Volatility Persistence and Time-Varying Betas in the UK Real Estate Market

A Paper Presented at the ARES Annual Meeting
April 2002
Naples, Florida

By

Stephen L. Lee

Department of Land Management and Development,
School of Business, The University of Reading,
Reading RG6 6AW, England.

Phone: +44 118 931 6338, Fax: +44 118 931 8172, E-mail: S.L.Lee@reading.ac.uk

Abstract

This paper investigates the degree of return volatility persistence and the time-varying behaviour of systematic risk (beta) for 31 market segments in the UK real estate market. The findings suggest that different property types exhibit differences in volatility persistence and time variability. There is also evidence that the volatility persistence of each market segment and its systematic risk are significantly positively related. Thus, the systematic risks of different property types tend to move in different directions during periods of increased market volatility. Finally, the market segments with systematic risks less than one tend to show negative time variability, while market segments with systematic risk greater than one generally show positive time variability, indicating a positive relationship between the volatility of the market and the systematic risk of individual market segments. Consequently safer and riskier market segments are affected differently by increases in market volatility.

Keywords: *Volatility Persistence, Time Varying Betas, UK Real Estate Returns.*

Volatility Persistence and Time-Varying Betas in the UK Real Estate Market

1. Introduction

There is increasing evidence to support the persistence and time-varying volatility of equity market across the world (e.g. Poon and Taylor, 1992, Schwert and Seguin 1990). In particular, the studies show that the first order autocorrelation in returns increases in periods of low volatility and decreases in periods of high volatility (Senta and Wadhwani, 1992 and LeBaron, 1992). In other words, volatility and autocorrelation are significantly negatively related. This is a phenomenon that is not limited to equity markets, (e.g. Koutmos, 1994 and Giovannini and Jorian, 1989). Examination of the persistence of volatility across different asset markets is important as Giovannini and Jorian (1989) find that the statistical performance of capital asset pricing models improves significantly when the conditional variance in time series returns is not constrained to be constant over time. Recent studies use the ARCH methodology to jointly model the mean and volatility of time series returns of an asset. The general conclusions of which are that volatility persistence can last a considerable time and that the duration of such persistence depends on the assets under investigation. However, despite the extensive evidence of the persistence of volatility in equity market there is no work focusing on the behaviour of volatility persistence in the direct real estate market.

There is considerable evidence that suggests that the systematic risk of equity markets are time varying for individual stocks and portfolios of differing sizes, Blume (1971, 1975), Ohlson and Rosenberg (1982), Lee and Chen (1982), Bos and Newbold (1984), Simmonds et al. (1986) and Collins et al (1987). In contrast, only one study formally investigated the instability in real estate portfolio betas, Lee (2001). The author concludes that real estate portfolio betas are unstable and that this instability is not related to a specific property-type or region. This implies that the systematic risk of an asset cannot be assumed to be constant over time and needs to be modelled by a time-varying parameter. This is particularly important as it implies that when the systematic risk of an asset is estimated using ordinary least squares (OLS) regression techniques and it is assumed that the beta is a constant, when in fact the beta is time varying, the residuals will be heteroskedastic. As a result, the beta estimate will be inconsistent and any inference about the significance of the result will be compromised. Schwert and Seguin (1990) discuss the implications of such heteroskedasticity for testing capital asset pricing models and propose a single index market model (SIMM) for US equities yielding time-varying betas, an approach that as been successfully applied to international equity markets by Koutmos *et al* (1994).

The purpose of this paper is to present evidence on the time-varying behaviour and volatility persistence in 31 markets segments in the UK real estate market using 14 years of monthly data. The volatility behaviour of the returns of these market segments is also compared to that of the value-weighted market index. Then using the method proposed by Schwert and Seguin (1990), time-varying betas are estimated for each of the 31 market segments.

The remainder of the paper is organised as follows. The next section discusses the data used and presents preliminary results. Section three describes the statistical methodology employed to study volatility persistence and presents the results of the analysis. Section four then presents the model of Schwert and Seguin (1990) and the results for the time-varying betas. Finally, section five concludes the paper and suggests directions for future research.

2. Data and Preliminary Findings

The data used in this study are the monthly total returns data complied by the Investment Property Databank (IPD), covering the period 1987:1 to 2000:12, a total of 168 observations. The data divided into a number of property-types and geographical regions making a total of 31 real estate market segments. The returns of the market index (IPDMI) are represented by the value-weighted performance of all the properties within the database. Monthly returns were calculated as the change in the logarithm of successive return indices of the various market segments, that is, $R_t = 100 * \log(I_t / I_{t-1})$, where: R_t is the return at time t; I_t is the return index at time t and I_{t-1} is the return index at time t-1.

Table 1 contains summary statistics for the monthly return series of the market index and the 31 market segments. An examination of Table 1 indicates that the industrial sector offered the highest returns on average over the period of analysis, the office sector showing the least. The retail sector presented the lowest risk (standard deviation) and the office sector the highest. All market segments display significant positive skewness, except for offices in the City of London, which shows significantly negative skewness. In contrast, returns of the market index are fairly symmetric. The market and all the markets segments showed significant positive excess kurtosis (i.e. greater than 3). Thus, all the time series data are leptokurtic and so display greater peakedness than expected from normally distributed data. All the market segments exhibit significant departures from normality at the 1% level, as shown by the Jarque-Bera (JB) statistic, while the returns of the market index are significant at the 10% level. Such departure from normality can be credited to the presence of a high proportion of zero returns and too few larger negative and positive returns. This can be attributed to the thinly traded nature of direct property where new information is infrequent and is only slowly impounded into valuations, upon which the capital returns are based, Lizieri and Ward (2000).

Table 1 also shows the unit root (stationary) tests for the logarithm of the index values and returns series. A number of alternative tests are available for testing whether a series is stationary or not, the Augmented Dickey-Fuller (ADF), Dickey and Fuller (1979), as well as the Phillips-Perron (PP) test developed by Phillips (1987) and Phillips and Perron (1988). However, the ADF test is only valid under the crucial assumption that the data is homoskedasticity and shows no evidence of autocorrelation. To correct for this the ADF test requires the introduction of lagged first difference terms, which introduces the question of the required lag order. The usual, but not helpful, advice is to include lags of sufficient length to whiten the residuals. In contrast, the PP tests do not require the assumption of homoskedasticity of the error term (Phillips, 1987), and uses a nonparametric correction for autocorrelation. Consequently, the PP tests provide unit root tests results that are robust to both serial correlation and heteroskedasticity in the residuals. The following analysis, therefore, employs the PP test. Acceptance of the null implies that the data exhibits a unit root and that further differencing of the series is necessary to investigate its stochastic properties. The results in Table 2 indicate that there is a unit root in the logarithm of the indices in all cases; however, the null is rejected for the return series.

Table 1: Summary Statistics for the Market Index and the 31 Segments: Monthly Data 1987:1 to 2000:12

Market Segment	Mean	SD	Sks	Kurt	JB	PP(In)	PP(R)
Retail Central London	0.93	1.33	0.46	9.98	347.1	-0.92	-7.91
Retail Rest of London	0.73	0.84	1.01*	4.64*	47.7	-1.75	-6.68
Retail Inner South East	0.62	1.01	1.19*	6.51	125.4	-1.71	-7.28
Retail Outer South East	0.65	0.89	1.43*	6.61	148.7	-2.77	-7.37
Retail Eastern	0.64	0.88	0.85*	5.86	77.5	-1.77	-8.13
Retail South West	0.61	0.84	0.77*	6.16	86.5	-1.66	-8.04
Retail East Midlands	0.80	0.92	2.01*	10.83	542.0	-2.55	-9.90
Retail West Midlands	0.66	0.84	1.20*	7.97	213.3	-1.78	-9.01
Retail Yorkshire & Humberside	0.73	0.87	1.01*	5.65	77.7	-1.61	-8.88
Retail North West	0.73	1.01	1.63*	11.93	632.7	-1.61	-7.78
Retail North East	0.61	0.95	0.32	7.50	144.5	-1.44	-10.06
Retail Scotland	0.86	0.95	1.89*	12.98	797.0	-1.53	-8.35
Retail Wales	0.85	0.89	1.35*	7.61	200.3	-1.79	-10.73
Offices City of London	0.47	1.66	-1.08*	8.94	279.4	-0.40	-7.70
Offices Mid-Town	0.73	1.71	0.04	5.15	32.5	-0.99	-6.33
Offices West End	0.93	1.55	0.81*	8.52	231.9	-1.21	-6.55
Offices Rest of London	0.88	1.14	0.52	3.93	13.5	-0.44	-7.68
Offices Inner South East	0.76	1.06	-0.23	4.62	19.9	-0.60	-6.99
Offices Outer South East	0.74	1.11	0.79*	5.12	48.9	-1.71	-7.65
Offices Eastern	0.88	1.47	2.36*	19.57	2077.5	-1.65	-8.11
Offices South West	0.86	1.34	0.33	5.96	64.3	-1.84	-7.56
Offices Midlands & Wales	0.93	1.06	1.67*	7.81	240.1	-1.84	-9.74
Offices Rest of England	1.14	1.34	1.73*	6.42	165.7	-2.38	-8.23
Offices Scotland	0.76	1.26	1.47*	7.92	230.1	-1.72	-7.38
Industrials London	1.09	1.10	1.43*	10.14	413.9	-1.66	-7.93
Industrials Inner South East	0.93	1.06	0.45	3.66*	8.9	-1.53	-7.59
Industrials Outer South East	1.09	1.07	0.91*	4.98	50.7	-2.37	-8.13
Industrials Eastern	1.06	1.24	0.88*	6.37	101.0	-2.28	-8.31
Industrials South West	1.16	1.12	1.74*	8.88	326.3	-2.49	-9.20
Industrials Midlands & Wales	1.21	1.18	1.42*	6.78	156.2	-2.29	-6.80
Industrials Northeast &Scotland	1.26	1.11	1.42*	5.42	97.3	-2.17	-8.15
Retail Average	**0.73**	**0.94**	**1.16**	**8.02**	**264.7**	**-1.76**	**-8.47**
Office Average	**0.83**	**1.34**	**0.77**	**7.63**	**309.5**	**-1.34**	**-7.63**
Industrial Average	**1.11**	**1.13**	**1.18**	**6.60**	**164.9**	**-2.11**	**-8.02**
Overall Average	**0.85**	**1.12**	**1.03**	**7.56**	**258.0**	**-1.69**	**-8.07**
IPDMI	**0.84**	**0.85**	**0.28**	**3.59**	**4.6***	**-1.47**	**-6.12**

Note: Sk is the skewness statistic * indicates significance at the 5% level. Kurt is the Kurtosis statistics. All the kurtosis values are significant at the 5% level, except * which is significant at the 10% level
JB is the Jarque-Bera statistic for normality. All the JB statistics are significant at the 1% level.
PP is the Phillips-Perron test for stationarity. The critical value for the PP tests is –4.02 at the 1% level.

Inspection of the correlograms for each market segment and the market index indicates that the returns exhibit significant autocorrelation, see Table 1 in the appendix. In particular, the industrial sector tends to have autocorrelation coefficients that are greater in magnitude and significance, at all lags, while the retail sector shows the least. The autocorrelation coefficients are generally smaller as the lag length increases, especially for the retail sector, nonetheless for all market segments and the market index the autocorrelation statistics up to the 12th lag are significantly different from zero, based on Ljund-Box (LB) Q-statistics.

Table 2, in the appendix, shows the correlograms for the squared returns. Here a number of changes in the pattern between the squared returns and the underlying return series can be detected. First, the autocorrelation coefficients are significant up to lag two for all market segments and the market index, except for the Central London retail segment and offices in the City of London and the Eastern region. Beyond the first two lags the autocorrelation coefficients of the squared returns become increasing significant as the lag length increases. This implies that non-linear dependency is prevalent in all market segments and the market index. Strong autocorrelation in the squared returns is also a symptom of changing unconditional or conditional variance. Secondly, although the industrial sector still shows the greatest autocorrelations by magnitude and significance, it is now the office sector that shows the least values. This suggests that the volatility of industrial sector is likely to be more clustered than the volatility of the office sector.

In summary, the preliminary analysis indicates that the returns are more skewed and leptokurtic than normal and that while the returns are stationary the index values are not. Finally, there is evidence of linear and non-linear dependencies in the return series suggesting that the conditional variance may be time dependent. Thus further investigation of the stochastic properties of the various returns series necessarily involves proper modelling of these dependencies.

3. Modelling Volatility Persistence

The presence of linear dependency in the return series suggests that the conditional mean of the return distribution is a function of either past residuals (Scholes and Williams, 1977) or past returns (Lo and MacKinlay, 1988). Likewise, the presence of second-moment dependencies suggests that the conditional variance is time-dependent and heteroskedastic. Thus the conditional mean and variance of each return series is modelled using the Generalised AutoRegressive Conditional Heteroskedastic (GARCH) family of statistical processes to capture the effect of changing volatility in a time series (see Engle, 1982 and Bollerslev, 1986). Following Bollerslev (1986), we specify the conditional variance as a GARCH(p,q) process, where the conditional variance h at time t is a function of its past squared errors (from the mean equation) and its own conditional variance h:

$$h_t = m + \sum_{i=1}^{p} b\varepsilon_{t-i}^2 + c\sum_{i=1}^{q} h_{t-i} \qquad (1)$$

where p and q are the order of the process. That is the conditional variance at time t is a linear function of the previous p period errors squared and its own conditional variance up to period q. This autoregressive specification can, therefore, capture any persistence in return volatility. In addition, with financial data, this model captures the tendency for volatility clustering, identified by Fama (1965) and Mandelbrot (1963). The sum of the b and c measures the degree of persistence in the conditional variance process. For stability of the volatility process, the coefficients of the lagged errors (b) and lagged conditional variances (c) must sum to less than one.

Several addition characteristics of real estate returns need to be incorporated into the model. The high cost of obtaining information and length of time needed to negotiate the purchasing and selling of property in direct real estate markets would suggest that serial correlation within real estate returns is possible, without implying any inefficiency in the pricing. However, the incident of “appraisal bias” may imply pricing inefficiency. Because these institutional factors can induce a serial correlation in these returns, while the GARCH models assume that the conditional error is serially uncorrelated, it is necessary to extract this serial correlation from the real estate return’s first moment. To allow for such serial correlation Bollerslev (1987) and French *et al* (1987) adjust the conditional mean return equation by means of a first-order moving average term, MA(1)[1]. In particular, Poon and Taylor (1992) argue that inclusion of an insignificant MA term is unlikely to affect the reliability of the inferences but the consequences of ignoring a relevant MA term can be severe.

[1] While the use of a MA(1) process may not fully capture all the effects of a thin market, sensitivity analysis shows that the use of an AR(1) instead of the MA(1) process does not substantially alter the magnitude or significance of the coefficient estimates.

The pattern of autocorrelation, reported in Tables 1 and 2 of the appendix, is consistent with an ARMA process in the returns series of the various market segments. Consequently an ARMA(1,1) specification in the conditional mean is used so as to provide a parsimonious representation of the autocorrelation in the returns series. Hence the full specification that is estimated is an ARMA(1,1)-GARCH(1,1)[2] process, where the mean equation is given in equation 2:

$$R_{i,t} = \mu_i + \phi_i R_{i,t-1} + \varepsilon_{i,t} - \theta\varepsilon_{i,t-1} \quad (2)$$

where $R_{i,t}$, is the return of the *ith* market segment in month t, $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$ and Ω_{t-1} is the set of all available information at time t-l. The autoregressive coefficient ϕ, captures first-order autocorrelation in the series[3], while the moving average coefficient θ, provides a parsimonious representation of the decay in the autocorrelation function of the returns. The conditional variance equation to be estimated is given by the following:

$$h_t = m + b_i\varepsilon^2_{t-j} + c_i h_{t-1} \quad (3)$$

In equation 3 the conditional variance h is modelled as a GARCH(1,1)[4] process thus the coefficient b measures the impact of past volatility shocks (i.e. past squared unexpected returns from equation 2) has on the current conditional variance, while the coefficient c measures the impact of past conditional variance as on current conditional variance, that is the collective impact of all past shocks on the current conditional variance. Given $b, c \geq 0$, a large shock to the variance in the current period will increase the variance in the next period, thereby increasing the chance of a large shock in the next period. Moreover, as $(b + c) \rightarrow 1$, the impact of these shocks becomes more persistent.

The ARMA(1,1)-GARCH(1,1) model estimated the each of the 31 market segments and the market index, the results presented in Table 2. Statistical inference regarding the coefficients is based on robust standard errors derived by Bollerslev and Woodridge (1992) in order to allow for possible violations of the assumption of normality, as conventional approaches tend to underestimate the true standard errors.

As can be seen in Table 2 all of the coefficients in the mean equation have the correct signs. In addition, the coefficient of the returns lagged one period and the MA terms are all significant at the 1% level in all market segments. The impact of lagged returns is greatest, on average, in the office sector (0.935) and least in the retail sector (0.896). Interestingly, there is a tendency for the coefficient value to fall the further away the segment is from London and the Southeast. This indicates that the effect of past returns is greatest for the office sector, especially in the South, and least for the retail sector as suggested by the autocorrelation functions in Tables 1 and 2 in the appendix.

---

[2] In a different context Brown and Ong (1998) derive a similar representation of monthly returns in the UK.

[3] Second and third order lags were also considered but proved insignificant. A first order lag in returns is also consistent with the optimal behaviour of valuers in carry out appraisals, Quan and Quigley (1991).

[4] Alternative specifications were also tried such as GARCH(1,2) and GARCH(2,2) but the GARCH(1,1) proved to be the model with the greatest log likelihood ratio. Confirming the argument of Engle (1995) that the GARCH(1,1) remains "the leading generic model for almost all classes of returns."

Table 2: ARMA(1,1)-GARCH(1,1) Results for the Market Index and the 31 Segments

Market Segment	m	R_{t-1}	MA1	m	b	c	HL	Sk	Kurt	JB
Retail Central London	0.052	0.927	-0.521	-0.008	0.110	0.880	69	1.03*	8.58	246.2
Retail Rest of London	0.113	0.874	-0.312	0.284	0.003	0.046	0	1.28*	7.33	176.0
Retail Inner South East	0.023	0.906	-0.515	0.038	0.269	0.686	15	0.30	5.08	32.7
Retail Outer South East	0.065	0.869	-0.349	0.005	0.091	0.884	28	1.36*	7.46	189.5
Retail Eastern	0.047	0.915	-0.396	0.012	0.013	0.944	10	0.81*	7.56	162.9
Retail South West	0.063	0.864	-0.428	0.103	0.424	0.333	2	0.24	6.06	66.9
Retail East Midlands	0.030	0.945	-0.466	0.076	0.454	0.405	5	0.43	3.77	9.2*
Retail West Midlands	0.034	0.968	-0.626	0.286	0.678	0.091	1	0.69*	4.53	29.8
Retail Yorkshire & Humberside	0.037	0.929	-0.439	0.111	0.745	0.187	10	-0.11	6.09	66.9
Retail North West	0.041	0.886	-0.280	0.044	0.341	0.621	18	0.07	6.00	62.6
Retail North East	0.092	0.827	-0.537	0.530	0.423	0.053	1	-0.53	8.46	215.4
Retail Scotland	0.089	0.900	-0.476	0.070	0.304	0.571	5	1.17*	5.81	93.3
Retail Wales	0.151	0.844	-0.455	0.375	0.135	0.222	1	1.05*	7.05	145.0
Offices City of London	0.042	0.953	-0.668	-0.006	0.002	0.985	52	-0.28	7.85	165.7
Offices Mid-Town	0.053	0.956	-0.612	-0.001	0.049	0.944	100	-0.04	5.83	55.9
Offices West End	0.077	0.936	-0.479	0.005	0.021	0.960	35	0.91*	8.95	269.2
Offices Rest of London	0.058	0.952	-0.560	0.020	0.122	0.842	19	0.76*	4.91	41.4
Offices Inner South East	0.049	0.943	-0.435	-0.001	0.045	0.944	62	-0.10	8.44	206.5
Offices Outer South East	0.028	0.980	-0.546	0.036	0.430	0.560	69	0.31	5.82	58.2
Offices Eastern	0.034	0.918	-0.467	0.500	0.780	0.061	4	-0.08	6.76	98.3
Offices South West	0.075	0.921	-0.509	0.000	0.070	0.925	151	0.17	7.02	113.5
Offices Midlands & Wales	0.082	0.903	-0.616	0.007	0.097	0.886	41	1.18*	5.79	93.3
Offices Rest of England	0.092	0.889	-0.493	-0.004	0.034	0.953	53	0.77	4.14	25.8
Offices Scotland	0.050	0.933	-0.466	0.005	0.018	0.960	31	1.53*	11.49	566.5
Industrials London	0.090	0.929	-0.510	0.061	0.285	0.646	10	0.63	7.22	135.1
Industrials Inner South East	0.038	0.974	-0.564	0.013	0.049	0.897	13	0.50	3.80	11.4
Industrials Outer South East	0.059	0.950	-0.559	0.014	0.310	0.680	69	0.54	3.26	8.5*
Industrials Eastern	0.084	0.914	-0.545	0.000	0.020	0.963	39	0.34	4.49	18.8
Industrials South West	0.115	0.881	-0.333	0.016	0.420	0.575	138	0.70*	5.51	57.4
Industrials Midlands & Wales	0.110	0.878	-0.510	0.001	0.300	0.695	138	0.17	4.67	20.2
Industrials Northeast &Scotland	0.105	0.901	-0.444	-0.001	0.048	0.937	43	0.72*	4.28	25.7
Retail	**0.064**	**0.896**	**-0.446**	**0.148**	**0.305**	**0.434**	**13**	**0.60**	**6.45**	**115.1**
Office	**0.058**	**0.935**	**-0.532**	**0.051**	**0.152**	**0.820**	**56**	**0.47**	**7.00**	**154.0**
Industrial	**0.086**	**0.918**	**-0.495**	**0.015**	**0.204**	**0.770**	**64**	**0.51**	**4.75**	**39.6**
IPDMI	**0.039**	**0.958**	**-0.313**	**0.017**	**0.148**	**0.728**	**5**	**-0.25**	**8.86**	**241.0**

Note: Sk is the Skewness statistic, * indicates significance at the 5% level. Kurt is the kurtosis statistic and all the values are all significant at the 5% level. JB is the Jarque-Bera test is a test of normality. All JB statistics are significant at the 5% level except those marked *.

The conditional variance equation for the market index and all 31 market segments shows the b and c coefficients are all highly significant. The high significance of both coefficients confirm the findings of previous studies, in the equity and bond markets, see for example Poon and Taylor (1992), Hamao *et al* (1990). In addition, the log-likelihood ratio test rejects the hypothesis of homoskedastic returns of all market segments and the market portfolio. This implies that conditional heteroskedasticity is present in each of the market segment return series and the market index.

Looking in detail across the market segments clearly there is a lack of homogeneity across and within the property-types concerning the magnitude of b and c. For instance the magnitude of b that captures the impact that unexpected return has on volatility the next month ranges from 0.013 to 0.780. Across the individual property types we can see that on average the greatest impact is on the retail sector (0.305) followed by industrials (0.204) and then the office sector (0.152). This means that a return shock in the retail sector causes over twice as much volatility in the next month as a return shock to the office sector.

The c coefficient, which captures the tendency for shocks to the conditional variance to persist, are just as heterogeneous with the values ranging from 0.091 to 0.985. The greatest impact is on average for the office sector (0.820), especially in London, and the least in the retails sector (0.434), particularly the further away the region is from London. Volatility persistence, as measured by the sum of b and c, is high for all market segments but always less than 1. In particular the combination of b and c suggests that shocks to the volatility of the office and industrial sectors are much more persistent than shocks to the retail sector. A more intuitive way of measuring persistence in the volatility processes is to calculate the half-life (HL) of a shock to the process, that is, the time that it takes for half of the shock to have dissipated, where the HL for the *ith* segment may be calculated as $HL_i = \log(0.5)/(\log(b_i + c_i))$. In the case of the retail sector the HL is just over one year at 13 months on average, for the office sector the figure is just under four years at 40 months, whereas for the industrial sector, the HL is about over five years at 64 months.

Finally, Table 2 presents several diagnostic tests performed on the standardised residuals for the purpose of testing the robustness of the results and the adequacy of the models. A particular appealing property of the GARCH model is that it allows the series to have excess kurtosis without violating the normality assumption, and therefore to be symmetric, Engle (1982). Nonetheless, all standardised residuals still display evidence of non-normality, as indicated by the JB tests, except for retails in the East Midlands and industrials in the Outer Southeast. However, the sizes of the skewness and kurtosis statistics are, in the main, of a lower magnitude and significance than the original returns. For instance, the skewness statistics of the standardised residuals is now only significant for 13 of the market segments compared with 24 for the original series. This suggests that the standardised residuals are closer to normality than the original data. In this respect, the estimated models appear to explain of the normality violations in the original return series. Inspection of the correlograms of the standardised residuals (Table 3 in the appendix) indicates that the first and second order residuals are below their critical values, rejecting the hypothesis of linear dependencies in each market segment and the market index. However, LB Q-statistics for lags 6 and 12 still show significant dependencies at these higher lags, for a number of segments. Be that as it may the correlograms and the LB Q-statistics of the squared standardised residuals (Table 4 in the appendix), shows that non-linear dependencies have been eliminated for all segments and the market index and at all lags. This indicates that the model fares well in terms of accounting for the heteroskedasticity and changing unconditional or conditional variance in the original series.

4. Time-Varying Betas

The simplest way to calculate a portfolio beta is to use the single index market model (SIMM) that links the returns of the asset to the returns of a market index by the following equation:

$$r_{it} = \alpha + \beta_i r_{mt} + \varepsilon_{it} \quad \text{for } t = 1, \ldots\ldots T \tag{4}$$

where r_{it} is the return of the *ith* asset at time t, r_{mt} is the return of the market index at time t, β (beta) is the slope coefficient of the regression measuring the change in the asset's returns relative to those of the market and α (alpha) is a measure of the asset's returns independent of the market.

Schwert and Seguin (1990) suggest that the time-varying beta conditional upon the market volatility can be modeled by the following equation:

$$\beta_i = \beta_i + \delta_i / \sigma^2_{mt} \tag{5}$$

where σ^2_{mt} is the conditional variance of returns of the market index. According to equation 5, the time-varying beta consists of a constant term β and a time-varying term δ. A positive δ implies that the systematic risk of the *ith* assets varies inversely with market volatility, whereas a negative δ implies that systematic risk and market volatility is positively related. In other words if δ is negative (positive), increases in market volatility leads to an increase (decrease) in the beta of the asset, other things held constant. Substituting equation (5) into equation (4) gives the following heteroskedastic market model (HMM):

$$r_{it} = \alpha + \beta_i r_{mt} + \delta_i (r_{mt} / \sigma^2_{mt}) + \varepsilon_{it} \quad \text{for } t = 1,......T \qquad (6)$$

Table 3 presents the heteroskedasticity consistent estimates of equation (6) using the Newey-West method. The conditional variance of the market index derived from the ARMA(1,1)-GARCH(1,1) model shown in Table 2.

The time-varying coefficient δ is negative for all regions in the retail sector, significantly so for 9 regions at the 10% level. This implies that as the volatility of the market increases the systematic risk of the retail sector increases. In contrast δ is positive for 7 of the 11 office regions, 4 significant at the 10% level. The significantly positive coefficients concentrated in London and the Southeast. Thus, an increase in market volatility tends to lead to a fall in the systematic risk of offices, especially in the Southeast. This implies that the systematic risk of the retail and office property-types tend to move in opposite directions in periods of increased market volatility. In contrast, the incidence of negative and positive δ coefficients in the industrial sector is almost equally split between the regions. Interestingly the positive values are concentrated in the South and negative values in the North, with the northern regions displaying the greater evidence of significance. Consequently, different property-types and different regions behave differently with increases in market volatility.

Table 3 shows that the on average the time varying estimates of β are almost identical to those of the SIMM, 1.032 compared with 0.990. This provides evidence that the results in the first part of Table 3 are not driven by any interaction between the two explanatory variables. Further evidence is provides by the adjusted R-squared values of the models. The adjusted R-squared values of the SIMM are nearly identical to those of the time varying model. Therefore, the improvement in explanatory power can be attributed to the market volatility term.

Table 3 also shows that on average for those market segments with betas less than one, the δ coefficient tends to be negative, while the market segments with betas greater than one δ are positive. There is a significantly negative relationship (-0.36, p=0.047) between the systematic risk and time-varying coefficients, based on the Spearman rank correlation test. This supports the view that safe and risky assets are affected differently by increases in market volatility. Finally, there is a significantly positive correlation between systematic risk and volatility persistence (0.49, p=0.005). This implies that the market segments with the greatest volatility persistence generally show negative δ coefficients, indicating a direct relationship between market volatility and systematic risk.

Table 3: Beta Estimates of SIMM and HMM

	HMM				SIMM	
Market Segment	**a**	**b**	**d**	**AdjRSq**	**b**	**AdjRSq**
Retail Central London	0.056	1.124	-0.009	46.2	1.068	46.4
Retail Rest of London	0.078	0.943	-0.019*	70.3	0.825	69.6
Retail Inner South East	-0.116	1.154	-0.032*	66.0	0.960	64.5
Retail Outer South East	0.026	1.041	-0.035*	64.1	0.828	61.6
Retail Eastern	-0.019	0.866	-0.008	65.5	0.821	62.9
Retail South West	-0.009	1.019	-0.032*	71.0	0.823	68.6
Retail East Midlands	0.210	1.001	-0.034*	55.6	0.795	53.6
Retail West Midlands	0.087	0.990	-0.035*	63.3	0.772	60.3
Retail Yorkshire & Humberside	0.106	0.939	-0.022*	61.5	0.803	60.6
Retail North West	0.075	1.003	-0.026*	51.4	0.847	50.6
Retail North East	0.116	0.683	-0.011	30.0	0.618	30.2
Retail Scotland	0.291	0.987	-0.036*	48.9	0.769	46.8
Retail Wales	0.370	0.786	-0.024	37.1	0.637	36.2
Offices City of London	-0.769	0.696	0.089*	44.9	1.243	40.2
Offices Mid-Town	-0.705	1.451	0.028	64.7	1.620	64.3
Offices West End	-0.429	1.090	0.057*	64.3	1.435	61.4
Offices Rest of London	-0.051	0.984	0.013	62.8	1.066	62.8
Offices Inner South East	-0.254	0.898	0.035*	80.6	1.112	78.5
Offices Outer South East	-0.153	0.843	0.024	57.8	0.993	57.2
Offices Eastern	-0.218	1.107	0.022	51.5	1.242	51.4
Offices South West	-0.117	1.425	-0.030*	62.6	1.244	61.9
Offices Midlands & Wales	0.292	0.812	-0.006	37.5	0.773	37.8
Offices Rest of England	0.316	1.212	-0.029	44.3	1.031	42.1
Offices Scotland	-0.124	1.106	-0.006	51.6	1.072	51.6
Industrials London	0.203	0.943	0.012	60.8	1.014	60.8
Industrials Inner South East	0.013	0.849	0.027*	67.2	1.014	66.3
Industrials Outer South East	0.271	1.008	-0.004	60.7	0.984	60.8
Industrials Eastern	-0.004	1.082	0.020	68.3	1.205	68.0
Industrials South West	0.407	1.254	-0.040*	61.7	1.014	58.6
Industrials Midlands & Wales	0.372	1.387	-0.046*	65.1	1.106	62.6
Industrials Northeast &Scotland	0.575	1.311	-0.058*	58.5	0.956	53.5
Retail Average	**0.098**	**0.964**	**-0.025**	**56.2**	**0.813**	**54.8**
Office Average	**-0.201**	**1.057**	**0.018**	**56.6**	**1.166**	**55.4**
Industrial Average	**0.262**	**1.119**	**-0.013**	**63.2**	**1.042**	**61.5**
Overall Average	**0.029**	**1.032**	**-0.007**	**57.9**	**0.990**	**56.5**

Note: all β_1 values are significant at the 1%, β_2 marked with * are significant at the 10% level.

5. Conclusions

Estimates of the volatility of returns are essential for measuring the systematic risk (beta) of assets. This paper presents evidence of non-linearity in the variance of real estate returns for all market segments in the UK and finds that first order serial correlations are negatively related to the conditional variance of returns. The estimated ARMA(1,1)-GARCH(1,1) model for each market segment and the market index shows that different property types display differences in volatility. Then using the time varying model of Schwert and Seguin (1990), the results shows that different property types display differences in time variability. There is also evidence that the volatility persistence of each market segment and its systematic risk are significantly positively related. Thus, the systematic risks of different property-types tend to move in different directions during periods of increased market volatility. Finally, low risk market segments (i.e. with betas less than one) tend to show negative time-variability, while high risk market segments (i.e. with betas greater than one) generally show positive time-variability, indicating a positive relationship between the volatility of the market and individual market segments systematic risk. Consequently safer and riskier market segments are affected differently by increases in market volatility.

Finally, there are at least two issues that need to be addressed when considering the estimation of the models in this study. First, the capital values of individual properties upon which the return series are based may be subject to appraisal bias; see Fisher, *et al* (1994) and Corgel and deRoos (1999) for comprehensive reviews. Consequently, this leads to significant serial correlation in the market index due to the temporal and cross sectional aggregation of individual property valuations (Geltner, 1991 and Brown and Matysiak 1998). This serial correlation in the market index may affect the significance and consistency of the parameter estimates (Fowler *et al*, 1979). Nonetheless, the GARCH model presented is designed to account for any heteroskedasticity and serial autocorrelation within the residuals. The second issue is the impact that volatility spillovers across property-types and geographical regions may have on the results. For instance, due to the close geographical proximity of each market segment within and between the different property types, it is quite likely that shocks in one market segment may spillover into others, leading to increases in conditional volatility in that market segment in addition to, or irrespective of, increases in volatility in the market index. Testing for both these impacts should prove a useful area of future research.

References

Blume, M. E. (1971) On the Assessment of Risk, *Journal of Finance*, **26**, 1-10.

Blume, M. E. (1975) Betas and their Regression Tendencies, *Journal of Finance*, **30**, 785-795.

Bollerslev, T. (1986), Generalized Autoregressive Conditional Heteroskedasticity, *Journal of Econometrics*, **31**, 307-27.

Bollerslev, T., Chou, R.Y. and Kroner, K.E (1992), ARCH Modelling in Finance: A Review of the Theory and Empirical Evidence, *Journal of Econometrics*, **52**, 5-59.

Bollerslev, T., Engle, R.E and Wooldridge, J.M. (1988), A Capital Asset Pricing Model with Time-Varying Covariances, *Journal of Political Economy*, **96**, 116-31.

Bos, T. and Newbold, P. (1984) An Empirical Investigation of the Possibility of Stochastic Systematic Risk in the Market Model, *Journal of Business*, **57**, 35-41.

Brown, G.R. and Ong, S-E. (1998) *Smoothing and Serial Cross Correlation in Property Returns*, Presented at the European Real Estate Society Meeting, Maastricht, June.

Collins, D. W. Ledolter, J. and Rayburn, J. (1987) Some Further Evidence on the Stochastic Properties of Systematic Risk, *Journal of Business*, **60**, 425-448.

Corgel, J.B. and deRoos, J.A. (1999) Recovery of Real Estate Returns for Portfolio Allocation, *Journal of Real Estate Finance and Economics*, **18**, 279-296.

Dickey, D.A. and Fuller, W.A. (1979) Distribution of the Estimators for Autoregressive Time Series with a Unit Root, *Journal of the American Statistical Association*, **74**, 427-431.

Engle, R.E (1982), Autoregressive Conditional Heteroskedasticity with Estimates of the Variance of UK Inflation, *Econometrica*, **50**, 987-1007.

Engle, R.E, Lilien, D. and Robbins, R. (1987), Estimating Time Varying Risk Premia in the Term Structure: the ARCH-M model, *Econometrica*, **55**, 391-407.

Fama, E. (1965), The Behaviour of Stock Market Prices, *Journal of Business*, **38**, 34-105.

Fisher, J.D., Geltner, D.M. and Webb, R.B. (1994) Value Indices of Commercial Real Estate: A Comparison of Index Construction Methods, *Journal of Real Estate Finance and Economics*, **9**, 137-164.

Fowler, D., Rorke, H. and Jog, V.M. (1978) Heterokedasicity, R^2 and Thin Trading on the Toronto Stock Exchange, *Journal of Finance*, December, 1201-1210.

French, K., Scwert, W. and Stambaugh, R., (1987) Expected Stock Returns and Volatility, *Journal of Financial Economics*, **19**, 3-29.

Giovannini, A. and Jorion, P. (1989) The Time Variation of Risk and Return in Foreign Exchange and Stock Markets, *Journal of Finance*, **44**, 307-325.

Hamao, Y., Masulis, R.W. and Hg, V. (1990) Correlation in Price Changes and Volatility Across International Stock Markets, *Review of Financial Studies*, **3**, 281-307.

Koutmos, G. (1994) Time Dependent Autocorrelation in EMS Exchange rates, *Journal of International, Financial markets, Institutions and Money*, **3**, 65-84.

Koutmos, G., Lee, U. and Theodossiou, P., (1994) Time-Varying Betas and Volatility Persistence in International Stock Markets, *Journal of Economics and Business*, **46**, 101-112.

LeBaron, B. (1992) Some Relations Between Volatility and Serial Correlation in Stock Market Returns, *Journal of Business*, **65**, 199-219.

Lee, C.F. and Chen, CR. (1982) Beta Stability and Tendency: An Application of the Variable Mean Response Regression Model, *Journal of Economics and Business*, **34**, 201-206.

Lee, S.L. (2001) *The Stability of Real Estate Portfolio Betas and the Portfolio Construction Process*, Presented at the 6th Annual Meeting of the Asian Real Estate Society (AsRES), Tokyo, Japan, August 1-3 2001.

Lo, A. and MacKinlay, C. (1990) An Econometric Analysis of Nonsynchornous Trading, *Journal of Econometrics*, **45**, 181-211.

Lizieri, C. and Ward, C.W.R. (2000) The Distribution of Real Estate Returns. In: Knight, J. and Satchell, S. (eds) *Return Distributions in Finance*. London: Butterworth-Heinemann, 2000, 47-74.

Mandelbrot, B. (1963), The Variation of Certain Speculative Prices, *Journal of Business*, **36**, 394-419.

Ohlson, J. and Rosenberg, B. (1982) Systematic Risk of the CRSP Equal-weighted Common Stock Index: A History Estimated by Stochastic Parameter Regression, *Journal of Business*, **55**, 121-145.

Perron, P. (1988) Trends and Random Walks in Macroeconomic Time Series: Further Evidence from a New Approach, *Journal of Economic Dynamics and Control*, **12**, 297-332.

Phillips, P.C.B. (1987), Time Series Regression with Unit Root, *Econometrica*, **55**, 2, 227-302.

Phillips, P.C.B. and Perron, P. (1988) Testing for a Unit Root in Time Series Regression, *Biometrika*, **75**, 335-346.

Poon, S-H. and Taylor, S.J. (1992), Stock Returns and Volatility: An Empirical Study of the UK Stock Market, *Journal Banking and Finance*, **16**, 37-59.

Sentana, E. and Wadhwani, S., (1992) Feedback Traders and Stock Return Autocorrelation: Evidence from a Century of Daily Data, *Economic Journal*, **102**, 415-425.

Scholes, M. and Willams, J. (1977) Estimating Betas from Nonsynchronous Data, *Journal of Financial Economics*, **5**, 309-386.

Schwert, W. and Seguin, P. (1990) Heteroskedasicity in Stock Returns, *Journal of Finance*, **45**, 1129-1155.

Simmonds, R., La Motte, L. and McWhorter, A. (1986) Testing for Nonstationarity of Market Risk: An Exact Test and Power Considerations, *Journal of Financial and Quantitative Analysis*, **21**, 209-220.

Appendix:

Table 1: Correlogram of the Market Index and the 31 Segments Monthly Returns

Market Segment	r 1	r 2	r 3	r 4	r 5	r 6	LB(1)	LB2(2)	LB(6)	LB(12)
IPDMI	**0.89**	**0.85**	**0.82**	**0.74**	**0.67**	**0.60**	**135.21**	**260.03**	**610.65**	**748.96**
Retail Central London	0.54	0.50	0.42	0.45	0.46	0.49	50.42	93.54	237.32	338.75
Retail Rest of London	0.74	0.63	0.64	0.55	0.54	0.52	92.49	160.22	383.67	451.78
Retail Inner South East	0.64	0.62	0.59	0.51	0.43	0.46	70.37	136.91	313.23	361.37
Retail Outer South East	0.71	0.59	0.57	0.49	0.46	0.47	86.46	146.97	320.74	384.75
Retail Eastern	0.63	0.64	0.55	0.52	0.38	0.35	67.81	138.30	285.76	325.34
Retail South West	0.69	0.66	0.61	0.49	0.43	0.37	82.19	156.54	320.38	348.37
Retail East Midlands	0.54	0.62	0.53	0.46	0.41	0.35	48.88	115.00	252.41	294.46
Retail West Midlands	0.56	0.51	0.55	0.45	0.38	0.30	54.21	99.54	228.01	258.70
Retail Yorkshire & Humberside	0.59	0.59	0.58	0.51	0.36	0.34	60.09	119.10	265.63	289.50
Retail North West	0.60	0.47	0.45	0.38	0.26	0.26	62.01	100.66	183.50	198.52
Retail North East	0.39	0.35	0.29	0.24	0.20	0.17	26.11	46.54	83.19	99.55
Retail Scotland	0.57	0.54	0.42	0.35	0.26	0.28	55.76	106.26	184.41	192.47
Retail Wales	0.41	0.28	0.33	0.25	0.16	0.23	28.10	41.82	85.15	88.32
Offices City of London	0.58	0.51	0.61	0.45	0.51	0.50	56.62	100.62	289.94	465.03
Offices Mid-Town	0.69	0.69	0.65	0.68	0.56	0.63	81.65	162.35	442.05	659.00
Offices West End	0.64	0.57	0.53	0.57	0.62	0.65	70.55	127.04	371.68	566.36
Offices Rest of London	0.68	0.60	0.64	0.52	0.52	0.52	77.90	140.51	353.45	447.03
Offices Inner South East	0.74	0.70	0.64	0.65	0.55	0.52	92.43	177.59	423.96	531.68
Offices Outer South East	0.64	0.59	0.52	0.49	0.44	0.47	69.75	129.07	291.00	338.54
Offices Eastern	0.46	0.51	0.58	0.44	0.43	0.38	36.15	81.39	229.96	302.28
Offices South West	0.68	0.63	0.66	0.57	0.50	0.45	80.09	148.55	358.86	426.36
Offices Midlands & Wales	0.45	0.40	0.62	0.41	0.30	0.44	34.72	62.18	207.28	236.08
Offices Rest of England	0.60	0.55	0.46	0.48	0.47	0.48	62.10	113.30	269.73	318.00
Offices Scotland	0.63	0.67	0.49	0.54	0.45	0.54	67.66	143.97	322.95	399.13
Industrials London	0.62	0.62	0.60	0.49	0.47	0.41	64.59	129.87	302.23	355.37
Industrials Inner South East	0.68	0.68	0.66	0.56	0.55	0.50	79.03	158.60	386.83	496.78
Industrials Outer South East	0.71	0.63	0.64	0.54	0.46	0.46	85.78	154.40	348.63	428.14
Industrials Eastern	0.60	0.61	0.63	0.57	0.50	0.52	61.61	125.76	343.02	465.99
Industrials South West	0.61	0.54	0.49	0.45	0.36	0.33	62.60	111.83	230.00	269.50
Industrials Midlands & Wales	0.71	0.68	0.68	0.52	0.45	0.35	86.92	167.17	351.33	385.76
Industrials Northeast &Scotland	0.69	0.71	0.60	0.62	0.42	0.45	80.43	167.97	362.92	424.59
Retail Average	**0.59**	**0.54**	**0.50**	**0.43**	**0.36**	**0.35**	**60.38**	**112.42**	**241.80**	**279.37**
Office Average	**0.62**	**0.58**	**0.58**	**0.53**	**0.49**	**0.51**	**66.33**	**126.05**	**323.71**	**426.32**
Industrial Average	**0.66**	**0.64**	**0.61**	**0.53**	**0.46**	**0.43**	**74.42**	**145.09**	**332.14**	**403.73**
Overall Average	**0.61**	**0.58**	**0.56**	**0.49**	**0.43**	**0.42**	**65.66**	**124.63**	**291.27**	**359.60**

All autocorrelation coefficients are significant at all lags.

Table 2: Correlogram of the Market Index and the 31 Segments Squared Returns

Market Segment	r 1	r 2	r 3	r 4	r 5	r 6	LB(1)	LB2(2)	LB(6)	LB(12)
IPDMI	**0.75**	**0.67**	**0.64**	**0.51**	**0.39**	**0.32**	**96.37**	**172.68**	**333.89**	**360.83**
Retail Central London	0.10	0.10	0.00	0.07	0.14	0.32	1.76*	3.38*	25.90	29.22
Retail Rest of London	0.57	0.34	0.40	0.33	0.34	0.42	55.19	75.27	173.87	188.75
Retail Inner South East	0.40	0.34	0.36	0.26	0.18	0.29	27.04	46.90	101.37	107.34
Retail Outer South East	0.54	0.27	0.21	0.18	0.17	0.34	49.67	61.78	100.37	127.67
Retail Eastern	0.26	0.39	0.21	0.25	0.06	0.24	11.55	37.76	67.40	83.14
Retail South West	0.44	0.49	0.37	0.17	0.12	0.04	32.46	74.02	105.28	107.47
Retail East Midlands	0.16	0.37	0.24	0.22	0.16	0.16	4.62	27.67	55.19	66.61
Retail West Midlands	0.29	0.22	0.40	0.14	0.05	0.04	14.58	23.14	54.95	56.30
Retail Yorkshire & Humberside	0.40	0.52	0.39	0.30	0.13	0.10	27.63	73.78	120.75	123.45
Retail North West	0.23	0.11	0.12	0.08	0.07	0.00	9.05	11.26	15.59	17.43
Retail North East	0.26	0.13	0.09	0.04	0.06	0.06	11.56	14.32	17.37	22.58
Retail Scotland	0.36	0.30	0.20	0.10	0.02	0.02	22.67	37.89	46.39	47.13
Retail Wales	0.34	0.13	0.18	0.08	0.02	0.06	19.98	22.66	30.17	32.33
Offices City of London	0.07	0.01	0.20	-0.02	0.10	0.05	0.79*	0.81*	9.88	29.60
Offices Mid-Town	0.23	0.20	0.21	0.46	0.12	0.29	8.63	15.75	77.84	99.75
Offices West End	0.19	0.07	0.06	0.13	0.28	0.37	6.18	7.11	47.88	60.58
Offices Rest of London	0.32	0.31	0.51	0.15	0.21	0.37	17.54	34.52	116.80	125.39
Offices Inner South East	0.34	0.35	0.20	0.38	0.16	0.13	20.04	40.63	79.87	81.74
Offices Outer South East	0.40	0.32	0.18	0.22	0.30	0.36	27.88	45.46	98.30	144.15
Offices Eastern	0.05	0.12	0.26	0.10	0.10	0.11	0.40*	2.87*	19.79	26.81
Offices South West	0.49	0.38	0.49	0.36	0.32	0.25	40.28	64.76	158.46	192.00
Offices Midlands & Wales	0.29	0.24	0.67	0.36	0.23	0.40	14.67	24.50	160.91	186.37
Offices Rest of England	0.40	0.39	0.27	0.32	0.42	0.47	27.92	54.04	153.68	199.33
Offices Scotland	0.26	0.42	0.18	0.34	0.14	0.41	11.63	41.77	101.07	139.43
Industrials London	0.23	0.29	0.22	0.20	0.19	0.20	8.65	23.01	51.63	69.65
Industrials Inner South East	0.34	0.40	0.41	0.32	0.39	0.28	20.23	48.27	134.59	191.22
Industrials Outer South East	0.62	0.50	0.41	0.28	0.26	0.34	65.86	108.32	183.42	261.62
Industrials Eastern	0.29	0.32	0.40	0.33	0.34	0.44	14.77	32.24	133.95	212.24
Industrials South West	0.37	0.34	0.24	0.24	0.14	0.16	23.86	43.58	71.57	96.87
Industrials Midlands & Wales	0.61	0.55	0.61	0.32	0.24	0.24	62.98	115.66	218.03	243.65
Industrials Northeast &Scotland	0.58	0.65	0.48	0.60	0.33	0.38	56.58	128.68	276.52	338.15
Retail Average	**0.34**	**0.28**	**0.25**	**0.17**	**0.12**	**0.16**	**22.13**	**39.22**	**70.35**	**77.65**
Office Average	**0.28**	**0.26**	**0.29**	**0.25**	**0.22**	**0.29**	**16.00**	**30.20**	**93.13**	**116.83**
Industrial Average	**0.43**	**0.44**	**0.40**	**0.33**	**0.27**	**0.29**	**36.13**	**71.40**	**152.82**	**201.91**
Overall Average	**0.34**	**0.31**	**0.30**	**0.24**	**0.19**	**0.24**	**23.12**	**43.28**	**97.06**	**119.61**

All autocorrelation coefficients are significant except those marked *.

Table 3: Correlogram of the Residual Returns

Market Segment	r 1	r 2	r 3	r 4	r 5	r 6	LB(1)	LB2(2)	LB(6)
IPDMI	**-0.01**	**0.01**	**0.01**	**-0.03**	**-0.05**	**0.04**	**0.02**	**0.05**	**0.98**
Retail Central London	-0.01	0.01	0.01	-0.03	-0.05	0.04	0.02	0.05	0.98
Retail Rest of London	0.06	0.08	0.08	-0.03	0.08	0.41	0.59	1.70	33.76*
Retail Inner South East	-0.01	0.00	-0.03	0.00	-0.05	0.04	0.01	0.02	0.83
Retail Outer South East	0.08	0.04	-0.04	-0.06	-0.02	0.00	1.21	1.51	2.60
Retail Eastern	0.07	-0.02	-0.03	-0.01	0.07	0.00	0.90	1.00	1.96
Retail South West	-0.05	0.00	0.04	-0.07	-0.03	0.09	0.38	0.38	2.94
Retail East Midlands	0.02	0.01	-0.10	0.03	0.03	0.10	0.04	0.05	3.74
Retail West Midlands	0.06	-0.02	0.17	0.01	-0.06	0.09	0.56	0.62	7.87
Retail Yorkshire & Humberside	0.01	-0.05	-0.01	0.03	0.00	-0.05	0.04	0.54	1.07
Retail North West	0.01	-0.02	-0.08	-0.03	0.11	-0.04	0.02	0.10	3.84
Retail North East	-0.03	-0.02	-0.06	-0.05	0.00	-0.03	0.11	0.19	1.39
Retail Scotland	0.00	0.15	-0.06	-0.06	-0.05	-0.02	0.00	3.79	5.51
Retail Wales	0.04	-0.01	-0.05	-0.01	-0.03	0.01	0.22	0.25	0.86
Offices City of London	0.06	-0.01	0.06	-0.01	-0.02	-0.04	0.69	0.72	1.58
Offices Mid-Town	-0.01	-0.06	0.06	0.05	-0.04	0.07	0.02	0.71	2.89
Offices West End	0.03	0.00	-0.01	-0.05	-0.05	0.13	0.18	0.18	3.88
Offices Rest of London	-0.04	-0.06	0.05	0.02	-0.03	0.04	0.32	1.03	1.91
Offices Inner South East	-0.03	-0.02	-0.01	0.08	-0.04	0.05	0.13	0.18	2.20
Offices Outer South East	0.12	-0.08	-0.08	0.00	0.07	-0.06	2.49	3.49	5.93
Offices Eastern	-0.05	-0.07	0.05	-0.03	-0.07	0.15	0.46	1.23	6.60*
Offices South West	0.05	-0.05	-0.02	-0.03	0.20	0.04	0.48	0.84	8.30*
Offices Midlands & Wales	-0.04	0.02	0.17	0.03	-0.07	0.16	0.29	0.37	10.67*
Offices Rest of England	-0.03	0.04	0.12	-0.09	-0.03	0.39	0.18	0.40	31.48*
Offices Scotland	0.00	-0.03	0.00	-0.04	-0.04	0.08	0.00	0.16	1.80
Industrials London	-0.06	0.17	-0.02	-0.08	-0.01	-0.03	0.52	5.28	6.58
Industrials Inner South East	-0.05	-0.03	-0.01	0.28	0.08	-0.04	0.36	0.54	15.05*
Industrials Outer South East	0.03	0.03	0.00	-0.04	-0.11	0.00	0.18	0.28	2.60
Industrials Eastern	0.00	0.00	0.09	-0.02	0.01	0.12	0.00	0.00	3.98
Industrials South West	-0.01	-0.07	-0.03	-0.04	-0.05	-0.05	0.02	0.94	2.28
Industrials Midlands & Wales	-0.06	-0.04	0.02	0.09	0.04	-0.11	0.59	0.80	4.34
Industrials Northeast &Scotland	0.01	-0.08	0.13	0.02	0.07	0.00	0.01	1.07	4.87
Retail Average	**0.02**	**0.01**	**-0.01**	**-0.02**	**0.00**	**0.05**	**0.32**	**0.78**	**5.18**
Office Average	**0.01**	**-0.03**	**0.04**	**-0.01**	**-0.01**	**0.09**	**0.48**	**0.85**	**7.02**
Industrial Average	**-0.02**	**0.00**	**0.03**	**0.03**	**0.00**	**-0.01**	**0.24**	**1.27**	**5.67**
Overall Average	**0.01**	**-0.01**	**0.01**	**0.00**	**0.00**	**0.05**	**0.36**	**0.92**	**5.94**

All autocorrelation coefficients are insignificant except those marked *.

Table 4: Correlogram of Squared Residual Returns

Market Segment	r 1	r 2	r 3	r 4	r 5	r 6	LB(1)	LB2(2)	LB(6)
IPDMI	**-0.01**	**-0.02**	**-0.01**	**-0.02**	**-0.01**	**0.01**	**0.02**	**0.06**	**0.15**
Retail Central London	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.02	0.03	0.11
Retail Rest of London	-0.01	0.01	-0.01	-0.02	0.00	0.41	0.00	0.02	28.83*
Retail Inner South East	-0.02	-0.02	-0.02	-0.02	-0.03	0.04	0.08	0.14	0.69
Retail Outer South East	0.01	-0.01	-0.02	-0.02	-0.02	-0.02	0.03	0.04	0.24
Retail Eastern	0.00	-0.01	-0.01	-0.01	0.02	-0.01	0.00	0.02	0.12
Retail South West	-0.04	-0.01	0.02	-0.04	-0.03	0.01	0.25	0.25	0.80
Retail East Midlands	0.00	0.01	-0.06	-0.02	-0.02	0.04	0.00	0.02	1.09
Retail West Midlands	0.04	-0.03	0.12	0.00	-0.03	0.00	0.23	0.36	2.81
Retail Yorkshire & Humberside	-0.01	-0.03	-0.02	0.00	-0.02	-0.03	0.03	0.13	0.39
Retail North West	-0.02	-0.03	-0.04	-0.03	0.12	-0.02	0.10	0.23	2.97
Retail North East	-0.02	-0.02	-0.02	-0.02	-0.01	-0.02	0.07	0.14	0.40
Retail Scotland	-0.02	0.17	-0.04	-0.04	-0.03	-0.03	0.08	4.88	5.73
Retail Wales	-0.01	-0.02	-0.03	-0.02	-0.02	-0.02	0.00	0.06	0.34
Offices City of London	0.00	-0.01	0.01	-0.02	-0.02	-0.02	0.00	0.03	0.16
Offices Mid-Town	-0.02	-0.04	-0.01	0.02	-0.04	0.01	0.08	0.36	0.71
Offices West End	-0.01	-0.02	-0.02	-0.02	-0.02	0.05	0.03	0.08	0.68
Offices Rest of London	-0.02	-0.02	-0.01	-0.01	-0.01	0.00	0.06	0.14	0.20
Offices Inner South East	-0.02	-0.02	-0.02	0.01	-0.02	-0.01	0.05	0.08	0.25
Offices Outer South East	0.11	-0.03	-0.03	-0.01	0.03	-0.03	2.05	2.20	2.70
Offices Eastern	-0.03	-0.04	0.01	-0.04	-0.04	0.03	0.10	0.35	1.02
Offices South West	0.00	-0.03	-0.03	-0.03	0.24	0.01	0.00	0.18	10.45*
Offices Midlands & Wales	-0.03	-0.01	0.02	-0.01	-0.03	0.05	0.15	0.18	0.77
Offices Rest of England	-0.04	-0.02	0.03	-0.05	-0.04	0.40	0.29	0.35	29.80*
Offices Scotland	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.02	0.05	0.14
Industrials London	-0.03	0.14	-0.02	-0.03	-0.02	-0.02	0.12	3.48	3.88
Industrials Inner South East	-0.03	-0.02	-0.02	0.24	0.01	-0.02	0.12	0.17	10.23*
Industrials Outer South East	0.04	-0.01	-0.01	-0.04	-0.05	-0.02	0.20	0.22	1.06
Industrials Eastern	-0.02	-0.03	0.01	-0.04	0.00	0.22	0.06	0.23	8.77
Industrials South West	-0.01	-0.03	-0.02	-0.02	-0.03	-0.03	0.02	0.15	0.53
Industrials Midlands & Wales	-0.04	-0.02	-0.02	0.00	0.02	-0.04	0.21	0.29	0.73
Industrials Northeast &Scotland	-0.02	-0.03	0.03	-0.02	0.02	-0.02	0.10	0.30	0.62
Retail Average	**-0.01**	**0.00**	**-0.01**	**-0.02**	**-0.01**	**0.03**	**0.07**	**0.49**	**3.43**
Office Average	**-0.01**	**-0.02**	**0.00**	**-0.01**	**0.00**	**0.04**	**0.26**	**0.36**	**4.26**
Industrial Average	**-0.02**	**0.00**	**-0.01**	**0.01**	**-0.01**	**0.01**	**0.12**	**0.69**	**3.69**
Overall Average	**-0.01**	**-0.01**	**-0.01**	**-0.01**	**0.00**	**0.03**	**0.15**	**0.49**	**3.78**

All autocorrelation coefficients are insignificant except those marked *.