research memorandum

CONDITIONAL HETEROSCEDASTICITY IN STOCK RETURNS: INTERNATIONAL EVIDENCE

A. Corhay and A. Tourani Rad

RM 91-014

Faculty of Economics
Limburg University
P.O. box 616
6200 MD Maastricht

CONDITIONAL HETEROSCEDASTICITY IN STOCK RETURNS: INTERNATIONAL EVIDENCE

A. Corhay and A. Tourani Rad

RM 91-014

J.E.Lit.code: 520

CONDITIONAL HETEROSCEDASTICITY IN STOCK RETURNS: INTERNATIONAL EVIDENCE

A. Corhay

University of Liège (Belgium) and University of Limburg (The Netherlands)

A. Tourani Rad

University of Limburg (The Netherlands)

ABSTRACT

This paper investigates the presence of non-linear dependence in daily stock returns in several Stock Exchanges. Although daily returns seem to be uncorrelated, the rejection of linear models suggests the return cannot be seen as an independent increment process. This leads to the rejection of the random walk model. Models of return-generating that empirically fit the data best are processes with conditional heteroscedastic innovations. Particularly, the generalized autoregressive conditional heteroscedastic GARCH(1,1) process turns out to be the best in most cases.

I. INTRODUCTION

Knowledge of the distribution of security returns is important for both theoretical and empirical studies in finance. For instance, the distributional characteristics of stock returns have important implications for mean-variance portfolio theory, theoretical models of capital asset pricing, and valuation of contingent claims. Moreover, empirical tests of asset pricing models and the efficient market hypothesis make statistical inferences based on distributional assumptions of stock returns, and estimation of the variance is essential in the Black-Scholes option pricing formula.

A standard assumption implicit in many studies is that the stock returns are normally distributed. This is convenient in that the normal distribution can be fully described by its mean and standard deviation and that the distributions of all relevant test statistics are well known. Tests of normality hypothesis were first reported by Osborne (1964). Other studies, however, questioned the normality assumption and showed that distribution of stock returns have fatter tails and are more peaked than the normal distribution. Mandelbrot (1963) observed that the family of stable Paretian distributions whose members exhibit heavy tails, conforms better to the distribution of stock returns. Fama (1965) contributed further evidence supporting Mandelbrot's hypothesis.

Since then there has been many models of stock returns describing processes that could generate distributions having heavier tails than normal distributions. For instance, Paretz (1972), Blattberg and Gonedes (1974) showed that the scaled-t distribution, which can be derived as a continuous variance mixture of normal distributions, fits better daily stock returns than infinite variance stable Paretian distributions. Other models using different mixtures of normal to generate distributions that would account for the higher magnitude of kurtosis, are, among others, the Poisson mixtures of Press (1967) and the discrete mixtures of Kon (1984). Furthermore, Clark (1973), Epps and Epps (1976), Merton (1982) and Tauchen and Pitts (1983) put forward models where the distribution of variance is a function of the arrival of the information rate, the trading activity and the trading volume. Such models are, however, too complex to be used in empirical applications.

There is yet no unanimity regarding the best stochastic return generating model. The general conclusion, however, seems to be that stock returns are approximately uncorrelated, but not independent, and described by distributions with fatter tails. One of the most recent proposed class of return generating process in the literature that can capture the temporal dependence of stock return series is the class of autoregressive conditional heteroscedastic processes introduced by Engle (1982) and its generalized version by Bollerslev (1986). According to these processes the conditional error is normally distributed with conditional variance defined as a linear function of past square errors and lagged conditional variance. They allow for volatility clustering, that is, large changes are followed by large changes, and small by small, which has long been recognized as an important feature of stock returns behaviour. Empirical studies showed indeed that such processes are successful in modelling various time series. See, for example, French, Schwert and Stambaugh (1987), Baillie and Bollerslev (1989), Hsieh (1989) and Baillie and De Gennaro (1990).

As far as stock markets are concerned, this class of models has been mainly applied to American stock markets. Our contribution in this paper is to show whether such models can adequately describe stock price behaviour of other capital markets which are much smaller and thinner than the American ones. To that end, we have selected nine countries throughout the world. The study of stock price behaviour in these markets is interesting for that it can provide further evidence in favour of or against the use of this type of models for describing stock price behaviour.

The structure of the paper is the following. After some preliminaries, sections two and three present the data and examine the statistical properties of the return distributions. In the fourth section we determine, using ARMA models, which return generating process fits the data best for the various countries in our sample. The fifth section is then devoted to the presentation and the estimation of autoregressive conditional heteroscedastic processes.

II. THE DATA

For this study, we have selected the indices of nine major stock markets representing three geographical areas: North America, Europe and the Far East. The daily market indices were collected from DATASTREAM for the period 1/1/1980 to 30/9/1990. They are value weighted indices for the U.S. (Standard & Poor's Composite), Canada (Toronto Composite), the U.K. (FT All-Shares), France (CAC General), Italy (Milan Banca), Japan (Nikkei Down Jones), Australia (All Ordinary Shares), Singapore (Straits Times) and South Korea (Composite). The daily returns of these market indices, 2803 observations for the whole period, are continuously compounded returns. They are calculated as the difference in natural logarithm of the index value for two consecutive days, $R_t = \log(P_t) - \log(P_{t-1})$.

III. Statistical Analysis

This section contains a detailed analysis of the distributional and time-series properties of the stock market indices returns in the sample. A range of descriptive statistics are presented in table I, as well as the maximised likelihood function value when a normal distribution is imposed on data. The results confirm the well known fact that daily stock returns are not normally distributed, but are leptokurtic and skewed, whatever the country concerned. All distributions are negatively highly skewed, indicating that they are non-symmetric, and they all exhibit high level of kurtosis meaning they are more peaked and have fatter tails than normal distributions.

In order to test the hypothesis whether returns are strict white noise, i.e. random walk, the Box-Pierce test statistics up to lag 25 is calculated and presented in the table. This is a joint test that the first k autocorrelation coefficients are zero. Under the null hypothesis, that the sample autocorrelations are not asymptotically correlated, the Box-Pierce statistic, $Q = n\sum_{i=1}^{k}\rho(i)^2$, has chi-square distribution with k degrees of freedom, where $\rho(i)$ is the i-th autocorrelation. The values of Q are all significant at the five per cent level but that of the US. This implies that the null hypothesis of strict white noise is rejected for eight countries, reflecting a rather long range of dependency in the returns series. However, it can be questioned whether this test accounts for the full probability distribution of the returns series since heteroscedasticity can lead to the underestimation of the standard error, $\sqrt{1/n}$, of each sample, and therefore to the overestimation of the t- and χ^2-statistics. Diebold (1987) provides a heteroscedasticity-consistent estimate of the standard error for the i-th sample autocorrelation coefficient:

$$S(i) = \sqrt{\frac{1}{n}\left(1 + \frac{\gamma_R{}^2(i)}{\sigma^4}\right)} \qquad (1)$$

TABLE I — SAMPLE STATISTICS ON DAILY RETURNS SERIES*

	Australia	Canada	France	Italy	Japan	Korea	Singapore	U.K.	U.S.
Returns statistics									
Sample size	2803	2803	2803	2803	2803	2803	2803	2803	2803
Mean ($x10^3$)	.3600	.1981	.4699	.6819	.4143	.5759	.3302	.5109	.3718
t(mean=0)	1.6734	1.1934	2.3998	2.5259	2.2739	2.4761	1.3366	2.9908	1.8153
Variance ($x10^3$)	.1297	.0772	.1074	.2043	.0930	.1516	.1711	.0817	.1176
Skewness	-6.1140	-.9756	-1.5118	-.9916	-1.6974	-.9585	-3.1946	-1.6873	-3.5178
Kurtosis	150.4648	22.2828	16.9419	11.7387	36.6880	18.3631	50.6137	19.6622	75.0082
Log-Likelihood	11142.2	11869.4	11406.5	10506.1	11608.4	10924.1	10754.8	11789.03	11280.3
Autocorrelations									
ρ1	.1190	.1691	.1461	.1367	.0600	.0686	.2082	.1367	.0334
	(.0489)	(.0739)	(.0292)	(.0351)	(.0654)	(.0302)	(.0763)	(.0651)	(.0570)
ρ2	−.0285	.0227	.0455	-.0378	-.0880	.0022	-.0015	.0477	-.0380
	(.0454)	(.0578)	(.0399)	(.0325)	(.0395)	(.0260)	(.0648)	(.0481)	(.0663)
ρ3	.0988	.0104	.0273	.0447	.0240	-.0111	.0359	.0261	-.0108
	(.0650)	(.0488)	(.0353)	(.0372)	(.0440)	(.0246)	(.0724)	(.0394)	(.0489)
ρ4	.1129	.0452	.0218	.0601	.0473	.0003	.0580	.0535	-.0447
	(.0624)	(.0479)	(.0307)	(.0337)	(.0412)	(.0229)	(.0520)	(.0479)	(.0286)
ρ5	.0624	.0437	.0177	.0062	-.0564	-.0122	.0202	.0153	.0477
	(.0631)	(.0430)	(.0285)	(.0300)	(.0368)	(.0236)	(.0388)	(.0385)	(.0637)
ρ10	.0317	.0176	.0661	.0682	.0537	.0356	.0077	.0541	-.0035
	(.0485)	(.0355)	(.0323)	(.0283)	(.0310)	(.0205)	(.0383)	(.0292)	(.0341)
ρ15	.0404	.0531	-.0035	.0283	-.0149	-.0001	-.0209	.0294	.0066
	(.0275)	(.0258)	(.0292)	(.0259)	(.0291)	(.0197)	(.0246)	(.0255)	(.0254)
ρ20	.0225	.0490	.0302	.0413	.0002	.0173	.0327	.0099	.0234
	(.0471)	(.0221)	(.0277)	(.0267)	(.0348)	(.0206)	(.0226)	(.0269)	(.0290)
ρ25	-.0168	.0017	-.0249	.0005	.0435	-.0155	.0390	-.0305	-.0019
	(.0177)	(.0205)	(.0268)	(.0258)	(.0229)	(.0189)	(.0192)	(.0209)	(.0200)
Q(25)	191.43	130.89	154.23	139.58	102.09	41.40	171.41	111.13	29.95
Q*(25)	36.32	27.43	65.66	52.64	30.56	27.96	28.83	26.30	9.95

* Values of the tests statistically significant at the five per cent level are underlined. Numbers in parentheses are heteroscedasticity-consistent standard errors.

where $\gamma_R{}^2(i)$ is the i-th sample autocovariance of the square data and σ is the sample standard deviation of the data. These adjusted standard errors are presented in the table I under their respective autocorrelation coefficient. It can be seen that only few autocorrelation coefficients are statistically different from zero.

Using these adjusted standard errors, Diebold proposed an adjusted Box-Pierce statistic:

$$Q^* = \sum_{i=1}^{k}\left(\rho(i)/(S(i))^2\right) \qquad (2)$$

which is asymptotically chi-square distributed with k degrees of freedom, under the null hypothesis of no serial correlation in the data. The values of Q^* which are presented in table I are much lower than the non adjusted ones. They are significant at five per cent level for France and Italy only. So, even after adjusting for heteroscedasticity, there remains some significant autocorrelations in the series of returns for these two countries.

A comparison between the values of Q and Q^* suggests that the rejection of serial independence using Q, which is based on the standard testing procedure, is due to the presence of heteroscedasticity in the returns series. The presence of significant values of Q^* in the French and Italian returns indices indicates, however, that these returns series are not strict white noise processes. Furthermore, the fact that the first lag autocorrelation is significant for seven countries implies the rejection of white noise, i.e. uncorrelated process. Therefore, we have to eliminate the serial correlation in the return series before searching for appropriate models that could account for heteroscedasticity in the returns. One way to do this is to apply Autoregressive Moving Average (ARMA) models.

IV. ARMA MODELS

The class of univariate ARMA models might adequately represent the behaviour of the stock returns. Therefore, several ARMA models were applied to the returns series. An AR(1) model appears to fit returns series best.

$$R_t = \phi_0 + \phi_1 R_{t-1} + \varepsilon_t \qquad (3)$$

The estimates of the above regression model for each country are presented in table II. In order to observe whether the residuals ε_t obtained from equation (3) are uncorrelated, we applied the same tests for normality and serial correlation as for the returns series. As before, the values of the autocorrelation coefficients and their respective standard errors adjusted for heteroscedasticity are presented in table II. The first order autocorrelation coefficient for all countries is not significantly different from zero. Furthermore, the results indicate that the AR(1) transformation of the returns provides an uncorrelated series of residuals.

The estimate of ϕ_1 is statistically significant, except for the US. The Dickey-Fuller test for unit roots indicates that ϕ_1 is significantly less than one. The series of returns appear to follow a stationary random walk. As far as the assumption of normality of the residuals is concerned, it can be rejected. The residual series appear to be leptokurtic and skewed. Moreover, again a comparison between values of Q and Q^* indicates that the residuals series still exhibit heteroscedasticity.

The presence of heteroscedasticity in stock prices and in the market model has been documented by, for example, Morgan (1976) and Giaccoto and Ali (1982). But while they focused on unconditional heteroscedasticity, in this paper we use Engle's Autoregressive Conditional Heteroscedastic (ARCH) model which focuses on conditional volatility movements. It is interesting to note that, according to Diebold et al. (1988), the presence of ARCH effect appears to be generally independent of unconditional heteroscedasticity. Excess kurtosis observed in both returns and residuals series can be related to conditional heteroscedasticity, that is, its presence can be due to

TABLE II — THE AUTOREGRESSIVE MODEL * $R_t = \phi_0 + \phi_1 R_{t-1} + \varepsilon_t$

	Australia	Canada	France	Italy	Japan	Korea	Singapore	U.K.	U.S.
ϕ_0	.0003	.0002	.0004	.0006	.0004	.0005	.0003	.0004	.0004
$t(\phi_0)$	1.4620	1.0141	2.0704	2.1861	2.1339	2.3095	1.0797	2.6220	1.7920
ϕ_1	.1190	.1691	.1461	.1367	.0603	.0686	.2082	.1367	.0334
$t(\phi_1)$	6.3420	9.0774	7.8140	7.3012	3.1887	3.6405	11.2623	7.3075	1.7714
Fuller's test	2469.55	2329.12	2813.10	2781.80	2634.84	2610.61	2219.52	2815.59	2709.33
Residuals statistics									
Mean ($x10^3$)	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
Variance ($x10^3$)	.1279	.0750	.1052	.2005	.0927	.0151	.01637	.0802	.1173
Skewness	-5.8730	-.3882	-1.4215	-.8295	-1.4989	-.9282	-2.6753	-1.3075	-3.4417
Kurtosis	146.4650	25.4891	17.3579	12.1476	36.8685	18.6647	42.0886	16.8439	73.1866
Autocorrelations									
ρ_1	.0047	.0008	-.0036	.0075	.0055	.0001	.0097	-.0045	.0010
	(.0618)	(.0763)	(.0323)	(.0393)	(.0702)	(.0322)	(.0793)	(.0660)	(.0605)
ρ_2	-.0548	-.0070	.0216	-.0646	-.0935	-.0019	-.0548	.0275	-.0382
	(.0499)	(.0665)	(.0419)	(.0321)	(.0399)	(.0263)	(.0627)	(.0537)	(.0651)
ρ_3	.0911	-.0006	.0185	.0431	.0270	-.0114	.0269	.0131	-.0079
	(.0695)	(.0576)	(.0336)	(.0384)	(.0449)	(.0244)	(.0776)	(.0431)	(.0502)
ρ_4	.0969	.0386	.0208	.0554	.0498	.0019	.0511	.0495	-.0449
	(.0586)	(.0454)	(.0300)	(.0332)	(.0405)	(.0225)	(.0500)	(.0444)	(.0293)
ρ_5	.0543	.0369	-.0227	.0049	-.0566	-.0110	.0028	.0056	.0491
	(.0581)	(.0428)	(.0301)	(.0301)	(.0373)	(.0236)	(.0354)	(.0394)	(.0639)
ρ_{10}	.0274	.0295	.0514	.0642	.0508	.0329	.0037	.0457	-.0030
	(.0478)	(.0359)	(.0321)	(.0281)	(.0303)	(.0205)	(.0357)	(.0305)	(.0335)
ρ_{15}	.0406	.0491	-.0047	.0213	-.0160	-.0011	-.0219	.0344	.0065
	(.0259)	(.0263)	(.0291)	(.0261)	(.0292)	(.0194)	(.0245)	(.0259)	(.0253)
ρ_{20}	.0223	.0505	.0280	.0368	.0020	.0177	.0295	.0084	.0243
	(.0429)	(.0213)	(.0272)	(.0267)	(.0336)	(.0205)	(.0220)	(.0263)	(.0286)
ρ_{25}	-.0138	.0080	.0205	.0010	.0427	-.0150	.0302	-.0271	-.0040
	(.0171)	(.0204)	(.0267)	(.0252)	(.0229)	(.0189)	(.0188)	(.0208)	(.0202)
Q(25)	139.84	48.9130	76.32	92.09	92.14	23.67	44.59	43.95	26.80
Adjusted Q(25)	27.84	21.8670	34.54	38.34	29.22	19.27	17.17	17.67	9.32

*statistical tests significant at the five per cent level are underlined. Numbers in parentheses are heteroscedasticity-consistent standard errors.

a time varying pattern of the volatility. ARCH models and its extensions have been successfully applied, for instance, in foreign exchange markets by Baillie and Bollerslev (1989) and Hsieh (1989), and in stock markets by Akgiray (1989) and Baillie and De Gennaro (1990).

V. CONDITIONAL HETEROSCEDASTIC MODELS

The ARCH process imposes an autoregressive structure on the conditional variance which permits volatility shocks to persist over time. In this process, the conditional error distribution is normal, with a conditional variance that is a linear function of past squared innovations. The model, denoted by ARCH(p), is the following:

$$\varepsilon_t | \psi_{t-1} \sim N(0, h_t)$$

$$h_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \, \varepsilon_{t-i}^2 \qquad (4)$$

with $p>0$; $\alpha_i>0$, $i=0,\ldots,p$, and where ψ_t is the information set of all information through time t, and the ε_t are obtained from a linear regression model.

An important extension of the ARCH model is the Generalized Autoregressive Conditional Heteroscedasticity (GARCH) process of Bollerslev (1986), denoted by GARCH(p,q). In this model, the linear function of the conditional variance includes lagged conditional variances as well. The equation (4) in the case of a GARCH model becomes:

$$h_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \, \varepsilon_{t-i}^2 + \sum_{i=1}^{q} \beta_j \, h_{t-j} \qquad (5)$$

where also $q \geq 0$ and $\beta_j \geq 0$, $j=1,\ldots,q$.

The parameters of a (G)ARCH model are obtained through a maximum likelihood estimation. Given the return series and initial values of ε_l and h_l, for $l=0,\ldots,r$ and with $r=\max(p,q)$, the log-likelihood function we have to maximise for a normal distribution is the following:

$$L(\phi | p,q) = -\frac{1}{2} T \ln(2\pi) + \sum_{t=r}^{T} \ln\left(\frac{1}{\sqrt{h_t}}\right) \exp\left(\frac{-\varepsilon_t^2}{2h_t}\right) \qquad (6)$$

where T is the number of observations;

h_t, the conditional variance, is defined by equations (4) and (5) for the ARCH and GARCH models respectively;

ε_t^2 are the residuals obtained from the appropriate linear regression model according to the country in consideration.

As the values of p and q have to be prespecified in the model, we tested several combinations of p and q. The values of the maximised likelihood functions for all pairs of p and q are presented in table III. We also calculated the generalized likelihood ratio $LR=-2\{L(\phi_n)-L(\phi_a)\}$ of the maximised likelihood functions under the null hypothesis, i.e., the normal distribution, and the various alternate hypothesis. Under the null hypothesis LR is chi-square distributed with degrees of freedom equal to the difference in the number of parameters under the two hypotheses. Table III gives the values of the LR test for each model. It can be observed that the value of the LR test for all (G)ARCH models is statistically significant at the one percent level, which means that all of these models fit the data more likely than does the normal distribution. In order to distinguish between an improvement in the likelihood function due to a better fit and an improvement due to an increase in the number of parameters, we also calculated Schwarz's order selection criterion, $SIC=-2L(\phi)+(\ln T)K$, where K is the number of parameters in the model. According to this criterion, the model with the lowest SIC value fits the data best. The SIC values are reported in table III. The GARCH(1,1) model has the lowest SIC values for all countries except France. For the latter no GARCH model converged and ARCH(3) is the best.

Table IV contains the results of the best model fitting the series of returns for each country. The sum of $\sum_{i=1}^{p}\alpha_i+\sum_{j=1}^{q}\beta_j$ in the conditional variance equations measures the persistence of the volatility. Engle and Bollerslev (1986) have shown that if this sum is equal to one, the GARCH process becomes an integrated GARCH or IGARCH process. Such integrated model implies the persistence of a forecast of the conditional

TABLE III — MAXIMUM LOG LIKELIHOODS FOR (G)ARCH MODELS

Model	p,q	Log likel.	L R test	Schwarz criterion	Log likel.	L R test	Schwarz criterion	Log likel.	L R test	Schwarz criterion
			Australia			Canada			France	
Normal	-	11142.20			11869.45			11406.50		
ARCH	(1,0)	11747.09	1209.78	-23486.24	12220.90	24441.80	-24433.86	11560.95	308.90	-23113.96
ARCH	(2,0)	11791.97	1299.54	-23568.06	12320.07	24640.14	-24624.26	11664.35	515.70	-23312.82
ARCH	(3,0)	11799.43	1314.46	-23575.04	12360.68	24721.36	-24697.54	11677.31	541.62	-23330.80
GARCH	(1,1)	11815.91	1347.42	-23615.94	12429.54	24859.08	-24843.20	...		
GARCH	(2,1)	...			12431.64	24863.28	-24839.46	...		
GARCH	(1,2)	11815.75	1347.10	-23607.68	...			...		
GARCH	(2,2)	...			12424.74	24849.48	-24817.73	...		
			Italy			Japan			Korea	
Normal	-	10506.12			11608.42			10924.09		
ARCH	(1,0)	10653.91	295.58	-21299.88	12004.09	791.34	-24000.24	11006.52	164.86	-22005.10
ARCH	(2,0)	10757.64	503.04	-21499.40	12175.28	1133.72	-24334.68	11197.96	547.74	-22380.04
ARCH	(3,0)	10886.73	761.22	-21749.64	12209.14	1201.44	-24394.46	11204.59	561.00	-22385.36
GARCH	(1,1)	10992.68	973.12	-21969.48	12276.02	1335.20	-24536.16	11226.24	604.30	-22436.60
GARCH	(2,1)	...			12273.66	1330.48	-24523.50	11228.10	608.02	-22432.38
GARCH	(1,2)	...			...			11228.82	609.46	-22433.82
GARCH	(2,2)	10998.15	984.06	-21964.55	...			...		
			Singapore			UK			US	
Normal	-	10754.82			11789.03			11280.33		
ARCH	(1,0)	11220.27	1428.30	-22432.60	11991.12	404.18	-23974.30	11518.75	476.84	-23029.56
ARCH	(2,0)	11250.69	1489.14	-22485.50	12046.90	515.74	-24077.92	11550.89	541.12	-23085.90
ARCH	(3,0)	11263.74	1515.24	-22503.66	12062.77	547.48	-24101.72	11579.58	598.50	-23135.34
GARCH	(1,1)	11310.22	1608.20	-22604.56	12097.46	616.86	-24179.04	11628.24	695.82	-23240.60
GARCH	(2,1)	...			12091.50	604.94	-24159.18	11609.84	659.02	-23195.86
GARCH	(1,2)	11309.73	1607.22	-22595.64	...			11623.64	686.62	-23223.46
GARCH	(2,2)	...			...			...		

... indicates where the optimization routine failed.

TABLE IV — MODEL ESTIMATES*

	Australia	Canada	France	Italy	Japan	Korea	Singapore	U.K.	U.S.
ϕ_0(thousands)	.4640	.2028	.6881	.8061	.7497	.5349	.7071	.6775	.5659
$t(\phi_0)$	3.2308	1.5072	4.1215	3.8546	6.0871	2.7571	3.2792	4.6100	3.1553
ϕ_1	.2785	.2393	.2031	.1909	.1120	.0781	.0228	.1519	.0363
$t(\phi_1)$	14.6743	11.1819	9.5706	7.7043	4.8351	3.5881	10.3832	7.5064	1.7200
α_0(thousands)	.0152	.0040	.0581	.0064	.0034	.0146	.0131	.0053	.0057
$t(\alpha_0)$	6.3579	5.9440	24.7654	6.2055	5.5519	6.2576	7.6012	5.1517	4.7490
α_1	.3577	.1663	.1739	.1394	.2516	.1408	.1615	.1131	.0926
$t(\alpha_1)$	11.4415	9.4190	6.6687	9.0820	10.6218	8.2204	9.9759	7.5200	8.7481
α_2	–	–	.1612	–	–	–	–	–	–
$t(\alpha_2)$	–	–	6.4882	–	–	–	–	–	–
α_3	–	–	.0978	–	–	–	–	–	–
$t(\alpha_3)$	–	–	4.3288	–	–	–	–	–	–
β_1	.5365	.7781	–	.8367	.7456	.7553	.7542	.8153	.8553
$t(\beta_1)$	12.6990	34.2959	–	52.0732	33.1067	26.3456	35.1162	35.6342	45.6222
$\sum_{i=1}^{p}\alpha_i + \sum_{j=1}^{q}\beta_j$	.8942	.9444	.4329	.9761	.9972	.8961	.9157	.9284	.9479
σ_ε^2 (x10^3)	.1437	.0719	.1025	.2678	1.2143	.1405	.1554	.0740	.1094
σ_R^2 (x10^3)	.1558	.0763	.1069	.2779	1.2297	.1414	.1555	.0758	.1095

* t statistics significant at the one percent level are underlined.

variance over all future horizons and also an infinite variance of the unconditional distribution of ε_t. We calculated the sum of the parameters $\sum_{i=1}^{p}\alpha_i+\sum_{j=1}^{q}\beta_j$ for the appropriate (G)ARCH models. They are all less than unity, though rather close to one for some, which indicates a long persistence of shocks in volatility. This means that the process is second order stationary and that the second moment exists. The unconditional variances of residuals, shown in table IV, are respectively $\sigma_\varepsilon^2=\alpha_0/(1-\sum_{i=1}^{3}\alpha_i)$ for France and $\sigma_\varepsilon^2=\alpha_0/(1-\alpha_1-\beta_1)$ for the other countries. As for the unconditional variances of returns, it is $\sigma_R^2=\sigma_\varepsilon^2/(1-\phi_1^2)$.

VI. CONCLUSIONS

This paper provides empirical support that the class of autoregressive conditional heteroscedasticity models is generally consistent with the stochastic behaviour of daily stock returns in nine countries. The results show that stock market indices exhibit a significant level of non linear dependence which cannot be accounted for by the random walk model. Descriptive statistics and normality tests reveal that the distribution of returns is not normal, whatever the country concerned. It has further been shown that the residuals obtained after applying an AR(1) model, which accounts for the presence of autocorrelation in the returns, exhibit non linear dependence and non normality. Then we tested various models belonging to the class of autoregressive conditional heteroscedasticity models. The results reveal that this class of models supersedes the random walk model. And among the different models the GARCH(1,1) fits the data best for all countries except France for which ARCH(3) fits better.

VII. REFERENCES

Akgiray, V., 'Conditional Heteroscedasticity in Time Series of Stock Returns: Evidence and Forecasts', Journal of Business, 62, 1989, pp. 55-80.

Baillie, R.T. and Bollerslev, T., 'The Message in Daily Exchange Rates: A Conditional-Variance Tale', Journal of Business & Economic Statistics, 7, 1989, pp. 297-305.

Baillie, R.T. and De Gennaro, R.P., 'Stock Returns and Volatility', Journal of Financial and Quantitative Analysis, 25, 1990, pp. 203-214.

Black, F. and Scholes M., 'The Pricing of Options and Corporate Liabilities', Journal of Political Economy, 81, 1973, pp. 637-654.

Blattberg, R.C. and Gonedes, N.J., 'A Comparison of the Stable and Student Distribution of Statistical Models for Stock Prices', Journal of Business, 47, 1974, pp. 244-280.

Bollerslev, T., 'Generalized Autoregressive Conditional Heteroskedasticity', Journal of Econometrics, 31, 1986, pp. 307-327.

Diebold, F.X., 'Testing for Serial Correlation in the Presence of ARCH', Proceedings from the American Statistic Association, Business and Economic Statistics Section, 1987, pp. 323-328.

Diebold, F.X., Im, J. and Lee, C.J., 'Conditional Heteroscedasticity in the Market', Finance and Economics Discussion Series, 42, Division of Research and Statistics, Federal Reserve Board, Washington D.C, 1988.

Engle, R., 'Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of UK inflation', Econometrica, 50, 1982, pp. 987-1008.

Epps, T.W. and Epps, M.L., 'The Stochastic Dependence of Security Price Changes and Transaction Volumes: Implications for the Mixture of Distributions Hypothesis', Econometrica, 44, 1976, pp. 305-322.

Fama, E.F., 'The Behavior of Stock Market Prices', Journal of Business, 38, 1965, pp. 34-105.

French, K.R. , Schwert, G.W. and Stambaugh, R.F., 'Expected Stock Returns and Volatility', Journal of Financial Economics, 19, 1987, pp. 3-29.

Hsieh, D.A., 'Modelling Heteroscedasticity in Daily Foreign-Exchange Rates', Journal of Business & Economic Statistics, 7, 1989, pp. 307-317.

Kon, S., 'Models of Stock Returns: A Comparison', Journal of Finance, 39, 1984, pp. 147-165.

Mandelbrot, B., 'The Variation of Certain Speculative Prices', Journal of Business, 36, 1963, pp. 394-419.

Merton, R., 'On the Mathematics and Economics Assumptions of Continuous-Time Models', , Sharpe, W. and Cootner, C., Financial Economics, Englewood Cliffs, N.J. Prentice-Hall, 1982.

Morgan, I., 'Stock Prices and Heteroscedasticity', Journal of Business, 49, 1976, pp. 496-508.

Paretz, P.D., 'The Distribution of Share Price Changes', Journal of Business, 45, 1972, pp. 49-55.

Press, S.J., 'A Compound Events Model for Security Prices', Journal of Business, 40, 1967, pp. 317-335.

Schwarz, G., 'Estimating the Dimension of a Model', The Annals of Statistics, 6, 1978, pp. 461-464.

Tauchen, G.E. and Pitts, M., 'The Price Variability-Volume Relationship on Speculative Markets', Econometrica, 51, 1983, pp. 485-505.

Overzicht Research Memoranda Rijksuniversiteit Limburg, Faculteit der Economische Wetenschappen vanaf 1990 (tel. 043-888830)

RM 90-001 M.H.C. Lever
Union Wage Setting, Productivity and Unemployment in the Netherlands (1954-1987)

RM 90-002 A. van Witteloostuyn and A. van Lier
Chaotic Patterns in Cournot Competition

RM 90-003 M. van Wegberg en A. van Witteloostuyn
Multimarkt Concurrentie: Strategische afhankelijkheden bij simultane concurrentie op meerdere markten

RM 90-004 A. van Witteloostuyn
Methods of Dynamic Economics: (Non)market Clearing and Expectations

RM 90-005 A. van Witteloostuyn
Multimarket Competition and Strategic Management

RM 90-006 A. van Witteloostuyn
Externe Organisatie en de moderne theorie van concurrentie

RM 90-007 A. van Witteloostuyn
Toetredingsbelemmerende Strategieën: Een aanzet tot empirisch onderzoek

RM 90-008 M. Vendrik
Preference drifts in labor supply; towards an integration of some economic and psychological motivation theories

RM 90-009 M. Lever and T. van Veen
Union wage setting, employment and investment; a survey of theory and empirical evidence

RM 90-010 P. de Gijsel, J. Muysken, G.L.M. Wolfs
Interne arbeidsmarkten en beloning bij mannen en vrouwen in Nederland

RM 90-011 J.G. Backhaus
Taxatation and Entrepreneurship: An Austrian Approach to Public Finance

RM 90-012 J. Soeters, R. Schwan
Towards an empirical assessment of internal labor market configurations

RM 90-013 J. . Muysken, E. de Regt
Persistence in structural unemployment

RM 90-014 H. Schreuder
Tijdige wijzigingen in mangement en leiderschap als element van organisatiestrategie

RM 90-015 M.J. van Diepen and K.M. van Hee
A formal semantics for Z and the link between Z and the relational algebra.

RM 90-016 J.G.A. van Mierlo
Spatial Analysis of Electoral Competition and Demand/Sypply Analysis of Economic Policy. The Case of the Netherlands: 1946-1982

RM 90-017 J.G.A. van Mierlo
Politieke verdeling in een gemengde economische orde.

RM 90-018 A.P. van Veen en N.G.J. Janssen
Nieuwe financiële instrumenten. Over NIF, RUF, FRA, FRN, swaps: achtergrond en betekenis.

RM 90-019 W. Dijkhuis
EST, specifying what is there.

RM 90-020 L.H.H. Bollen and J.H.R. van de Poel
Small firms' disclosure-costs in the Netherlands.

RM 90-021 A. van Witteloostuijn and M. van Wegberg
Multimarket Competition and European Integration.

RM 90-022 J. Spangenberg and H. Schreuder
The Joint Impact of Scale, Scope and Atmosphere on Scientific Performance in Economics.

RM 90-023 L. Delsen en T. van Veen
The Swedisch Model: Partially Relevant for other European Countries.

RM 90-024 M. van Wegberg
Potential Competition though Vertical Integration

RM 90-025 J.G. Backhaus
Die Politische ökonomie der Schutzzolltheorie

RM 90-026 M. van Wegberg and A. van Witteloostuijn
Credible entry threat into contestable markets

RM 90-027 A.W.J. Kolen and J.K. Lenstra
Combinatorics in operations research

RM 90-028 J.G. Backhaus
Henry George and the Environment

RM 90-029 Marc van Wegberg, Michiel Roscam Abbing & A. van Witteloostuijn
Multimarket Collusion: European Integration May reduce Competition

RM 90-030 A. van Witteloostuijn
Multimarket Competition & Business Strategy

RM 90-031 M.C.M. Vendrik
Habits, Hysteresis and Catastrophes in Labor Supply.

RM 90-032 H. Schreuder
Coase, Hayek, and Hierarchy

RM 90-033 A.J. van Reeken
Leren omgaan met onzekerheden; het ontstaan en het belang van risico-beheersing bij automatiseringsprojecten

RM 90-034 J.G.A. van Mierlo
Public Sector Credit Institutions in the European Community. Country Report on the Netherlands.

RM 90-035 A. van Witteloostuijn
Multimarket competition and market performance

RM 90-036 L. Zou
Multi-agents' Incentives and Efficiency: Cooperative v.s. Absentee Ownership

RM 90-037 J.G. Backhaus
Friedrich List and the Political Economy of Protective Tariffs

RM 90-038 P.J.C. Claessen and A.J. van Reeken
Nieuwe ontwikkelingen in de management accounting

RM 90-039 A. Bauer, W. Domschke, E. Pesch
Competitive Location on a network

RM 90-040 H. Friedrich, J. Kessler, E. Pesch and B. Schildt
Batch Scheduling on Parallel Units in Acrylic-glass production

RM 90-041 J.G. Backhaus and J.J. Krabbe
Incentive Taxation and the Environment: Complex - yet feasible

RM 90-042 G.L.M. Wolfs
Tenure in the Dutch Economy

RM 90-043 J.G. Backhaus
Das System Althoff: Eine ökonomische Analyse

RM 90-044 J.G. Backhaus
Die Beteiligung von Arbeitnehmern an Unternehmungsentscheidungen: Ein Vergleich von Strukturelementen: B.R.D.-U.S.A.

RM 90-045 F.G. Volmer RA
Hoeveel informatie geeft de Gemeente-rekening? Toepassing van een disclosure-index op de verslaggeving door gemeenten.

RM 90-046 A. Corhay and A. Tourani Rad
Conditional Heteroskedasticity in Stock Returns: Evidence From Amsterdam Stock Exchange

RM 90-047 W. Dijkhuis en A. van Reeken
Een typologie voor Case-tools

RM 90-048 H. Schreuder and A. van Witteloostuyn
The Ecology of Organizations and the Economics of Firms

RM 90-049 N.L.J. Ulder, E.H.L. Aarts, H.J. Bandelt, P.J.M. van Laarhoven and E. Pesch
Genetic Local Search Algorithms for the Traveling Salesman Problem

RM 90-050 J.L.G. Dietz
The essential system model

RM 90-051 T. Ziesemer
Debt Cycle, Debt Crisis and Exports as Engine and Handmaiden of Growth

RM 90-052 C. Kerckhoffs, C. de Neubourg and F. Palm
The determinants of individual unemployment duration in the Netherlands

RM 90-053 J.G.A. van Mierlo en A. van Witteloostuijn
Interactie tussen Particuliere Ondernemingen en Publieke Instellingen.

1991

RM 91.001 G.A. Pfann and F.C. Palm
Asymmetric adjustment costs in non-linear labour demand models with empirical evidence for the Dutch and UK manufacuring sectors

RM 91.002 T.E. Nijman, F.C. Palm and C.C.P. Wolff
Premia in forward foreign exchange as unobserved components

RM 91.003 L. Zou
Threat-Based Implementation of Incentive Compatible Mechanisms

RM 91.004 J.G.A. van Mierlo and F.K.M. van Nispen
Mirror, mirror on the wall, who is the fairest of them all? Why public policies for environmental problems have failed sofar in representative democracy

RM 91.005 J. Soeters en G.L.M. Wolfs
Economische organisatietheorieën en beloningssystemen

RM 91.006 C.C.J.M.C. Kerckhoffs and G.L.M. Wolfs
Duration of Job Tenure in the Dutch Economy

RM 91.007 H. Schreuder
Timely Management Changes as a Element of Organizational Strategy

RM 91.008 K.G. Koedijk and C.J.M. Kool
Dominant interest and inflation differentials within the EMS.

RM 91.009 J. Birner
Neoclassical economics as mathematical metaphysics

RM 91.010 Y. Crama, A.W.J. Kolen, A.G. Oerlemans, F.C.R. Spieksma
Minimizing the Number of Tool Switches on a Flexible Machine.

RM 91-011 R. Schwan and J. Soeters
The strategy of vacancy filling from internal and external labor market sources.

RM 91-012 P. Schotman
When uit roots matter: excess volatility and excess smoothness of long term interest rates.

RM 91-013 P. Schotman and H.K. van Dijk
On Bayesian Routes to Unit Roots.

RM 91-014 A. Corhay and A. Tourani Rad
Conditional heteroscedasticity in stock returns: international evidence.

RM 91-015 R. Cremers en A. Tourani Rad
Een empirisch onderzoek naar de gevolgen van fusie tussen Nationale Nederlanden en NMB-Postbankgroep.