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Market, interest rate and foreign exchange rate risk in Australian banking: A GARCH-M approach

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Abstract

This study employs an extended version of the Generalised Autoregressive Conditional Heteroskedasticity in Mean (GARCH-M) model to consider the time-series sensitivity of Australian bank stock returns to market, interest rate and foreign exchange rate risks. Daily Australian bank portfolio returns, a market wide accumulation index, short, medium and long-term interest rates, and a trade-weighted foreign exchange index are used to model these risks over the period 1996 to 2001. The results suggest that market risk is an important determinant of bank stock returns, along with short and medium term interest rate levels and their volatility. However, long-term interest rates and the foreign exchange rate do not appear to be significant factors in the Australian bank return generating process over the period considered.

1. Introduction

Once the institutional core of a national financial system, the Australian banking sector now lies enmeshed in the evolutionary process shaping the Australian, and more generally, global financial system (Hoenig, 2000). With stringent regulation in the immediate post-WWII era, Australian bank activity primarily revolved around a 'traditional' product mix of domestic borrowing and lending and was generally viewed as a 'low-risk proposition' with minimal credit, interest rate and foreign exchange rate risks (Edey and Gray, 1996; Faff and Howard, 1999). However, financial deregulation in the 1980s saw the removal of restrictive controls on banks' loan and deposit portfolios, interest rates and investment activities alongside the broader program of microeconomic reform and the introduction of flexible exchange rates. In response, banking in Australia has fundamentally changed as banks have sought to manage changes in the level and volatility of the core market, interest rate and foreign exchange rate risks. Duration gaps have shortened, loans securitised, off-balance sheet activities increased and derivative positions expanded as banks have expanded their range and pricing of financial products, both domestically and internationally, during a period of unprecedented global financial activity.

Unfortunately, and despite the clear importance of an understanding of operational risk in the banking sector, very little empirical evidence is found concerning the Australian institutional milieu. Indeed, most existing literature has an overwhelming North American focus. A comparison with international studies highlights this deficiency. Madura and Zarruk (1995), Adjaoud and Rahman (1996), Prasad and Rajan (1995), Choi, *et al.* (1998) and Chamberlain, *et al.* (1997), for example, have examined the joint interaction of market, interest rate and foreign exchange rate risks in US financial institutions. No comparable Australian study exists. Similarly, despite the proliferation of international work concerning interest rate risk in banks [see, for instance, Kane and Unal (1988), Akella and Chen (1990), Brewer and Lee (1990), Kwan (1991), Madura and Zurruk (1995), Adjaoud and Rahman (1996), Flannery, *et al.* (1997) and Elyasiani and Mansur (1998)] a single study by Faff and Howard (1999) constituents Australian endeavours in this area.

Just as importantly, the foreign exchange rate risk of Australian banks is, as yet, unquantified, and while market risk in banking has already attracted some attention in the Australian context [see, for instance, Brooks and Faff (1995, 1997); Brooks, *et al.* (1997a, 1997b, 1998); Lie, *et al.* (2000)] most of these studies are concerned with the period before the mid-1990s. Finally, most of the existing research on the nature of Australian banking risk ignores the sizeable advances made in the autoregressive conditional heteroskedastic (ARCH) family of techniques to model the effect of these three risks and their volatility on the bank stock return generation process. Though these frameworks discard the restrictive assumptions of linearity, independence, and constant conditional variance they are nonetheless frequently overlooked in the banking literature.

Accordingly, the purpose of the present paper is to jointly quantify market, interest rate and foreign exchange rate risks in Australian banking using advanced time-series techniques. The paper itself is divided into four main areas. The first section explains the methodology employed in the analysis. The data used is discussed in the second section. The results are dealt with in the third section. The paper ends with some brief concluding remarks.

2. Model specification

Most research into market, interest rate and foreign exchange rate risk in banking has been undertaken using single or multi-factor least squares regression whereby the parameter estimates provide an indication of risk sensitivity. Examples of two-factor models, largely concerned with market and interest rate risk, include Chance and Lane (1980), Lynge and Zumwalt (1980), Flannery and James (1982, 1984a, 1984b), Booth and Officer (1985), Kane and Unal (1988), Akella and Chen (1990), Brewer and Lee (1990), Madura and Zurruk (1995), and Adjaoud and Rahman (1996). Alternatively, Choi, *et al*. (1992) and Wetmore and Brick (1994) have employed a three-factor approach to model market, interest rate and foreign exchange rate risk simultaneously.

However, recent empirical evidence suggests that bank sensitivities to market, interest rate and foreign exchange rate risk are time varying. For example, Kane and Unal (1988), Akella and Chen (1990), Brewer and Lee (1990), Neuberger (1991) and Kwan (1991) have established the time varying properties of interest rate risk. Likewise, Choi, *et al*. (1992), Wetmore and Brick (1994), and Tai (2000) have found that financial institution responsiveness to foreign exchange rates is also time-dependent. And Song (1994), Brooks, *et al*. (1997a, 1998, 2000), McKenzie, *et al*. (2000a, 2000b) and Brooks and Faff (1995) document the time-varying sensitivities of market returns in banking stocks. Accordingly, Autoregressive Conditional Heteroskedasticity (ARCH) techniques have found favour in the literature. For example, Song (1994) applies a univariate two-factor ARCH model to the question of bank sensitivity to market and interest rate risk. Similarly, Elyasiani and Mansur (1998) adopt a Generalised Autoregressive Conditional Heteroskedasticity (GARCH) in mean model (GARCH-M) to consider the affects of interest rate levels and volatility on bank shares.

The GARCH(p,q)-M model employed extends the work of Elyasiani and Mansur (1998) and is described by a system of three equations:

$$R_{j,t} = b_0 + \sum_{i=1}^{n} b_1 R_{j,t-i} + b_m R_{m,t-1} + b_r R_{r,t-1} + b_e R_{e,t-1} + \log(\gamma h_{it}) + \varepsilon_{j,t} \quad (1)$$

$$h_{it} = \alpha_0 + \alpha_1 \varepsilon^2_{i,t-1} + \beta h_{i,t-1} + \delta CV_{t-1} \quad (2)$$

$$\varepsilon_{i,t-1} | \Omega_{t-1} \sim N(0, h_t) \quad (3)$$

where the variables in the mean equation (1) are as follows: $R_{j,t}$ is the return on the bank stock portfolio j at time t, $R_{m,t-1}$ is the return on the market at time $t-1$, $R_{r,t-1}$ is the return at time $t-1$ on the interest rate index, $R_{e,t-1}$ is the return on the foreign exchange rate index at $t-1$, h_t measures the stock return volatility or risk of bank portfolio j at time t, and $\varepsilon_{j,t}$ is the error term which is normally distributed with zero mean and a variance of h_t, as described by Equation (3). The sensitivity of bank portfolio j at t to the market return, interest rates and the foreign exchange rate at time *t-1* are measured by the parameters b_m, b_r and b_e, respectively, responsiveness to volatility at *t-1* is measure by parameter γ, and b_0 is the usual constant term. The conditional variance h_t follows the process described in (2 and is determined by the past squared error terms (ε^2_{t-1}) and past behaviour of the variance (h_{t-1}), or the usual GARCH process, in addition to conditional interest rate volatility at *t-1* (CV_{t-1}), α_0 is the time-invariant component of risk, α_1 is the ARCH parameter, β_i is the GARCH parameters and the parameter δ represents sensitivity to the conditional variance of the interest rate index, R_r. The robustness of the model depends on the non-negativity of the variance parameters, α_0, α_1 and β, and the sum of the ARCH and GARCH parameters being less than unity ($\alpha_1 + \beta < 1$).

With respect to the mean equation in (1) several points are noted. First, excess bank returns are not used. This derives from the fact that in the context of work relating to the market model it has been argued that in the absence of an intention to simultaneously test the *ex ante* CAPM, there is no real reason to depart from the use of raw returns, in favour of excess returns, particularly when "[in] Australia, there is difficulty in obtaining a suitable proxy" for the risk-free rate (Brailsford, *et al*., 2000: 10). Second, bank returns are specified as a function of the return on the market (R_m), interest rate (R_r) and foreign exchange rate (R_e). However, in addition to the specification outlined in (1), bank returns are also estimated as a function of an autoregressive process $\left(\sum_{i=1}^{n} b_1 R_{j,t-i}\right)$ and bank return volatility or risk ($\log(\gamma h_{it})$). Estimation of the mean equation in this form extends Elyasiani and Mansur's (1998) work through the inclusion of the return on the market and foreign exchange rate. Also following Elyasiani and Mansur (1998) the formulation includes the volatility variable (h_t) in the mean equation. Since $\log(h_t)$ is a better representation of risk than either standard deviation or variance this variable is specified in logarithmic form (Elyasiani and Mansur, 1998).

Third, the exogenous variables, R_m, R_r and R_e along with conditional interest rate volatility (CV) in (2) are lagged one period. This also follows Elyasiani and Mansur (1998) and is intended to avoid the error in variable problem and consequent estimator inconsistency that may result from contemporaneous correlation of the shocks to the financial markets (the error term) and the innovations in the independent variables. Finally, and in direct relation to the mean equation, there is the potential that the 'exogenous' variables considered might, in fact, be highly correlated. In order to eliminate the potential for such multicollinearity many of the earlier studies on bank sensitivity to interest rates and the market return orthogonalised the variables. That is, the interest rate series was regressed on the market returns, or vice versa, and the residuals from this regression were then used in the two-index model. However, Giliberto (1985) and Kane and Unal (1988), amongst others have pointed out the potential bias in this procedure whilst other studies have suggested that differences in the results from othogononalising or not, are statistically insignificant [see, for example, Neuberger (1991)]. Accordingly, unorthogonalised variables are specified (Faff and Howard, 1999).

As with the mean equation, there are several points worthy of note in relation to the variance equation in (2). First, a GARCH(1,1)-M is chosen. This means that only the previous period's squared past error terms (ε_{t-1}^2) have an impact on the variance and similarly, only the previous period's conditional variance (h_{t-1}) determine the current period's variance. Use of a one period lag for both the ARCH and GARCH parameters follows Elyasiani and Mansur (1998) who argue, "…the GARCH (1,1)-M specification achieves parsimony while simultaneously allowing for long memory in the volatility process". Second, consistent with Elyasiani and Mansur (1998) the usual GARCH-M case is extended by modelling the conditional variance as a function of the conditional interest rate volatility (CV_{t-1}) in addition to the lagged squared error terms and lagged conditional variance. The parameter δ determines the significance of this variable. In the event that $\delta = 0$ conditional variance collapses to the usual case. Inclusion of conditional interest rate volatility as a determinant of bank return volatility is arguably "…important because this variable conveys critical information about the overall volatility of the financial markets and it influences the volatility of the bank stock returns also at the micro level" (Elyasiani and Mansur, 1998: 545). Market volatility could also be arguably included in the variance equation on this basis. However, given the potential for severe multicollinearity between the market and interest rate volatility measures, market volatility is excluded (Elyasiani and Mansur, 1998).

3. Data description

3.1 Bank stock return specification

The sample consists of nine Australian commercial bank stocks listed on the Australian Stock Exchange (ASX) collected and complied by Datastream International into a value-weighted Australian Bank Index adjusted for dividends and capitalisation changes. Given the assumption of normality underling the GARCH-M model outlined above, continuously compounded returns are to be preferred over discrete returns. This is due to the fact that continuously compounded returns result in a lower value (except for zero returns), thus implying that the effect of any outliers or data errors is reduced, as this series is more likely to follow a normal distribution as compared with a discrete series. Further, continuously compounded returns are more consistent with return generation through calendar rather than trading time, and they also remove some of the increasing variability in the series as the price level increases (Brailsford, *et al*., 2000). This choice differs from the earlier work of Faff and Howard (1999) who use discrete returns.

For consistency the market, interest rate and foreign exchange rate variables discussed below are also converted assuming continuous compounding. Flannery and James (1984b), Kane and Unal (1988), Akella and Chen (1990), Song (1994), Wetmore and Brick (1994) and Faff and Howard (1999), amongst others, point out the need for consistent expression of all terms. The decision to use an index or portfolio of returns, rather than individual bank data, is considered advantageous because it is an "…efficient way to condense a substantial amount of information about bank stock return behaviour…" whilst smoothing out the noise in the data due to transitory shocks to individual banks which might otherwise distort the results (Elyasiani and Mansur, 1998: 539). Of course, one disadvantage is that variation among individual banks may be masked (Elyasiani and Mansur, 1998). One potential remedy followed in the US literature is the further division of the sample into classifications based on bank practise and size. For example, banks in the US are often categorised into money centre, large and regional banks. Unfortunately, due to the relative small number of institutions in the Australian banking sector as compared with their overseas counterparts arbitrarily dividing the sample may introduce misspecification bias.

3.2 Market index specification

The value-weighted ASX All Ordinaries Index (AOI) obtained from Datastream International proxies the market index. Consistent with the specification of the bank index, the market index is a total return or accumulation index and is adjusted for capitalisation changes. As with the bank stock returns the index is converted to a continuously compounded return series. Although indices other than the AOI may better represent the market portfolio, Brailsford, *et al*. (2000) suggest that using a broader index, such as the Australian Graduate School of Management's (AGSM) index which compromises all traded equities, introduces further problems. Therefore, following the bulk of the empirical literature the most common domestic index for Australia is used, despite the recognition that "…composition and weighting of the index can affect the individual betas and might affect the conclusions drawn" (Brailsford, *et al*., 2000: 12).

3.3 Interest rate index specification

Yields on 10 year and 5 year Treasury Bonds and 90 day Bank Accepted Bills are obtained from the Reserve Bank of Australia (RBA) and after conversion to continuously compounded holding period returns proxy the long, medium and short-term interest rates, respectively. In light of the prediction of the efficient market hypothesis that bank stock returns should only be related to unanticipated changes in interest rates with the expected component already reflected in the return, some studies estimate the 'innovation' rather than use actual or unadjusted interest rates. For example, the forecast errors from autoregressive models (Flannery and James, 1984b; Yourougou, 1990), the difference between the spot rate at time *t* and forward rate at *t-1* (Brewer and Lee, 1990), and the change in yield on the given maturity of a long-term bond (Scott and Peterson, 1986; Sweeney and Warga, 1986; Elyasiani and Mansur, 1998) have all been used to proxy the unanticipated component of interest rates. However, much evidence exists in the literature supporting interest rate sensitivity irrespective of whether interest rates are proxied by raw returns or otherwise (Song, 1994). These include studies by Flannery and James (1984b), Unal and Kane (1987), Bae (1990), Choi, *et al*. (1992) and Faff and Howard (1999).

3.4 Foreign exchange rate specification

The requisite foreign exchange rate data is collected from the Reserve Bank of Australia. Following Prasad and Rajan (1995), Choi, *et al*. (1992) and Wetmore and Brick (1994), the foreign exchange rate index is defined as the Australian currency value of one unit of foreign currency, where foreign currency is defined as the trade-weighted basket with current weights as set out in the Reserve Bank Bulletin. For consistency with the other variables included in the study and the empirical literature, for instance Prasad and Rajan (1995) and Choi, *et al*. (1992), the foreign exchange index is converted to a continuously compounded holding period return. Also for reasons of consistency with the interest rate variables, actual foreign exchange rate data rather than the 'innovations' in such are used.

3.5 Sampling frequency

Following McKenzie and Brooks' (2000) general work on ARCH and GARCH techniques, daily data excluding national holidays is specified. This data selection choice is also consistent with the work of Brewer and Lee (1990) and Adjaoud and Rahman (1996) in the context of interest rate sensitivity in bank stock returns. Lie's, *et al*. (2000) work on market returns and the foreign exchange rate study of Chamberlain, *et al*. (1997) also use daily data. Despite this, a substantial amount of the empirical work in this area employs monthly data, with a few studies such as those by Flannery and James (1984b), Wetmore and Brick (1994) and Dinenis and Staikouras (1998) preferring weekly sampling periods. Nevertheless, daily data is preferred for the following reasons. First, the use of monthly data has arguably been a result of historic phenomena whereby it has more widely available than either weekly or daily data (Brailsford, *et al*., 2000). Second, given the well-documented decline in ARCH effects for some assets "…as the periodicity of the sampling frequency decreases" statistical support for the use of daily over weekly sampling is also found (McKenzie and Brooks, 2000: 59) [see also Diebold (1988), Baille and Bollerslev (1989) and Andersen and Bollerslev (1997)]. However, one potential limitation for this study arising out of the use of a daily sampling frequency is there may be too much noise in the data and 'day of the week' effects may represent a problem.

3.6 Sample period

A 5-year sample period from 1 March 1996 to 28 February 2001 is specified. The justification for this particular sample period is as follows. First, with most studies on interest rate sensitivity considering periods prior and around the deregulation of the financial system, a study focusing on a more recent period should throw light on the nature of bank risk in the post-deregulation period. Second, this length of time results in 1,263 observations, thereby satisfying the claim that for statistically reliable ARCH regression estimates at least 300 observations are required (McClain, *et al*., 1996). Similarly, the suggestion that the significance of ARCH coefficients may change as the sample size is reduced does not present a problem with this number of observations (McKenzie, 1998). Moreover, whilst persistence in ARCH models has been related to sample size (McClain, *et al*., 1996), it is thought that this sample is not large enough to evoke the problem whereby "the sum of the alpha and beta coefficients asymptotes toward unity" as the sample size increases (McKenzie and Brooks, 2000: 59). Lastly, this period ensures that the banks included in the bank index were continuously listed on the stock exchange throughout the sample period.

4. Empirical results

Table 1 presents descriptive statistics for the continuously compounded returns included in the analysis of market, interest rate and foreign exchange rate risk; namely, bank portfolio returns, market returns, short, medium and long-term interest rate returns and the foreign exchange rate returns. During the sample period 1996-2001 the mean continuously compounded return is highest in the bank portfolio index and lowest in medium-term interest rates, while volatility is highest in medium-term interest rates and lowest in the foreign exchange rate. The sample skewness for all six variables is generally close to zero, but the sample kurtosis for all variables with the exception of short-term interest rates exceeds the normal value of three. Verification that the unit root has been removed from each series by the calculation of continuously compounded returns is indicated by the insignificant Augmented Dickey-Fuller (ADF) and Phillips-Perron statistics.

As the independent variables used to explain bank returns are hypothesised to be time-dependent, it follows that the bank return series must also be time dependent. From graphical displays (not shown here) it is readily apparent that the bank portfolio returns exhibit an upward trend. More formal support for the presence of non-stationarity in the bank portfolio is found through inspection of the autocorrelation function (also not shown) that indicates that Australian bank returns exhibit correlation at lag 1. This provides support for the inclusion of the autoregressive lag of one in the mean equation. Likewise, the autocorrelation from the squared observations of the bank portfolio also suggests there is substantial correlation in the squared values of the bank index. This is usually a good indication that the potential time-dependence of the relationship between market, interest rates and foreign exchange rates will be adequately modelled by a GARCH technique. Combined together, these results suggest that ARCH type modelling is the most appropriate framework for analysing banks stock returns and risk.

One particular issue in this analysis is the specification of bank portfolio returns as against individual bank returns, with the suggestion that portfolio returns may obscure unique individual bank responses to market, interest and foreign exchange rate risks. Summary statistics of the bank portfolio and its constituent individual banks (not shown here) show that the mean daily return of the Australian bank portfolio is approximately 3.9×10^{-4} with a variance of around 2×10^{-5}. The bank portfolio is also not normally distributed, as evidenced by non-zero skewness (-0.24828), kurtosis above three (4.83438), and more formally, a significant Jarque-Bera statistic (190.055). Comparing these figures with those for each individual bank, we find that most of the larger and medium-sized banks conform approximately well to the portfolio statistics. This is expected given that they comprise the largest weighting in calculation of the value-weighted index. However, some of the smaller banks diverge somewhat from the portfolio with returns and volatility less than the industry as a whole. Accordingly, the results of this analysis may not accurately describe the return generating process in these institutions.

Another potential concern arising out of the methodology is the degree of multicollinearity between the 'independent' variables. To address this correlations between each exogenous variable are calculated. Aside from the lagged bank index and the market return, which have a correlation of 0.7614, the remaining variables have correlation coefficients of less than 0.25. Brooks, *et al*. (1997b) indicate that a correlation coefficient between 0.637 and 0.771 may indicate a significant relationship. A more general rule of thumb is that if the pair-wise or zero-order correlation coefficient between two regressors is, say, in excess of 0.8, then multicollinearity is a serious problem. The correlation coefficients indicate that while multicollinearity is present it is not too serious a problem.

Table 1
Descriptive statistics of the continuously compounded variables in the mean equation

Statistic	Bank index at *t*-1	Market	Interest Rates: Long Term	Interest Rates: Medium Term	Interest Rates: Short Term	Foreign Exchange
Mean	3.920	1.910	-1.710	-1.780	-1.080	0.396
Median	5.380	3.340	0.000	0.000	0.000	0.000
Maximum	2.510	2.570	2.360	2.290	3.980	1.410
Minimum	-2.410	-3.030	-1.890	-2.510	-3.320	-1.080
Standard Deviation	4.760	3.850	5.050	5.150	3.440	2.700
Skewness	-0.243	-0.558	0.144	-0.060	-1.040	0.217
Kurtosis	4.820	9.190	4.350	4.950	0.361	4.880
Jarque-Bera	1.869	20.843	1.003	2.000	579.984	1.963
Jarque-Bera p-value	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***
Aug. Dickey-Fuller	-16.446	-16.870	-16.670	-16.498	-16.358	-15.970
Phillips-Perron	-32.174	-35.634	-37.515	-36.483	-31.099	-39.908
Observations	1263	1263	1263	1263	1263	1263

Notes: Asterisks represent significance at the * – .10, ** – .05 and *** – .01 level. Statistics for mean and median are $\times 10^{-4}$, maximum, minimum, JB and ADF are $\times 10^{-2}$ and standard deviation is $\times 10^{-3}$.

The final point to note relates to the sensitivity of the bank return generating process to long, medium or short-term interest rates, especially given that the bulk of empirical evidence has generally found that bank returns are more sensitive to longer-term rates. Correlation coefficients (not shown here) indicate a high degree of correlation (0.9396) between the 10-year and 5-year bond indices. Faff and Howard (1999) made a similar observation with regard to Australian interest rates over the period 1978 to 1992. However, unlike Faff and Howard (1999) who find that the correlation between either the long term or medium term interest rate and the short term rate is less that 0.5 in either case, here, there is evidence of a relatively high degree of correlation between the medium and short term indices (0.6170), though not between the long and short term (0.4875). Given these differences with Faff and Howard's (1999) prior Australian study, there appears ample reason to reconsider all three interest rates.

Table 2 presents various robustness checks associated with the GARCH-M model as it is generally necessary to consider the adequacy of the chosen GARCH-M model in order to be confident that the estimates in Table 3 are reliable. The sufficiency of the model is addressed on two levels. First, the general model performance is considered. Second, the added parameters resulting from the GARCH-M model are interpreted. To start with, the general adequacy of the model rests on whether it has captured all ARCH effects present in the data and whether the standardised residuals conform to the assumption that they are independent and identically distributed; that is, they are white noise and follow a normal distribution with zero mean and variance of one [iid. ~ N(0,1)]. With respect to the elimination of the remaining ARCH effects, the insignificant Ljung-Box (Q) statistic on the squared standardized residuals indicates an absence of remaining GARCH effects, as does the insignificant Lagrange Multiplier statistic. These conclusions are robust irrespective of the interest rate specification.

However, the significant Jarque-Bera statistics in Table 2 indicate that the assumption of normality is violated, though the Shapiro-Wilk tests of normality indicate that the null hypothesis that the residuals are normally distributed cannot be rejected at any conventional level. Brooks, *et al*. (1997b: 89) argue that provided standard deviation is close to one, a mean that is statistically different from zero will not disrupt the assumption of a robust model fit. Similar findings of non-normality have been found in the most relevant literature. For example, Elyasiani and Mansur (1998) similarly find that the normality assumption for each of the three portfolios considered is rejected. They attribute much of this non-normality to the failure of the models to account for the leptokurtic disturbances of market excess returns [see also McKenzie and Brooks (2000)]. Finally, the insignificant Ljung-Box (Q) statistic for the standardized residuals indicates that there is no serial correlation in the disturbances. On the basis of these statistics, the GARCH-M model appears to perform reasonably well.

Table 2.
General performance statistics

Statistic	Interest Rate Maturity		
	Long term	Medium term	Short term
Jarque-Bera (JB)	36.25	35.72	41.73
JB *p*-value ($\times 10^{-8}$)	(1.341) ***	(1.75) ***	(0.08664) ***
Shapiro-Wilk (SW)	0.9878	0.9874	0.9871
	(0.6212)	(0.5376)	(0.4763)
Ljung-Box (Q) statistic for standardised residuals	8.742	8.526	8.685
	(0.7248)	(0.7428)	(0.7296)
Ljung-Box (Q) statistic for squared standardised residuals	10.03	8.307	10.22
	(0.6136)	(0.7607)	(0.5971)
Lagrange Multiplier (LM)	10.27	8.477	10.31
	(0.5924)	(0.7469)	(0.5887)

Notes: Values in parentheses are *p*-values. Asterisks *, ** and *** represent significance at the .10, .05 and .01 levels, respectively.

The second issue with respect to the adequacy of the chosen GARCH-M model is the additional parameters that are estimated. First, with respect to the inclusion of an autoregressive process, it is clear from Table 3 that the bank return in the previous period is a determinant of its return in the current period. That is, the autoregressive lag parameter (b_1) is significant (at the .01 level) irrespective of the interest rate variable under consideration. The robustness checks in Table 4 also reject at the .01 level the null hypothesis that the autoregressive variable has no effect on bank returns (b_1 = 0). Second, the GARCH-M technique used also includes the conditional variance or volatility of the bank index, represented by γ, as a determinant of bank returns. Inclusion of this variable in the mean equation is premised on the notion that risk-adverse agents require compensation for holding risky assets. Subsequently, the return on the bank index is expected to increase with a corresponding increase in the volatility of its returns.

Surprisingly, Table 3 shows that for all three interest rate maturities (long, medium and short term) the coefficient, γ, is statistically insignificant. Table 4 also confirms that the likelihood ratio test of the null hypothesis that volatility does not affect bank returns ($\gamma = 0$) is also statistically insignificant for all interest rate maturities (χ^2 = 0.24; 0.08; 0.77). This differs from Elyasiani and Mansur (1998) who found a statistically significant volatility effect across the three bank portfolios considered [Money centre -0.00131, large -0.00142 and regional -0.001 at the .01, .01 and .10 levels, respectively]. The main implication is that the volatility risk premia is absent during the period analysed. One potential explanation for this finding is that over the period of the late 1990s, the bank portfolio return was significantly less volatile than in the immediate post-deregulation period in the 1980s and early 1990s. This is confirmed by examining the continuously compounded returns for the Australian bank index since the early 1970s (not shown here). A lower level of volatility in bank returns is also found when compared with comparable international studies. For instance, Elyasiani and Mansur (1998) calculate portfolio variances ranging from 0.003 to 0.005 for the three bank portfolios considered. This may be a product of both the different time periods studied along with institutional differences between the Australian and the US banking sectors.

Another point to note with respect to the volatility parameter (γ) is that it is negative: clearly contrary to the theoretical prediction that higher risk results in higher returns. Elyasiani and Mansur (1998: 551) make a similar finding and suggest, "[since] volatility is a measure of total risk, rather than the non-diversifiable systematic risk, the increase in it need not always be accompanied by an increase in the risk premium. Indeed, if fluctuations in volatility are mostly due to shocks to the unsystematic risk, the trade-off coefficient γ can have any sign". One alternative is that a negative risk-return trade-off may result from riskier periods coinciding with periods when investors are better able to bear risk or the fact that if investors want to save more during riskier times, and all assets are risky, competition can raise asset prices and lower the risk premium. More relevant in the present context is the suggestion that "…if banks are affected less strongly by random shocks than other sectors, investors will switch to bank stocks in response to the shocks, in order to avoid the sectors more strongly affected. This substitution process will result in a lower bank stock premium" (Elyasiani and Mansur, 1998: 551).

The figures in Table 3 also suggest that there is a significant time-invariant component in the bank return generating process since the constant in the variance equation (α_0) is significant [α_0 = 1.955 $\times 10^{-6}$ (.01 level); 1.382$\times 10^{-6}$ (.10 level); 2.605$\times 10^{-6}$ (.01 level)]. Neuberger (1994) also found a zero intercept term in the volatility equation, though Elyasiani and Mansur's (1998) estimated insignificant time-invariant parameters for all banks save the regional banking portfolio. However estimates in Table 3 also suggest that the Australian bank return generating process has a significant time dependent component. In particular, the ARCH (α_1) and GARCH (β) parameters are highly significant at the .01 level irrespective of the interest rate maturity under consideration (α_1 = 0.1319; 0.1329; 0.1279 and β = 0.6822; 0.6645; 0.7616). Further, the likelihood ratio test statistics in Table 4, also reject the hypotheses of time invariability in return volatility ($\alpha_1 = \beta = \delta = 0$)**,** irrespective of the interest rate index at any traditional level of significance (χ^2 = 103.60; 109.90; 104.51). Subsequently, despite a significant time-independent component of bank returns, a time-invariant model of banking returns is inappropriate due to the substantial time-dependent component.

Table 3.
Maximum likelihood estimates of GARCH(1, 1)-M models

		Interest Rate Maturity					
		Long term		Medium term		Short term	
Mean equation parameters	b_0	-0.0023	-0.5100	-0.0014	-0.3285	-0.0028	-0.6583
	b_1	0.2298 ***	5.3735	0.2242 ***	5.2559	0.2940 ***	5.5687
	b_m	-0.2082 ***	-4.1803	-0.2114 ***	-4.2335	-0.2091 ***	-4.3425
	b_r	-0.0312	-1.1976	-0.0622 ***	-2.3845	-0.1150 ***	-3.7612
	b_e	0.0209	0.4505	0.0238	0.5085	0.0277	0.6102
Variance equation parameters	γ	-0.0002	-0.6024	-0.0001	-0.4168	-0.0002	-0.7582
	α_0	0.0001 ***	2.4199	0.0001 *	1.5695	0.0001 ***	4.1897
	α_1	0.1319 ***	5.2313	0.1329 ***	5.0367	0.1279 ***	5.7492
	β	0.6822 ***	10.1403	0.6645 ***	9.6590	0.7616 ***	17.6051
	δ	0.0759 *	1.6241	0.1129 **	2.1899	-0.0157 ***	-2.8166
Statistics	$\alpha_1 + \beta$	0.8141		0.7974		0.8895	
	AIC	-10045.80		-10054.00		-10055.81	
	BIC	-9994.39		-10002.59		-10004.40	

The GARCH(1,1)-M models are estimated as follows:

$$R_{j,t} = b_0 + \sum_{i=1}^{n} b_1 R_{j,t-i} + b_m R_{m,t-1} + b_r R_{r,t-1} + b_e R_{e,t-1} + \log(\gamma h_{it}) + \varepsilon_{j,t}$$

$$h_{it} = \alpha_0 + \alpha_1 \varepsilon^2_{i,t-1} + \beta h_{i,t-1} + \delta CV_{t-1}$$

$$\varepsilon_{i,t-1} | \Omega_{t-1} \sim N(0, h_t)$$

where R_{jt} is the return on the bank portfolio at time t, R_{jt-1} is the lagged return on the portfolio, R_m and R_e are the return on the market and foreign exchange rate respectively, R_r is the return on the long, medium and short term interest rate index respectively, $\varepsilon_{j,t}$ denotes the error term which is dependent on the information set Ω_{t-1}, h_t is the conditional variance of return at time t. The optimal lag was determined to be 1. CV is the conditional variance on the long, medium and short term index respectively. Values in parentheses are t-statistics. Asterisks *, ** and *** represent significance at the .10, .05 and .01 levels, respectively.

Attention turns to the functional form chosen to describe the time-dependent component of bank returns with the addition of a variable for interest rate volatility. To start with, the hypothesis that the return generating process follows an ARCH specification ($\beta = \delta = \gamma = 0$) is rejected at the .01 level (χ^2 = 35.46; 42.46; 39.23) in all three models, as is the hypothesis that the return generating process follows an ARCH-M specification (χ^2 = 35.48; 42.36; 39.03). However, the null hypothesis that the return generating process follows a GARCH specification is only rejected when medium term interest rates are under consideration [χ^2 = 3.20; 8.12; 3.83]. This indicates that when considering the long and short-term interest rates, the volatility parameter (γ) and the interest rate volatility variable (δ) are not significantly different from zero. However, upon consideration of whether the return generating process for banks follows a pure GARCH-M specification (δ = 0), the null is rejected for both short and medium term interest rates (χ^2 = 2.46; 7.26; 3.01). It is therefore suggested that the appropriate model is the modified GARCH-M specification used in the analysis. In relation to this point, Elyasiani and Mansur (1998: 552) conclude, "…the rejection of a hypothesis is a sufficient condition for the rejection of any other hypothesis which is more restrictive in nature, namely one that imposes more constraints than implied by the former". Therefore, the rejection of the null hypotheses that the return generating process follows an ARCH, ARCH-M and GARCH process provides support for the suggestion that the more restrictive constant variance specification must also be rejected.

Lastlly, in terms of the constraints imposed by the use of a modified ARCH technique the constant (α_0), ARCH (α_1) and GARCH (β) parameters are all non-negative. The magnitude of the ARCH parameter (α_1 = 0.1319; 0.1329; 0.1279) is smaller than that of the GARCH parameter (β = 0.6822; 0.6645; 0.7616). Thus, the effect of last period's shock (ε^2_{t-1}) on bank volatility is smaller than the effect of the previous surprises (h_{t-1}). This finding is consistent with that of Elyasiani and Mansur (1998) and indicates that the market has a memory longer than one period and that volatility is more sensitive to its own lagged values than it is to new surprises in the market place.

Table 4.
The χ^2 statistics for various hypotheses tests

Hypotheses	Interest Rate Maturity		
	Long term	Medium term	Short term
There is no autoregressive process: b_1=0	28.40 ***	26.96 ***	28.43 ***
There is no market effect: b_m=0	16.48 ***	16.58 ***	16.63 ***
There is no interest rate level effect: b_r=0	1.38	5.56 **	10.69 ***
There is no foreign exchange effect: b_e=0	0.22	0.26	0.29
Volatility is not a significant factor: γ=0	0.24	0.08	0.77
Return volatility is time invariant: α_1=β=δ=0	103.60 ***	109.90 ***	104.51 ***
Return generating process follows an ARCH specification: β=δ=γ=0	35.46 ***	42.46 ***	39.23 ***
Return generating process follows an ARCH-M specification: β=δ=0	35.48 ***	42.36 ***	39.03 ***
Return generating process follows a GARCH specification: γ=δ=0	3.20	8.12 **	3.83
Interest rate volatility has no effect on bank risk and return: δ=0	2.46	7.26 ***	3.01 *
There is no interest rate effect: δ=b_3=0	3.40	11.60 ***	13.41 ***

Asterisks *, ** and *** represent significance at the .10, .05 and .01 levels, respectively. Figures are χ^2 values

The second constraint that must be complied with is that the sum of the ARCH and GARCH parameters ($\alpha_1 + \beta$) as a measure of volatility persistence should be less than unity. From Table 3 the sum of $\alpha_1 + \beta$ is less than one, indicating that the model is second order stationary, irrespective of whether short, medium or long term interest rates are used ($\alpha_1 + \beta$ = 0.8141; 0.7974; 0.8895). The relatively high value of the persistence measure provides evidence that shocks to the banking sector have highly persistent effects and that the response function of volatility decays at a relatively slow pace. For example, when long term rates are specified, the persistence measure ($\alpha_1 + \beta$) is 0.8141 thereby indicating that the proportion of the initial shock to the bank portfolio remaining after a 5-day period is $(0.8141)^5$ or 36 percent, and after two weeks 13 percent of the initial shocks persist. Generally the persistence documented here for the Australian bank portfolio is lower than Elyasiani and Mansur's (1998) findings for US banks over their sample period. This indicates that, at least for the sample chosen in this study, Australian banks are relatively more capable of absorbing shocks than their US counterparts. Alternatively, this observation may merely be a consequence of the less volatile bank environment in the late 1990s.

The major concern in this study is of course whether Australian bank stock returns are sensitive to market, interest rate and foreign exchange rate risk. The estimated coefficients in Table 3 and the chi-square statistics in Table 4 represent the associated hypothesis tests. First, and not surprisingly, the coefficients in Table 3 indicate that bank returns are highly sensitive to the return on the market as represented by the coefficient b_m. This result is invariant to the specification of the interest rate. The coefficient for market risk has a value of -0.2082, -0.2114 and -0.2091 for the model with long, medium and short-term interest rates, respectively. These results are supported by rejection at the .01 confidence interval of the null hypothesis of no market risk (b_m = 0) in Table 4 (χ^2 = 16.48, 16.58 and 16.63). The magnitude of this coefficient suggests that the Australian banking industry has relatively low systematic risk. This is comparable to previous Australian estimates of bank sensitivity to market risk (estimated coefficients in brackets), including Brooks and Faff (1995) (0.6222–1.2517), Brooks, *et al*. (1997b) (0.7867–0.8458), and Brooks, *et al*. (1998) (0.838–0.881).

The second hypothesis of interest is the magnitude of market risk as compared with the remaining variables. Noticeably the market return is found to explain a greater proportion of bank returns, that is b_m is larger in absolute magnitude, than interest rates irrespective of the maturity under consideration (b_r = -0.03127; -0.06219; -0.115 for long, medium and short term interest rates respectively). Similarly, the market index explains more than the foreign exchange rate, even ignoring the finding of foreign exchange insignificance discussed below (b_e = 0.0209; 0.02385; 0.02779). These findings are consistent with the results of Song (1994), amongst others.

The last hypothesis of interest in relation to the effect of market returns on Australian bank stocks is related to the time dependence of bank sensitivity to market returns. Preliminary evidence presented earlier suggested that market effects were time varying. As noted, in the event that market returns are time-dependent, a least squares regression is generally inappropriate for determining the relationship between these variables and bank returns. Thus, a GARCH-M model was specified to take into account this time-varying sensitivity. The significance of the variance equation parameters α and β in Table 3 and the rejection of the null hypothesis that returns are time invariant ($\alpha = \beta = \delta = 0$) in Table 4 indicates that the return process is indeed time-varying.

A second group of hypotheses addressed in this study concerns interest rate risk. First, in terms of the magnitude and direction of influence of interest rates on Australian bank returns, as indicated by the sign and significance of the interest rate coefficient b_r, Table 3 shows that the short and medium term interest rates are significant at the .01 level with coefficients of -0.115 and -0.06219 respectively. The importance of short and medium term rates to the bank return generating process is verified by the rejection of the null hypothesis of no interest rate level effect (b_r = 0) in Table 4. The finding of a significant negative relationship between short term interest rates and bank returns accords with findings by Booth and Officer (1985), Choi, *et al*. (1992), Bae (1990), and Faff and Howard (1999), amongst others. Conversely, Unal and Kane (1988) and Akella and Chen (1990) failed to find a significant short term interest rate effect. In relation to the negative sensitivity to medium term rates, Brewer and Lee (1990) and Bae (1990) have made similar findings.

More surprising however is the insignificance of the long-term interest rate. From Table 3 the coefficient on the long-term rate is 0.03127 lacks statistical significance at any usual level. This is consistent with the failure to reject the null hypothesis of no long-term interest rate level effect (b_r = 0) in Table 4 (χ^2 = 1.38). This result is inconsistent with much existing work in this area, including Elyasiani and Mansur (1998), Unal and Kane (1988), Kane and Unal (1988), and Akella and Chen (1990). A potential reason for this unexpected finding lies in the period considered such that while previous studies have focussed on the deregulation era this study considers the post-deregulation era exclusively. Given the move towards regulatory focus on internal management of bank's risks in recent years, as evidenced by adoption of the

Basle Accord, the banks' ability to manage long term interest rate exposure has increased. This may be compared with the situation immediately post-deregulation because "…deregulation was associated with increases in risks faced by banks which were not well prepared to manage higher risk" (Faff and Howard, 1999: 99). This also accords with the documented decline in longer-term interest rate sensitivity, especially Faff and Howard (1999) as the only other Australian study concerned with interest rate sensitivity.

The second hypothesis is that bank returns are likely to be more sensitive to longer-term interest rates than either medium or short term. Clearly, upon consideration of the interest rate coefficients (b_r) for long, medium and short term rates (-0.03127, -0.06219 and –0.115) the converse are true. That is, from early 1996 through to the beginning of 2001 Australian bank returns are more sensitive to short term interest rates, than either medium or long term, with long term rates providing the least explanatory power. The Akaike Information Criterion (AIC) and Schwartz Bayesian (BIC) model selection criterion presented in Table 3 support this conclusion whereby the most parsimonious specification for Australian bank returns, as indicated by the lowest AIC/BIC value, is the model including short term interest rates [AIC = -10055.81, BIC = -10004.4)]. This is contrary to the results of Lynge and Zumwalt (1980), Unal and Kane (1988), Bae (1990) and Faff and Howard (1999), amongst others.

One possibility is as follows. Historically Australian banks have had a substantial exposure to long-term interest rate risk as a result of the maturities mismatch between the major components of the banks' balance sheet in the form of deposits and loans. More recently, as the importance of the traditional bank product mix has declined and the banking sector's balance sheet has embraced shorter-term market-linked securities, the maturity length of the interest rate risk that is of relevance or concern to the banking sector has also declined. The process of this transformation in the typical bank balance sheet would therefore explain the documented decline in long-term interest rate sensitivity found in the literature to date. For example, Faff and Howard (1999) find that in the Australian context, long-term interest rate risk is insignificant in the latest sub sample considered. This explanation may validate the finding of no long-term interest rate risk in this study and also the finding that short-term interest rate risk is of greater import than either medium or long-term interest rates. Alternatively, another explanation for the lack of long term interest rate sensitivity is that the banks are better placed to hedge this exposure as compared to shorter term interest rate risk. Perhaps banks are more risk adverse to this length of interest rate risk and therefore undertake more rigorous hedging action for this maturity.

The third hypothesis concerning the effect of interest rates on bank returns that interest rate sensitivity is time-varying has already been supported. The significance of the variance equation parameters α and β in Table 3 and the rejection of the null hypothesis that returns are time invariant ($\alpha = \beta = \delta = 0$) in Table 4 indicate that the return process is time dependent. Lastly, interest rate volatility was also hypothesised as being an important determinant of bank returns in Australia. In terms of the model specified interest rate volatility is included as a determinant of bank return volatility, which is in turn a determinant of bank mean return. Considering the effect of interest rate volatility on bank return volatility the long term interest rate volatility has a value of 0.07595 and is significant at the .10 level, medium term interest rate volatility has a magnitude of 0.1129 and is significant at the .05 confidence interval, whilst short term interest rate volatility is significant at the .01 level and has a value of -0.01572. Similarly, the null hypothesis of no long term interest rate volatility effect in Table 4 (δ=0) cannot be rejected. Coupled with the marginal significance of the long term interest rate volatility coefficient in the main model estimation (Table 3) this indicates that long term interest rate volatility is not a particularly important determinant of bank return volatility. While this conflicts with Elyasiani and Mansur's (1998) findings for money centre and large bank portfolios, it is in accordance with their results for regional banks. Elyasiani and Mansur (1998: 556) suggest that an insignificant interest rate volatility parameter "…may indicate insignificant exposure to interest rate risk due to stronger risk aversion and hedging action".

While the null hypothesis of no medium term interest rate volatility effect is rejected at the .01 level, the hypothesis for short term interest rate volatility is only rejected at the .10 level. A potential reason for this is that since the 5-year medium term rate now represents the longest time horizon over which Australian banks deem relevant, the volatility in this rate is more important to banks than fluctuations in shorter-term rates. Lastly, in relation to the findings on the effect of interest rate volatility on bank volatility, the long and medium term interest volatility coefficients are positive whilst the short-term volatility has a negative relationship with bank return volatility. The negative coefficient for short-term volatility indicates that if interest rates become more volatile, bank stock returns will stabilise in the following period (i.e. the next day).

One possible explanation for the decline in stock return volatility in response to short term interest rates is that when short term interest rate volatility increases, banks seek shelter from short term interest rate risk and are capable of doing so within one day, for example by holding derivatives and matching the duration of assets and liabilities. This, in turn, results in lower bank stock volatility in the following period (the next day). This finding does not preclude (contemporaneous) movements of in bank variance (h_t) and conditional interest rate volatility (CV_{t-1}) in the same direction. Indeed, if CV is negatively autocorrelated (and δ is negative) the two variables will move together. By way of contrast, if long or medium term rates become more volatile, bank stock returns also become more volatile in the following period (Elyasiani and Mansur, 1998). The reason for the different responses between short and both medium and long term rates is that banks may have a slower response time to movements in the long and medium term interest rate volatility as compared with short term. Banks also appear to have a stronger reaction to short term interest rate volatility than either long or medium term. Again this is posited to be a result of shifting balance sheet exposures.

The final hypothesis concerning Australian bank returns is their sensitivity to foreign exchange rate risk. From the estimated coefficients in Table 3 it would appear that foreign exchange rate risk is not significant determinant of Australian bank stock returns, regardless of the interest rate maturity under consideration (b_e = 0.02090; 0.02385; 0.02779). This conclusion is supported by the failure to reject the null hypothesis of no foreign exchange rate effect ($b_e = 0$) in Table 4 (χ^2 = 0.25, 0.28, 0.30 for long, medium and short term interest rates, respectively). This is contrary to the US findings of Choi, *et al*., (1992), Wetmore and Brick (1994) and Tai (2000).

A number of potential explanations for this unexpected finding exist. First, and foremost, is that Australian banks simply are not exposed to significant foreign exchange rate risk over the sample period. However, in line with the globalisation of banking and increased offshore activities in the banking sector, at least some (major) Australian banks do have significant on-balance sheet foreign currency exposure. It is therefore inappropriate to assume that lack of balance sheet exposure to fluctuations in the foreign exchange rate is the reason for a failure to find that foreign exchange risk is significant to the Australian bank return generating process. Second, while exposed to adverse fluctuations in the foreign exchange rate, Australian banks may simply have adequately hedged their foreign exchange rate exposure throughout the sample period. Support for this argument is found in several different sources. Gizycki and Lowe (2000: 189), for example, found that while "…around 70 per cent of foreign borrowing by financial institutions is denominated in foreign currency, these institutions do not have large foreign currency risks, with the currency risk typically hedged through the swaps market. One indicator that the banks' foreign exchange risk is small is that the aggregate regulatory capital charge for the Australian banks' market risk (which includes foreign exchange risk) accounts for just 1 per cent of the total capital requirement, compared to over 5 per cent for the large Canadian and German banks, and over 10 per cent for the large Swiss banks". Similarly, Bank for International Settlements (BIS) statistics suggest that while net foreign currency liabilities currently represent around 13 percent of Australian banking assets, exposure to foreign exchange movements is arguably negligible due to the vast bulk of this exposure being hedged, "…in the derivatives markets, predominately using such instruments as cross-currency swaps and foreign exchange forwards. These hedges are off-balance sheet items and therefore generally are only recorded "…when they acquire some value (either positive or negative)" or they are not recorded at all (RBA, 2000c: 47).

A third possibility is that while foreign exchange rate exposure is an important factor in the return generation process, the effect has already been incorporated within the market risk parameter. Unfortunately, this argument is somewhat lessened by the minimal correlation (0.019) between the foreign exchange rate and market indices correlations. A fourth possibility is that the proxy used for foreign exchange rate risk may not accurately reflect the true portfolio of foreign exchange risk to which Australian banks are exposed. That is, the weights of the currencies used to formulate the trade-weighted index may not be representative of the banks' actual investments (Benson and Faff, 2000). Finally, use of a bank portfolio rather than individual bank returns may obscure aspects of individual foreign exchange exposure. For example, while the major Australian banks have significant foreign currency exposure, the exposure of the smaller banks is much less.

5. Concluding remarks

This study employs an extended version of the Generalised Autoregressive Conditional Heteroskedasticity in Mean (GARCH-M) model to consider the time-series sensitivity of Australian bank stock returns to market, interest rate and foreign exchange rate risks. Daily Australian bank portfolio returns, a market wide accumulation index, short, medium and long-term interest rates, and a trade-weighted foreign exchange index are used to model these risks over the period 1996 to 2001. The results suggest that market risk is an important determinant of bank stock returns, along with short and medium term interest rate levels and their volatility. However, long-term interest rates and the foreign exchange rate do not appear to be significant to the Australian bank return generating process over the period considered.

The study extends previous work in this area in two ways. First and foremost, the study represents the first attempt to simultaneously model market, interest rate and foreign exchange rate risk in the Australian banking sector. Second, the study employs a GARCH-M methodology to undertake this modelling exercise, and thereby allows for volatility to vary with time. Nonetheless, the study does suffer from a number of limitations, all of which suggest future directions for research. First, by specifying a portfolio of bank returns rather than individual bank stock returns the analysis may have obscured interesting differences in market, interest rate and foreign exchange rate risks among individual banks. Future work in this area should attempt to highlight the differences between Australian banks in much the same way as the US literature draws comparisons between, say, money centre, large and regional banks. Second, while this study has much to say about risks in the bank return generation process in the post-deregulation era, it does not provide an indication of how this compares with risk in the pre-deregulation and deregulation periods. A new dimension could then include a longer sample period to throw light on these changes.

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