 (-0.38)	0.1416*** (7.87)	0.0261 (1.39)	0.1262*** (6.91)
2. $b_{x-1}$	0.0602** (2.34)	0.0579** (2.56)	0.0546** (2.44)	0.0601*** (2.58)	0.0612*** (2.66)	0.0587** (2.48)	0.0602*** (2.64)
3. $\omega_i$	0.0072*** (2.70)	0.0016 (1.54)	0.0044** (2.57)	0.0112 (1.18)	0.0056** (2.43)	0.0022** (1.99)	0.0013 (1.49)
4. $\beta_i$	0.8638*** (47.35)	0.9155*** (54.13)	0.8498*** (49.59)	0.9247*** (89.23)	0.8834*** (43.94)	0.8994*** (55.26)	0.9217*** (97.97)
5. $\alpha_i$	0.0984*** (5.62)	0.0592*** (3.87)	0.1280*** (7.34)	0.0503*** (4.56)	0.1013*** (5.15)	0.0583*** (4.32)	0.0818*** (6.66)
6. $\gamma_i$	0.0309 (1.62)	0.0439*** (2.92)	0.0470** (2.12)	0.0271* (1.84)	-0.0037 (-0.20)	0.0553*** (2.92)	-0.0157 (-1.09)
7. $\alpha_{ix}$	0.0498** (2.50)	0.0047 (1.01)	0.0162* (1.80)	0.1360*** (4.17)	0.0184** (2.43)	0.0200*** (2.89)	0.0164** (2.46)
8. $\gamma_{ix}$	-0.0324 (-1.43)	-0.0026 (-0.47)	-0.0181* (-1.75)	-0.1708*** (-4.39)	-0.0195** (-2.18)	-0.0209*** (-2.81)	-0.0197** (-2.46)
9. $\gamma_x$	0.0506*** (2.76)	0.0503*** (3.11)	0.0498*** (3.06)	0.0503*** (2.96)	0.0482*** (2.93)	0.0503*** (3.14)	0.0507*** (3.07)
10. $\rho_{ix}$	0.0613*** (2.93)	-0.0366* (-1.69)	-0.0448** (-2.04)	-0.0180 (-0.90)	0.0907*** (4.34)	0.0142 (0.75)	0.0411** (2.00)

Notes: \*\*\* \*\* and \* indicate 1%, 5% and 10% levels of significance respectively; The number mentioned within parentheses and underneath each parameter estimate is its  $t$ -statistic; To save space, we report only the estimates of  $a_{x-1}$  in Equation 2,  $b_{x-1}$  in Equation 3, all parameters in Equation 5,  $\gamma_x$  in Equation 6 and the constant correlation ( $\rho_{ix}$ ) in Equation 7. The other estimates are omitted as those are not important in the discussion of empirical findings. However, they are available on request.

**Table 3**  
**Exchange rate exposure of sectoral returns and volatilities in Japan: maximum likelihood estimates**

Parameter	IT&H	O&G	PC&H	P&B	S&CS	S&OM	T
1. $a_{x-1}$	0.1759*** (6.45)	-0.1545*** (-5.94)	0.0378 (1.19)	-0.0235 (-1.21)	-0.0169 (-0.32)	0.0319 (1.12)	-0.0391 (-0.77)
2. $b_{x-1}$	0.0606*** (2.59)	0.0548** (2.28)	0.0587** (2.48)	0.0588** (2.46)	0.0592** (2.47)	0.0585** (2.46)	0.0575** (2.48)
3. $\omega_i$	0.0089** (2.09)	0.0038* (1.70)	0.0077 (1.21)	0.0036** (2.45)	0.0300** (2.54)	0.0133*** (2.64)	0.0313** (2.56)
4. $\beta_i$	0.9076*** (42.89)	0.8796*** (52.13)	0.9520*** (48.96)	0.9194*** (69.50)	0.8539*** (41.08)	0.8567*** (38.01)	0.9242*** (61.53)
5. $\alpha_i$	0.0692*** (4.43)	0.0977*** (4.82)	0.0342** (2.39)	0.0603*** (4.41)	0.1258** * (6.24)	0.1183*** (5.23)	0.0528*** (5.16)
6. $\gamma_i$	0.0251 (1.38)	0.0326 (1.27)	0.0038 (0.39)	0.0252** (2.00)	0.0091 (0.35)	0.0168 (0.79)	0.0277* (1.89)
7. $\alpha_{ix}$	0.0223 (0.91)	-0.0004 (-0.03)	0.0043 (0.28)	0.0090 (1.44)	0.1142*** (2.72)	0.0188 (0.89)	0.0343 (0.97)
8. $\gamma_{ix}$	-0.0207 (-0.66)	0.0497*** (3.62)	0.0079 (0.29)	-0.0071 (-0.86)	-0.1048** (-2.11)	0.0266 (0.97)	-0.0556 (-1.12)
9. $\gamma_x$	0.0483*** (3.07)	0.0486*** (2.94)	0.0501*** (2.91)	0.0504*** (3.15)	0.0503*** (3.03)	0.0498*** (3.03)	0.0501*** (3.08)
10. $\rho_{ix}$	0.0547*** (2.59)	-0.0747*** (-3.47)	-0.0091 (-0.36)	-0.0195 (-0.86)	0.0092 (0.38)	-0.0476** (-2.30)	-0.0547** (-2.52)

Notes: \*\*\* \*\* and \* indicate 1%, 5% and 10% levels of significance respectively; The number mentioned within parentheses and underneath each parameter estimate is its  $t$ -statistic; To save space, we report only the estimates of  $a_{x-1}$  in Equation 2,  $b_{x-1}$  in Equation 3, all parameters in Equation 5,  $\gamma_x$  in Equation 6 and the constant correlation ( $\rho_{ix}$ ) in Equation 7. The other estimates are omitted as those are not important in the discussion of empirical findings. However, they are available on request.

**Table 4**  
**Exchange rate exposure of market returns in Japan**

Component	Parameter	Estimate
Exposure: returns	$a_{x-1}$	0.0523 (0.93)
Exposure: variance	$\alpha_{mx}$	0.0389 (1.09)
Asymmetric variance exposure	$\gamma_{mx}$	0.0105 (0.18)
Correlation	$\rho_{mx}$	-0.0042 (-0.21)

Notes: The model is specified as follows:

$$r_{m,t} = a_0 + a_{x-1}r_{x,t-1} + a_{m-1}r_{m,t-1} + \varepsilon_{m,t}$$

$$r_{x,t} = b_0 + b_{x-1}r_{x,t-1} + \varepsilon_{x,t}$$

$$h_{m,t} = \omega_m + \alpha_m \varepsilon_{m,t-1}^2 + \gamma_m d_{m,t-1} \varepsilon_{m,t-1}^2 + \beta_m h_{i,t-1} + \alpha_{mx} \varepsilon_{x,t-1}^2 + \gamma_{mx} d_{x,t-1} \varepsilon_{x,t-1}^2$$

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

$$h_{mx,t} = \rho_{mx} (h_{m,t} h_{x,t})^{1/2}$$

Numbers within parentheses are t values of the relevant parameter estimates.

**Table 5**  
**Exchange rate exposure of sectoral returns and volatilities in Japan: a summary**

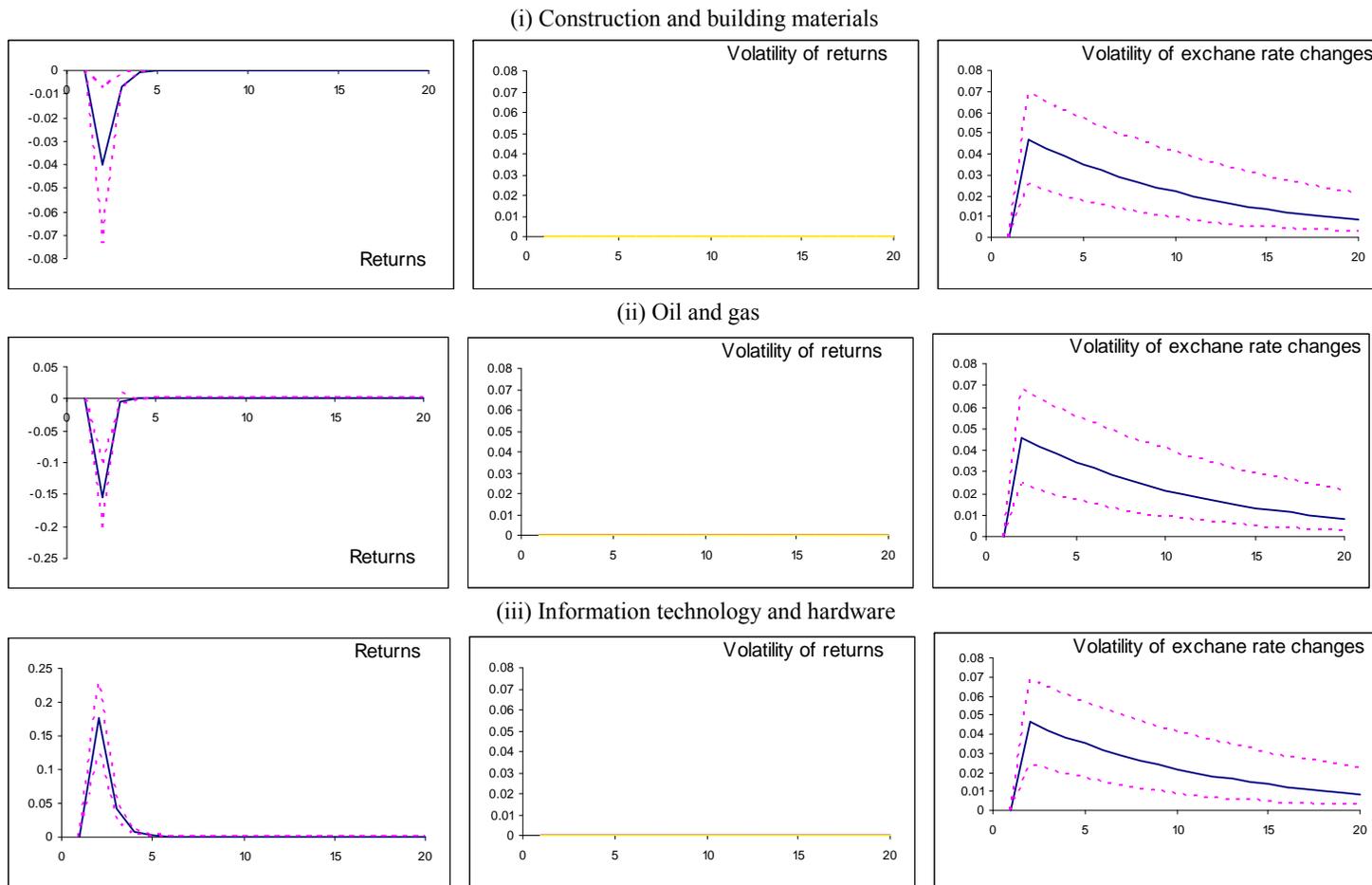
Sector	Exposure in returns ( $a_{x-1}$ )	Correlation ( $\rho_{ix}$ )	Exposure in volatility ( $\alpha_{ix}$ )	Asymmetric exposure in volatility ( $\gamma_{ix}$ )
A&P	√	√	√	–
C	–	–	–	–
C&BM	√	√	–	–
DI	–	–	√	√
E&EE.	√	√	√	√
E&M	–	–	√	√
HH&T	√	√	√	√
IT&H	√	√	–	–
Oil&G	√	√	–	√
PC& H	–	–	–	–
P&B	–	–	–	–
S&CS	–	–	√	√
S&OM	–	√	–	–
T	–	√	–	–

Notes: √ indicates that the relevant coefficient is significant at least at the 5% level significance.  
The relevant coefficients are  $a_{x-1}$ ,  $\rho_{ix}$ ,  $\alpha_{ix}$  and  $\gamma_{ix}$  in equations (2), (7) and (5) respectively.

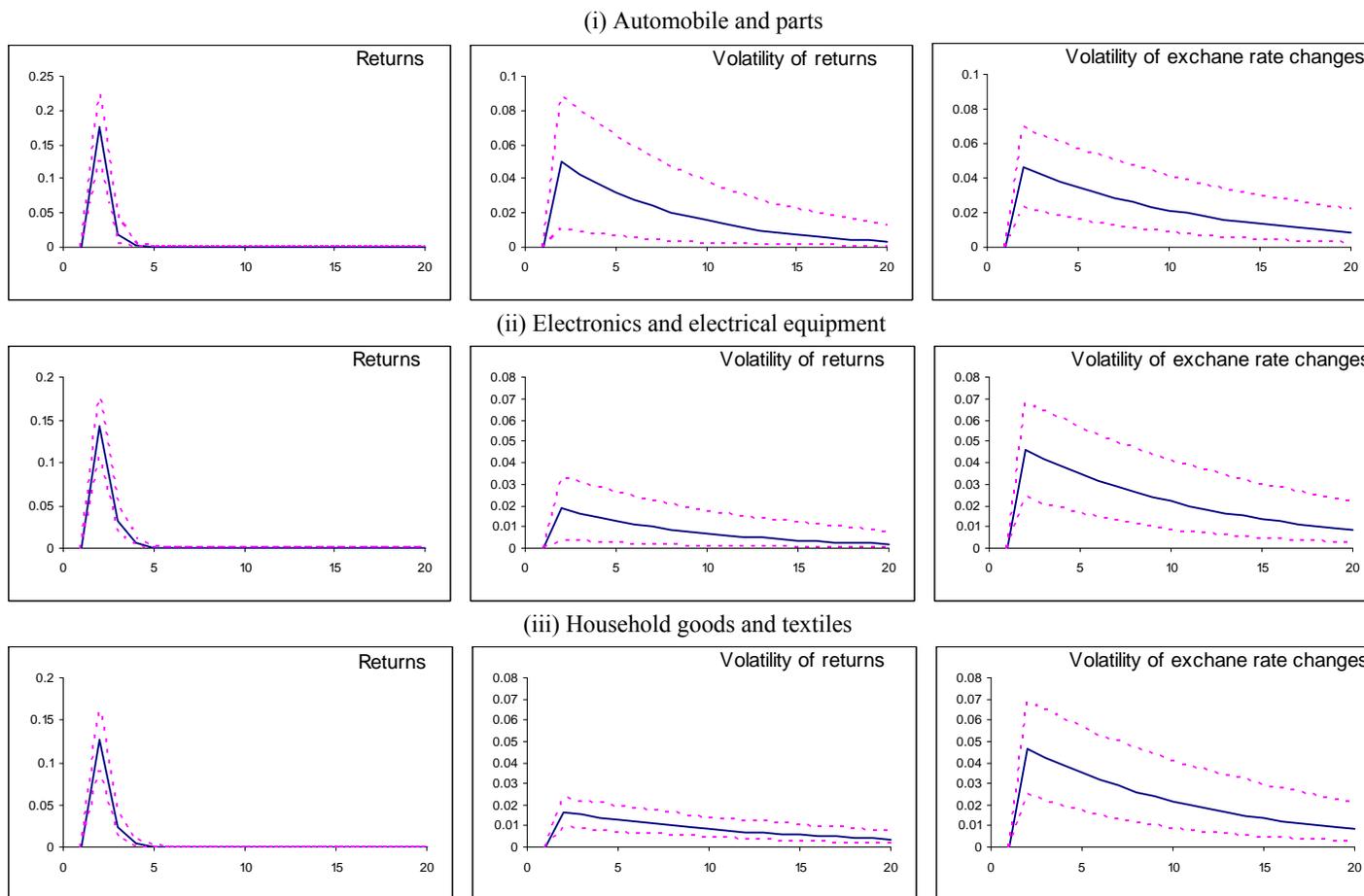
**Table 6****Diagnostics on standardized residuals**

Sector	A&P	C	C&M	DI	E&E	E&M	HH&T	IT&H	O&G	PC&H	P&B	S&CS	S&OM	T
Mean	0.0052	0.0160	0.0062	0.0106	0.0083	0.0093	0.0103	0.0084	0.0071	0.0042	0.0180	0.0085	0.0055	0.0079
Maximum	5.0581	3.9643	6.5205	6.0296	5.5131	5.0286	4.2519	4.4391	6.2825	4.7450	6.3451	7.1298	10.005	6.6381
Minimum	-4.4557	-4.2065	-4.5052	-4.2368	-4.6116	-5.5478	-4.1614	-5.1143	-6.8639	-4.0851	-4.6062	-4.7162	-4.0780	-4.7072
SD	0.9994	0.9993	0.9994	1.0014	0.9996	0.9994	0.9987	0.9988	0.9991	0.9991	0.9998	0.9986	0.9990	0.9994
Skewness	0.2752	0.1020	0.5636	0.1816	0.0539	0.1196	0.0741	0.1156	0.1167	0.2448	0.3666	0.3118	0.7072	0.4005
Kurtosis	5.2188	3.9049	5.7319	5.1213	5.0121	4.4031	4.3032	4.3153	5.6756	4.5331	5.3656	5.0357	8.8344	6.4862
Jarque-Bera stat	487.34	80.24	814.42	431.92	378.61	188.92	160.40	166.30	672.66	241.54	571.96	422.67	3360.81	1193.14
Q (20)	21.71	14.39	29.94	11.71	24.68	32.84	29.41	37.63	16.34	14.96	17.93	29.36	28.30	20.26
Q <sup>2</sup> (20)	22.46	36.92	35.92	28.64	20.15	22.49	26.47	22.28	14.50	40.40	15.36	18.99	9.26	25.46
Runs Test	1.24	0.34	0.52	-0.20	-0.33	2.62	1.21	-0.14	-0.45	-1.34	-0.13	1.53	2.92	3.76

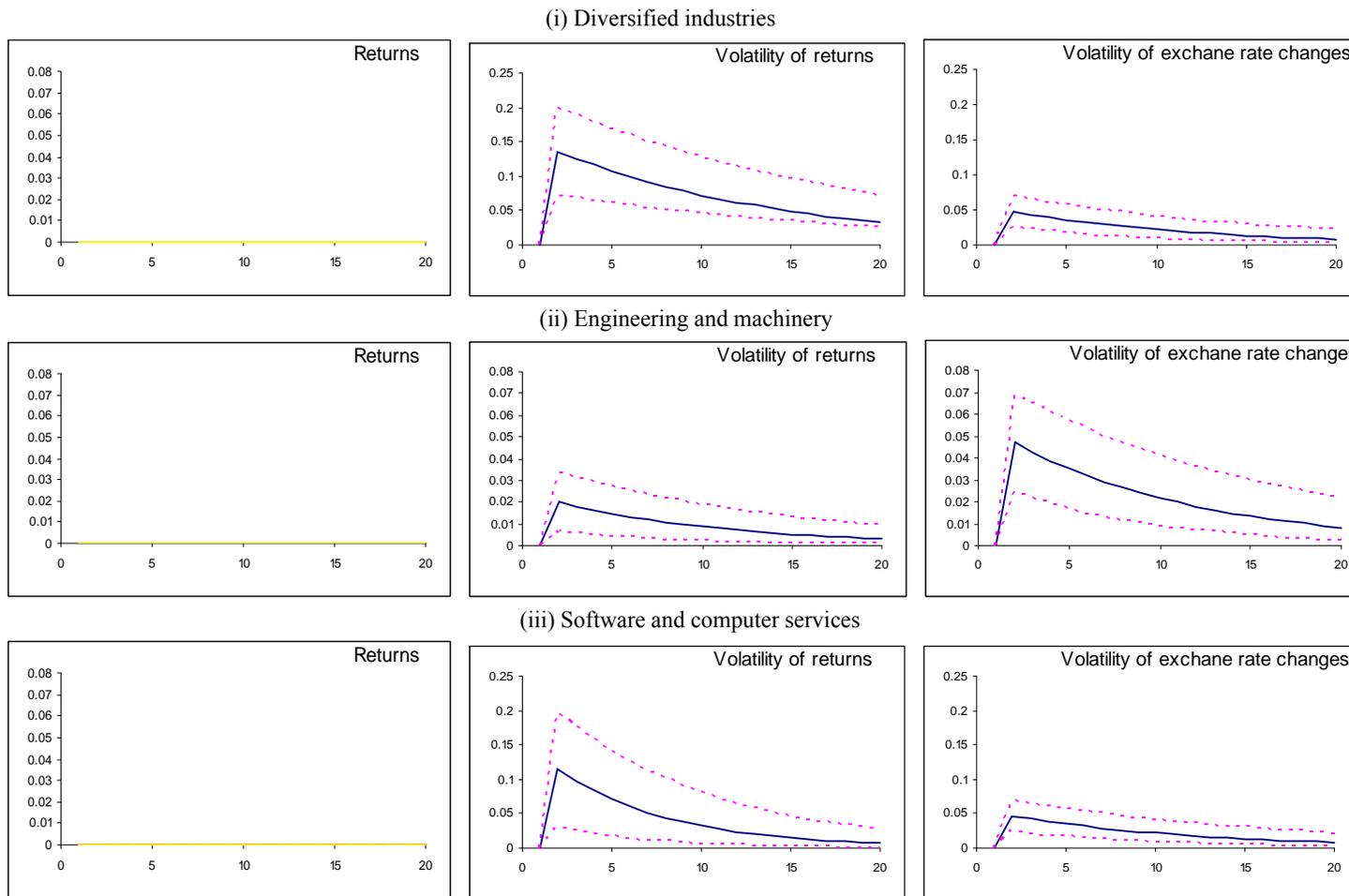
Notes: Q (20) and Q<sup>2</sup> (20) are Ljung-Box statistics of residuals and squared residuals respectively for 20 lags. They follow a  $\chi^2$  distribution and the critical value at the 5% level of significance with 20 degrees of freedom is 31.41.



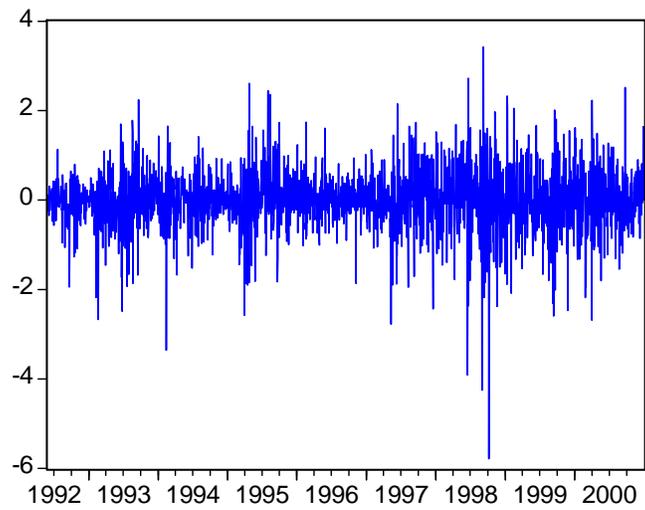
**Figure 1: Impulse response functions of the sectors in Group A**



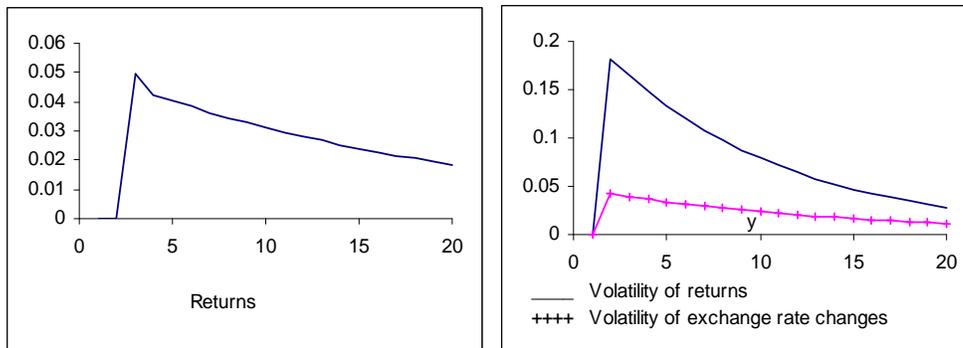
**Figure 2: Impulse response functions of the sectors in Group B**



**Figure 3: Impulse response functions of the sectors in Group C**



**Figure 4: Daily percentage changes of the relevant exchange rate during the sample period.**



**Figure 5: Indirect impact of an exchange rate shock on returns via the exposure of the conditional variance (Diversified industries sector)**