Do fat tails matter in GARCH estimation: testing market efficiency in two transition economies.

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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, the Czech Republic and Romania, to demonstrate the importance of using the correct GARCH specification. When residuals are characterised by 'fat tails' or kurtosis, the use of a GARCH-t specification is appropriate. Diagnostic tests suggest that the GARCH-t specification is appropriate for modelling stock market returns in Romania, whilst the standard GARCH specification is adequate for the Czech Republic. 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.

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 focused mainly 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; Agrawal 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).

It is quite common for studies of stock market efficiency to take account of time-varying volatility by use of a Generalised Autoregressive Conditional Heteroscedasticity (GARCH) framework (see for example, Emerson et al, 1997; Berument and Kiymaz, 2001). In most cases, however, researchers assume that the conditional disturbances follow a normal distribution whereas, in some cases, it may be that alternative distributional assumptions are warranted. A key feature of this paper is an explicit treatment of whether the assumption of functional form can affect inferences made regarding efficiency.

Until fairly recently, most investigations of stock market efficiency focused on developed stock markets. Following the collapse of communism, however, 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: 101) 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'. In other words, an efficient capital market helps deliver allocative efficiency and, through this, enhances economic development and the creation of a functioning market economy (see also Dickinson and Muragu, 1994).

There are good reasons for believing that, initially at least, newly-created stock markets are unlikely to operate efficiently (see, for example, the study by Wheeler *et al.* (2002) on the early years of operation of the Warsaw Stock Market). Initially, 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. Additionally, in the early stages of development, capital market regulation is likely to be weak. It is therefore surprising that policy makers in several Central and Eastern European countries allowed a non-standard creation of capital markets in their countries, typically as a by-product of voucher privatisation programmes.

The Czech Republic and Romania are illustrative cases since policy makers in these countries eschewed the evolutionary step-by-step approach in creating capital markets adopted in other countries in the region. Instead, voucher shares were simply transferred *en masse* to the newly-created market. The Czech Republic and Romania also provide an interesting case study because of the ten central and eastern European economies recently admitted to the EU, during the period of our investigation the Czech Republic was at the forefront of transition and joined the EU in 2004, whilst Romania still had some way to go and joined only in 2007. Admittance to the EU implies that both countries are now deemed to be a functioning market economy, but the point we make here is that there was a clear difference in the speed at which transition progressed.

In the case of Romania, Harrison and Paton (2005) 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.

The rest of this paper is organised as follows. In Section 2, we describe the main features of the Prague Stock Exchange (PSE) and the Bucharest Stock Exchange (BSE). Section 3 outlines 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 5, 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. The Prague and Bucharest Stock Exchanges

The PSE was established initially in 1871 and traded both securities and commodities. The latter were so important that the PSE became the key market for sugar for the whole of the Austro-Hungarian Empire. After the end of the First World War, however, the exchange reverted to a more conventional role and only securities were traded. The number and value of trades on the Exchange grew rapidly, but trading ceased with the outbreak of the Second World War and did not resume again until 6 April 1993. Initially trading was only in 7 securities, but the number of securities traded increased rapidly as mass privatisation created a whole new class of shareholders.

The PSE is based on the same principles as exchanges in developed countries. Business is conducted through licensed securities traders who are Exchange members. The Exchange and the activities of its members are regulated by the Securities Commission. Prices on the PSE are set by the Automated Trading System which clears buy and sell orders for each stock. An important feature of the PSE's price-setting mechanism is the existence of an upper limit on percentage price changes (5 per cent for most issues) on any single trading day.

The PSE was at the very forefront of stock exchange development in Central Europe and was one of the very first to be created in the region. It grew rapidly as a result of voucher privatisation and quickly established the highest ratio of stock market capitalisation to GDP in the region. Table 1 gives some relevant data.

The BSE began trading in 1882, but ceased trading in 1948 because, under communism, the whole economy was nationalised and private holdings of equity ceased to exist. Following the collapse of communism in 1989, Romania began the process of transition to a market economy and, as part of

Table 1: Trading on the Prague Stock Exchange: 1993-2002

Year	*No of trading sessions*	*Value of trades (CZK)bn*	*Turnover (CZK)m*	*Capitalisation (CZK)bn*	*No.of listed companies*
1993	41	7.1	7,130	NA	971
1994	161	42.6	42,601	353.1	1,028
1995	234	125.6	125,635	478.6	1,716
1996	249	249.9	249,946	539.2	1,670
1997	250	246.3	246,300	495.7	320
1998	251	172.6	172,588	416.2	304
1999	254	163.5	163,449	479.6	195
2000	249	264.1	264,139	442.9	151
2001	250	128.8	128,800	340.2	102
2002	250	197.4	197,400	357.9	79

this process, the BSE was created and began trading in 1995. The BSE is a public entity having the traditional departments of a stock exchange (trading, listing, and members), as well as a Registry Department and a Clearing and Settlement Department.

Table 2: Trading on the Romanian Stock Exchange: 1995-2002

Year	*No of trading sessions*	*No. of trades*	*No. of shares traded (volume)*	*Turnover (US$m)*	*Capitalisation (US$m)*	*No.of listed companies*
1995	5	379	42,761	0.96	100.37	9
1996	84	17,768	1,140,000,000	5.28	60.81	17
1997	207	609,651	615,796,189	260.43	632.47	75
1998	255	512,705	966,804,827	193.40	357.14	126
1999	249	415,046	1,069,280,848	125.01	316.80	126
2000	251	496,996	1,828468,521	87.34	427.22	115
2001	247	348,658	2,213,096,602	132.03	1228.52	65
2002	247	689,184	4,085,123,289	213.75	2717.51	65

In order to limit paper-based operations, the trading system of the BSE, like the PSE, is a computerised order-driven system which allows the interaction of actual buying and selling orders in the market. The trading session consists of a continuous trading mechanism for securities listed in the base and first tier categories. Likewise the settlement system is completely paperless and takes place three days after equity is traded. Table 2 gives some information on the growth of the Bucharest Stock Exchange.

3. 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. Autocorrelation, heteroscedasticity and volatility clustering are all common features of financial returns data. In such cases, it has been found useful to treat the variance of the error term at time t as a function of previous errors (Cragg, 1982; Engle, 1982).

The most common treatment of time-varying volatility in the analysis of stock returns is the use of Generalised ARCH (GARCH) models (Bollerslev, 1986). In general terms, a GARCH(p, q) model can be represented as follows:

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

where

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

and where ε_t is commonly assumed to follow a normal distribution with zero mean and variance σ^2; γ_i are the ARCH parameters; $\delta_i$are the GARCH parameter(s).

Thus, 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. Here, we use the Akaike Information Criterion (AIC) to determine the optimal lag length of the ARCH and GARCH parameters.

It is common to estimate GARCH models on the assumption that the conditional disturbances follow a normal distribution. 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. In this case, inferences based on the standard GARCH-model may be inappropriate. 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 n. In this formulation, ν is a parameter which can be estimated from maximising the log likelihood function:

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

where:

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

and q is the set of remaining parameters in the model (see Bollerslev, 1987).[2]

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. 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*). If the market is efficient, we would expect these coefficients to be zero.

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.

4. 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 higher 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 1 January 2000 until 16 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. Descriptive statistics for the raw series are presented in Table 3. Although we are interested ultimately in normality in the residuals in the conditional model discussed below, we commence by examining tests for normality in the raw returns. In the case of Romania, we can reject the null hypothesis of normality for the raw returns 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 in the raw returns.

Table 3: Summary Statistics for Daily Stock Market Returns: Romania and the Czech Republic

Number	676	677
Mean	0.095	-0.010
Std. 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 1 January 2000 to 16 September 2002.
(ii) *** indicates significance at the 1% level; ** at the 5% level;* at the 10% level.
(iii) The tests for skewness and kurtosis are based on D'Agostino, Balanger and D'Agostino (1990).
(iv) Normality is the Shapiro-Wilk test statistic for normality. This is normally distributed, based on the null hypothesis.

5. Results

We report our efficiency tests for the two stock exchanges in Tables 4 and 5. 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 prove 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 residuals 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 specification appropriate 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.[3]

We now test for the presence of particular market anomalies using the alternative distributional assumptions. Looking at the results for Romania (reported in Table 4), 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

Table 4: GARCH Estimates of Stock Market Returns: Romania

	1 *GARCH*	*2* *GARCH-t*
Return (*t*-1)	0.134***	0.084*
	(0.047)	(0.045)
Start of week	9.171 e-4	-0.041
	(0.136)	(0.129)
End of week	0.120	0.040
	(0.142)	(0.119)
January	0.165	0.113
	(0.247)	(0.250)
Start of month	0.062	-6.47 e-3
	(0.280)	(0.209)
Constant	0.065	0.022
	(0.078)	(0.065)
γ_0	0.178	1.189**
	(0.110)	(0.526)
γ_1	0.150***	0.441***
	(0.054)	(0.135)
δ_1	0.790***	0.237
	(0.037)	(0.221)
v	—	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 7 May 1997 to 16 September 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.

coefficient is much smaller both in absolute terms and in significance (p-value = 0.062). In other words, using the standard GARCH model (which the diagnostic tests suggest is inadequate in the case of Romania) would lead one to reject the hypothesis of market efficiency (at a 5% significance level). However, using the (correctly specified) GARCH-*t* model, one cannot reject the null hypothesis of efficiency.

Table 5: GARCH Estimates of Stock Market Returns: Czech Republic

	1 *GARCH*	*2* *GARCH-t*
Return (*t*-1)	0.035	0.034
	(0.040)	(0.039)
Start of week	-0.043	-0.044
	(0.061)	(0.109)
End of week	0.031	0.030
	(0.113)	(0.112)
January	0.000	0.000
	(0.000)	(0.000
Start of month	0.133	0.127
	(0.154)	(0.154)
Constant	0.004	0.002
	(0.061)	(0.064)
γ_0	0.090*	0.088**
	(0.055)	(0.030)
γ_1	0.054**	0.054***
	(0.023)	(0.015)
δ_1	0.885***	0.887
	(0.051)	(0.040)
v	-	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 7 May 1997 to 16 September 2002. (ii) Dependent variable is the stock market return on day *t*, defined as $\log(St/S_{t-1})$ 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.

Looking at the results for the Czech Republic (reported in Table 5), 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.

6. Conclusions

The evidence presented in this paper suggests that the choice of distributional assumption in GARCH models has important implications for inference. Estimating stock market returns in the context 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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Endnotes

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2. 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 see Dowd (2002).

3. 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.

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