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Do 'Fat Tails' Matter in GARCH Estimation? Stock market efficiency in Romania and the Czech Republic

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Abstract

The use of the GARCH-class of models is commonplace when examining stock market returns. In this paper we use data on stock markets in two transition economies to demonstrate the importance of using the correct GARCH specification. When returns are characterised by 'fat tails' or kurtosis the use of a GARCH-t specification is appropriate. Returns in Romania are symmetric, but characterised by kurtosis. Returns in the Czech Republic are normally distributed. Using a standard GARCH specification leads to rejection of the null hypothesis of market efficiency in Romania, whereas this null hypothesis cannot be rejected using the GARCH-t specification. The null hypothesis of efficiency cannot be rejected in the Czech Republic using either specification. Thus, we find that the presence of 'fat tails' can have important implications for inference in the analysis of stock market returns.

JEL Classifications: G14; P34.

Key words: GARCH; transition; stock market efficiency

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1. Introduction

Deviations in asset prices from a random walk model are a common finding in the financial literature and cast doubt on the efficient market hypothesis. Tests of the random walk model have mainly focused on irregularities where returns differ by small, though statistically significant amounts, at regular recurring points in time. Deviations of this nature are referred to as 'calendar effects' and Thaler (1987a, 1987b) provides partial surveys of these. The literature has identified several calendar anomalies including a day of the week effect, which is characterised by significantly negative mean returns on the first day of the trading week and abnormally high returns on the last (French 1980, Gibbons and Hess 1981, Keim and Stambaugh 1984, Agraval and Tandon 1994 and Fortune 1999); a January effect, where returns are significantly higher in January than any other month (Rozeff and Kinney 1976, Rogalski and Tinic 1986, Gultekin and Gultekin 1983 and Lee 1992); a turn of the month effect, where returns are significantly higher on turn of the month trading days than on other trading days in the first half of the month (Ariel, 1987) and a holiday effect, where returns are much higher on trading days immediately prior to holidays (Ariel, 1990, Kim and Park, 1994 and Mills and Coutts, 1995).

Until fairly recent times, most investigations of stock market efficiency focused on developed stock markets. However, following the collapse of communism, the countries of Central and Eastern Europe rapidly established institutions associated with a functioning market economy, including formal stock markets. The efficiency of these stock markets has an important influence on the allocation of resources and the EBRD (1998) has argued that "Markets tend to provide for an efficient allocation of resources when information about the goods and services being exchanged is widely available and reliable, when entry into the market by alternative providers is free, and when the exchange is not dependent upon an ongoing relationship between buyer and seller. Assuming that these preconditions are met, a securities market, like any other market, can deliver an efficient allocation of resources" (pp101). Testing the efficiency of these newly created stock markets is therefore important in gauging the extent to which transition from plan to market has been successful.

There are good reasons for believing that, initially at least, newly created stock markets are unlikely to operate efficiently. In the early days, trading is thin, there exist only limited disclosure requirements and the price discovery mechanism is not well understood by market participants. It is likely that efficiency will evolve as the market develops, trading activity increases and formal disclosure requirements are implemented. In the case of Romania, Harrison and Paton (2003) find evidence that the Bucharest Stock Exchange (BSE) exhibited weak form inefficiency from its inception in 1995 until about the beginning of 2000 after which there is evidence that the market is weak form efficient. In the case of the Czech Republic, Rockinger and Urga (2000) find that the Prague Stock Exchange (PSE) exhibits weak form efficiency from spring 1999 but that it might have been weak form efficient from as early as spring 1995. In this paper we test the efficiency of these two stock exchanges and demonstrate the importance of using the correct GARCH specification when data is characterised by 'fat tails' or kurtosis.

The rest of this paper is organised as follows. In Section 2, we describe the basic GARCH model and the GARCH-t version of this model. In the following section, we analyse data from the BSE and the PSE to test for the presence of kurtosis. In Section 4, we report the results of our efficiency tests using standard GARCH and GARCH-t models. In the last section, we present our conclusions and offer some advice on model specification in the presence of kurtosis.

2. GARCH and GARCH-t models

A common starting point for testing the existence of informational inefficiencies is to establish whether past movements in asset prices can be used to predict profit opportunities. In our context, on the assumption of an efficient market, current returns should follow a random walk process and lagged returns should have no explanatory power. When estimating such models, it is important to take account of the impact of time-varying volatility, or Autoregressive Conditional Heteroscedasticity (ARCH) (Engle, 1982). Not doing so is likely to lead to biased and inconsistent estimates. There exist a whole class of models to deal with ARCH effects. Most common in the analysis of stock returns is the use of Generalised ARCH (GARCH) models (Bollerslev, 1986). In these models, time-dependent volatility is estimated as a function of observed prior volatility, measured as the lagged value(s) of the squared regression disturbances and, also, lagged value(s) of the conditional variance. The order of the GARCH model is given by the number of lags in each case.

In general terms, a GARCH(p, q) model can be represented as follows:

$$R_t = \alpha_o + \sum_{i=1}^{k} \alpha_i R_{t-k} + \psi \sigma_t^2 + \varepsilon_t \qquad (1)$$

where

$$\sigma_t^2 = \gamma_0 + \sum_{i=1}^{q} \gamma_i \, \varepsilon_{t-1}^2 + \sum_{i=1}^{q} \delta_i \sigma_{t-1}^2 \qquad (2)$$

and where ε_t is assumed to follow a normal distribution with zero mean and variance σ^2; γ_i are the ARCH parameters; δ_i are the GARCH parameter(s). We use the Akaike Information Criterion (AIC) to determine the optimal lag length of the ARCH and GARCH parameters. Note that the presence of GARCH effects is consistent with informational efficiency, but only on the assumption that investors are risk neutral.

It is common to estimate GARCH models on the assumption that the conditional disturbances follow a normal distribution. In fact, there is considerable evidence (see, for example, Connolly, 1989) that, in the context of stock market returns, the distribution of the disturbances is often characterised by 'fat tails' or kurtosis and, in this case, inferences based on the standard GARCH-model may be inappropriate. Indeed, the summary statistics on the raw returns discussed above is suggestive that this may be a problem in our case. Several alternative estimation approaches that deal with this problem are available (see Dowd, 2002, for a discussion of these). Here we use a modified GARCH estimator, sometimes called GARCH-t, in which the error terms are assumed to follow a conditional student-t density with degrees of freedom given by ν. In this formulation, ν is a parameter which can be estimated from maximising the log likelihood function:

$$L(\theta,\nu) = \sum_{t=q+1}^{n} L_t(\theta,\nu) \tag{3}$$

where:

$$L(\theta,\nu) = log\{ B\left(\frac{\nu}{2},\frac{1}{2}\right)\} - \frac{1}{2}log(\nu-2) - \frac{1}{2}log\,\sigma_t^2 - \left(\frac{\nu+1}{2}\right)log\left(1+\frac{\varepsilon_T^2}{\sigma_t^2(\nu-2)}\right) \tag{4}$$

and θ is the set of remaining parameters in the model (see Bollerslev, 1987).[1]

In this paper, we seek to examine whether the assumption regarding kurtosis in the error term is of importance for inference in tests for various forms of market efficiency. Our primary indicator of efficiency is whether the coefficients on lagged returns are significant in equation 1. However, we also test for existence of the calendar effects discussed above. To do this, we supplement equation 1 by the inclusion of dummy variables for the first trading day of the week (*Start of week*), for the final trading day of the week (*End of week*), for trading days in January (*January*) and for trading days in the first half of the month (*Start of month*).

We estimate equation 1 firstly by using the standard GARCH model and then by using the GARCH-t model to allow for ‘fat tails’. We then examine whether the use of the standard GARCH model leads us to make false inferences at conventional significance levels on the existence or otherwise of inefficiency.

3. The Data

We consider stock exchange data for two separate markets: Romania and the Czech Republic. These two countries provide a useful experiment because, as we shall see below, returns in Romania are characterised by kurtosis whilst those in the Czech Republic are not.

Our data consists of observations from the Prague Stock Exchange 50 Index (PX 50) and from the Bucharest Exchange Traded Index (BET). The PX 50 consists of the most attractive domestic stocks traded on the PSE in terms of turnover and market capitalisation. The maximum number of shares included in the index is 50, (hence its name, PX 50) but currently only equity in 18 companies is included in the index. Company equity is listed on the BSE in two categories: a first tier listing and a second tier listing. The requirements for each listing differ but, among other things, a first tier listing requires a better standard of company performance and more stringent disclosure requirements. The BET consists of the ten most actively traded stocks from tier 1 and, like the PX 50, is a market value weighted index. Our data set consists of observations from both exchanges and runs from the 1st January 2000 until 16th September 2002.

We define returns on day t in the normal way as $R_t = \log(S_t/S_{t-1})$ where S_t is the value of the stock market index in US dollars at the close of trading on day t. Due to slightly different holiday arrangements, this leaves us with 676 observations from the BET and 677 from the PX 50.

[1] There exist alternative approaches to dealing with the issue of excessive kurtosis, for example using a stable Paretian process, mixture-of-normals distributions or a jump-diffusion process. For a discussion of these approaches

We conduct formal tests for normality on these three series and these are presented in Table 1. In the case of Romania, we reject the null hypothesis of normality at conventional significance levels. Decomposing this result, we find strong evidence of kurtosis ('fat tails'), but no significant evidence of skewness. In the case of the Czech Republic we find no evidence either of kurtosis or skewness and we cannot reject the null hypothesis of normality.

Table 1: Summary Statistics for Daily Stock Market Returns: Romania and the Czech Republic

	Romania	**Czech Republic**
Number	677	677
Mean	0.095	-0.010
Standard Deviation	1.779	1.225
Skewness	0.062	-0.022
Kurtosis	8.663***	3.199
Normality	8.696***	0.873

Notes
(i) The sample covers 1st January 2000 to 16th September 2002
(ii) *** indicates significance at the 1% level; ** at the 5% level;* at the 10% level.
(ii) The tests for skewness and kurtosis are based on D'Agostino, Balanger and D'Agostino (1990).
(iii) Normality is the Shapiro-Wilk test statistic for normality. This is normally distributed, based on the null hypothesis.

4. Results

We report our efficiency tests for the two stock exchanges in Tables 2 and 3. In each case, we report the results of the standard GARCH estimation in column 1 and the GARCH-t model, allowing for 'fat tails' in column 2.

For both countries, order of GARCH or ARCH parameters higher than 1 proves significant and, on the basis of the Akaike Information Criteria for model selection, we conclude that the first order model is optimal. The diagnostic tests for normality suggest strong evidence of non-normality in the error term for Romania, but not for the Czech Republic. Taken together with our descriptive statistics, this is suggestive that the standard GARCH specification is appropriate in the case of the Czech Republic and the GARCH-t

see Dowd (2002).

specification in the case of Romania. The choice is further confirmed by the fact that the degree of freedom parameter is strongly significant for the Romanian data, but not for the Czech republic.[2]

Looking at the results for Romania (reported in Table 2), neither the GARCH nor the GARCH-t specification provide any evidence of 'calendar effects'. The coefficient on lagged returns is positive and strongly significant (p-value = 0.005) in the standard GARCH model. This is strongly suggestive of market inefficiency in that lagged returns can be used to predict future returns. In the GARCH-t specification, however, this coefficient is much smaller both in absolute terms and in significance (p-value = 0.062). In other words, using a 5% significance level, we would reject the hypothesis of market inefficiency on the basis of the GARCH model, but not on the basis of the GARCH-t model.

Looking at the results for the Czech Republic (reported in Table 3), the coefficients and significance levels are extremely similar under both specifications. We would not be able to reject the null hypothesis of efficiency using either the standard GARCH or the GARCH-t model.

Table 2: GARCH Estimates of Stock Market Returns: Romania

	1	**2**
	GARCH	**GARCH-t**
Return (t-1)	0.134*** (0.047)	0.084* (0.045)
Start of week	9.171 e-4 (0.136)	-0.041 (0.129)
End of week	0.120 (0.142)	0.040 (0.119)
January	0.165 (0.247)	0.113 (0.250)
Start of month	0.062 (0.280)	-6.47 e-3 (0.209)
Constant	0.065 (0.078)	0.022 (0.065)

[2] A further alternative would be to allow for asymmetric effects by estimating an E-Garch model. The asymmetric parameter in such a specification proved insignificant for both countries. Further support for our specification is provided by the diagnostic test for residual ARCH effects and the Portmanteau test for serial correlation which are never significant at conventional levels.

γ_0	0.178 (0.110)	1.189** (0.526)
γ_1	0.150*** (0.054)	0.441*** (0.135)
δ_1	0.790*** (0.037)	0.237 (0.221)
ν	-	4.171*** (0.760)
Log-Likelihood	-1262.7	-1236.0
AIC	2543.3	2492.0
N	676	676
Normality	56.224***	210.68***
ARCH 1-2	1.785	0.964
Portmanteau	15.15	19.13

Notes
(i) Sample period is 7th May 1997 to 16th Sept 2002.
(ii) Dependent variable is the stock market return on day t, defined as $\log(S_t/S_{t-1})$ where S_t is the stock market index in $US at the close of trading on day t.
(iii) Figures in brackets are robust standard errors.
(iv) *** indicates significance at the 1% level; ** at the 5% level;* at the 10% level.
(v) AIC is the Akaike Information Criterion for model selection and is calculated as AIC = -2(L - k) where k is the number of parameters being estimated.
(vi) ARCH 1-2 is an LM test statistic for 1st and 2nd order ARCH and is distributed as F^2_{N-k-4} where N is the number of observations and K is the number of parameters. Portmanteau is the Ljung-Box portmanteau statistic for misspecification based on up to 24 lags. Normality is a test statistic for skew and kurtosis and follows a $\chi^2(2)$ distribution.

Table 3: GARCH Estimates of Stock Market Returns: Czech Republic

	1	2
	GARCH	**GARCH-t**
Return (t-1)	0.035 (0.040)	0.034 (0.039)
Start of week	-0.043 (0.061)	-0.044 (0.109)
End of week	0.031 (0.113)	0.030 (0.112)
January	0.000 (0.000)	0.000 (0.000
Start of month	0.133 (0.154)	0.127 (0.154)
Constant	0.004 (0.061)	0.002 (0.064)
γ_0	0.090* (0.055)	0.088** (0.030)
γ_1	0.054** (0.023)	0.054*** (0.015)
δ_1	0.885*** (0.051)	0.887 (0.040)
ν	-	89.43 (275.7)
Log-Likelihood	-1087.40	-1087.311
AIC	2192.79	2194.62
N	677	677
Normality	0.510	0.547
ARCH 1-2	0.516	0.513
Portmanteau	25.19	25.15

Notes
(i) Sample period is 7th May 1997 to 16th Sept 2002.
(ii) Dependent variable is the stock market return on day t, defined as $\log(S_t/S_{t-1})$ where S_t is the stock market index in $US at the close of trading on day t.
(iii) Figures in brackets are robust standard errors.
(iv) *** indicates significance at the 1% level; ** at the 5% level;* at the 10% level.
(v) AIC is the Akaike Information Criterion for model selection and is calculated as AIC = -2(L - k) where k is the number of parameters being estimated.
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5. Conclusions

The evidence presented in this paper suggests that 'fat tails' do matter. Estimating stock market returns on the basis of a standard GARCH model when, in fact, those returns are characterised by kurtosis would have led to a (false) rejection of efficiency in the case of Romania. In the case of the Czech Republic, where returns are not characterised by kurtosis, the GARCH and GARCH-t specifications lead to the same inference.

The analysis of stock market efficiency is of particular importance for transition economies as it can be an indicator of more general market efficiency. The evidence of this paper emphasises how important it is for researchers investigating financial markets to specify the econometric model correctly.

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