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GARCH Modelling in Finance: A Review of the Software Options

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Introduction
The econometric analysis of financial data has received an increasing amount of attention from academics over the past decade or so. Great advances in the ability of computers to record, process, store and retrieve huge volumes of data within an acceptable time have encouraged this interest. In broad terms, much financial data (particularly high frequency asset pricing series) has a number of specific characteristics which make its analysis more challenging than many other types of data.

First, the fact that asset price series are generated at extremely high frequencies implies that the number of observations can rapidly expand into hundreds of thousands, or perhaps in extreme cases, even millions. Second, the inability of traditional linear ("textbook") structural and time series models to capture the most important features of the data have led to the development and implementation of a number of relatively new non-linear models. Non-linear models are generally more complex and difficult to estimate than linear models, and often an analytical solution may not exist so that a slower, iterative procedure may be required.

Both of these facets of financial data imply that, as well as the more traditional features of software that are of interest (such as flexibility, user-friendliness, comprehensiveness, etc.), the speed of the program in arriving at the correct parameter values is of paramount importance. It may be, for example, that some modelling strategies are simply not feasible for very high frequency data, since such a great deal of CPU time is required.

The purpose of this review is to compare the relative properties of three popular software packages (GAUSS, RATS and TSP) for estimating one special case of a class of models which are generally of particular importance in financial econometrics, namely GARCH-(1,1) models, which are used in this review as an illustrative example. An outline of the remainder of this review is as follows. The next three sections give a brief description of each of the software packages used for comparison followed by two sections describing the GARCH modelling framework used as an illustrative example. The final sections offer some analysis and concluding remarks.

GAUSS version 3.2
GAUSS is, unlike RATS and TSP, not an econometrics package as such, but rather it is a high level programming language principally made up of commands and procedures for statistical analysis. Hence in principle all applications, even those such as linear regressions, must be programmed up from first principles. However,

twelve modules, known as "Gauss Applications" are available for specific problems, which will remove much of the work associated with using GAUSS. The most important add-in modules for the financial econometrician (together with their most useful features) are likely to be Linear Regression (OLS, 3SLS, SURE estimation), Maxlik (maximum likelihood estimation using various descent algorithms), Optmum (function optimisation), Time Series (ARIMA modelling), and CML (constrained maximum likelihood). GAUSS versions are available for DOS, Windows, Windows 95, and UNIX platforms.

RATS version 4.2
RATS is an econometric package designed specifically for time series analysis, although there are a number of procedures which would be useful for the analysis of cross-sectional or panel data. RATS contains many features which may potentially be useful for a financial econometrician, including estimation of ARIMA and many members of the GARCH family of models, simultaneous equations and VAR modelling, testing for unit roots and cointegration, generation of forecasts and simulations, Monte Carlo studies and bootstrapping. Various estimation techniques are available, including ordinary least squares, generalised least squares, nonlinear least squares, maximum likelihood and generalised method of moments (GMM). All of these are either pre-programmed into RATS as instructions, or are collected together in sets of instructions known as "procedures". RATS is available for DOS, Macintosh, Windows or UNIX/VMS.

TSP version 4.2
TSP is an easy-to-use general purpose package intended primarily for the estimation and simulation of econometric models. TSP also has a broad list of features useful for the econometric analysis of financial data, namely OLS, ARIMA modelling, Kalman filter estimation, ARCH/GARCH, Monte Carlo studies using data generated from various distributions, forecast generation, unit root and cointegration testing, VAR estimation and GMM (multiple and nonlinear). DOS and UNIX versions are available.

A Brief Note on GARCH Models
Virtually all readers interested in econometrics could not have failed to witness the vast number of papers using the GARCH family of models. Indeed, hardly a week goes by without another variant or extension being proposed. Suffice to say here that this model class is of paramount importance in financial econometrics for it relaxes the (almost invariably unrealistic for financial data) assumption that the variance of the error process is conditionally as well as unconditionally fixed. GARCH model are also able, at least in part, to model the unconditional leptokurtosis observed in many financial series.

This is not the appropriate place for a comprehensive review or list of references, but the interested reader is directed towards the excellent survey by Bollerslev *et al.* (1992) and the references therein. The simple GARCH-(1,1) model utilised in this study can be described by the following equation:

$$x_t = \sqrt{h_t} \cdot v_t \qquad\qquad\qquad (1)$$
$$\text{where } h_t = b_0 + b_v v_{t-1} + b_h h_{t-1} \quad , \quad v_t \sim N(0,1)$$

x_t is the dependent variable, h_t is the conditional variance, v_t is the Normal innovations stream, and b_0, b_v, b_h are parameters to be estimated.

Simulation Example

In order to test the ease of use and in particular the speed of the three packages within a consistent and logical framework, the following "mini-Monte Carlo" study is employed[1]. First, 500 series each of length 500 observations are generated using a Fortran program[2] for a GARCH-(1,1) model with standard Normal innovations, as given in equation (1) above. For the purpose of data generation, the parameters are set to $b_0 = 0.0108$, $b_v = 0.1244$, $b_h = 0.8516$. These values are derived from a GARCH estimation on a set of Swiss Franc / Sterling exchange rates, and are very reasonable values, given the results in the rest of the empirical literature on this subject.

The task of each package was to read in each of the data files, estimate a GARCH-(1,1) model on the data, and then to write the results to a text output file. All three packages were run under DOS on an IBM-compatible personal computer with a Pentium processor running at 133Mhz and with 16Mb of RAM.

Results and Analysis

A summary of some of the most important features is given in table 1.

Table 1: A Summary of the Performance and other Features of GAUSS, RATS and TSP for Estimating 500 GARCH-(1,1) Models.

	Package		
Characteristic	GAUSS	RATS	TSP
Total time taken / minutes	21	17	2
Approximate number of lines of code required[1]	26	13	4
Approximate price[2] for a single academic user	£455	US$ 500 (WinRATS-32) £350 (RATS 386)	US$ 400

Notes: [1] Number of lines requires to estimate one GARCH model on one series and send the results to an output file. [2] UK prices are for package obtained from Timberlake Consulting. TSP is only available direct from the producers of the program, TSP International.

The first feature worth noting is the surprising speed with which TSP was able to estimate all 500 GARCH models. It was over eight times quicker than the next fastest (RATS). This lightning speed is a little surprising, but may be a result of the longer history of TSP, which was originally developed without so many "bells and

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[1] Note that this exercise is merely undertaken to compare the properties of the packages, and is not intended to constitute a full Monte Carlo study.

[2] This should ensure that none of the packages has an unfair advantage over the other which might be the case if the data were generated from within one of the programs under consideration.

whistles" to run on machines which were very slow with small working memories relative to those currently available. Speed is still of great essence today for the estimation of non-linear models on large samples or models, or where a Monte Carlo study is employed.

Ease of usage can be proxied by the number of lines of computer code which are required in each case. There are a number of stages involved in estimating a GARCH model: reading in the data, specifying a mean and variance equation, and a log-likelihood function, running a linear regression to obtain appropriate starting values, and choosing the method of optimisation[3]. All of the packages essentially follow these same steps, the crucial difference between them being the extent to which the user must specify or code up the steps himself, or the extent to which they have already been incorporated into a pre-written routine. GAUSS and TSP are clearly at opposite ends of the spectrum in this case; in the latter, the user need only write the word "arch" (plus some options and the name of the dependent variable) in order to run a GARCH model[4]. This extremely easy-to-use approach has a clear advantage for those who are seeking to run the program quickly but who are not interested in the technicalities. It may, however, be viewed as a disadvantage since the model appears as a "black box", and the researcher does not even get to see the underlying model or log-likelihood function, let alone specify it.

Thus the user must also trade off a great deal of flexibility for this simplicity: ARCH, GARCH and GARCH-M are the only variants that are pre-programmed in the current version of TSP. If the researcher wanted any of the other large number of variants, such as EGARCH or the GJR formulation, he would have to program up the whole GARCH routine from scratch in order to be able to modify it. Adaptations would clearly be much easier in GAUSS or RATS, where the user must specify the mean, and variance equations and the log-likelihood function anyway. Some sample code for GARCH estimation using GAUSS and RATS is readily available on various World Wide Web pages and FTP sites, and in the case of RATS, is also distributed with the program and documented in the manual.

The only package which seemed to experience difficulties converging to a sensible optimum value of the parameters using the default convergence criteria for most of the models was GAUSS. Although convergence was not always achieved by the other two packages, the estimated parameter values were never far from their theoretical values. The problem was particularly serious with GAUSS since it caused the whole system to crash out of the program, whereas RATS and TSP would simply move on to the next data series. This is, in the opinion of the author, likely to be a particularly worrying problem in general since the estimation was "easy" here where the true DGP was known and appropriately specified in the estimated equation.[5]

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[3]In all cases, the BHHH method was used since this was available in all three cases and is well documented in the literature.

[4]Peculiarly, a GARCH-(1,1) model is the default for the command "ARCH" and not an ARCH model as one might have suspected from the name.

[5]Although it must be said that the author has experienced particularly extreme problems with non-convergence in the past using TSP.

Another point of comparison between the three packages is the amount of useful output that is automatically displayed with the regression results. As well as the parameter values, standard errors and the corresponding *t*-ratios, TSP and RATS also give out the number of observations used. Both also give information on the number of iterations taken and the maximised value of the log-likelihood, (they are given by the former if the silent option is not specified). These pieces of information may be useful in themselves, or may be required to compute diagnostics or for hypothesis testing. RATS and GAUSS could, of course, potentially provide more diagnostic information, although these would need to be written additionally.

Programming support is a valuable tool for the applied econometrician. To the knowledge of this author, the only supplier to provide support for users who run into programming difficulties (as opposed to the physical operation of the software) is Estima, the supplier of RATS. They operate an e-mail service, where users who have run into difficulties with the operation of the software, or whose programs just do not work can send an e-mail to the help-line. This service is extremely useful for researchers who have invested a great deal of time in writing programs, only to tear their hair out when those programs will not run, or will not give sensible answers. The lack of technical support and of good documentation for the applications modules in the case of GAUSS has already been highlighted in an earlier review in this journal by Heywood and Rebello (1996).

The cost of each package may also be an important consideration for hard-up academics on tight budgets. RATS and TSP are both obtainable from their respective creators in the US at a cost of $500 for both the Windows and DOS versions together. RATS is also distributed in the UK by Timberlake Consulting for a price of £350 for the DOS version. GAUSS cannot be obtained directly from Aptech, but again is available form Timberlake at a cost of £455. Since this does not include any of the add-in modules required for easy and effective use, GAUSS is by far the most expensive of the three packages reviewed.

Conclusions
To sum up, all three packages can be used to estimate simple models like a GARCH-(1,1) without too many difficulties. The three essentially follow the same steps; the essential difference is in the extent to which those stages are already programmed into instructions which can be called, or the extent to which they must be written by the researcher. GAUSS and RATS clearly represent the most flexible environment in which to work while TSP is noteworthy for its speed and compactness of code. However, RATS would definitely be the preferred choice of this author given the evidence above, and since it provides a useful compromise between simplicity and flexibility. One certainly needs to be a considerably more adept programmer in order to be able to use GAUSS. Furthermore, a large number of GARCH variants such as the GJR, E-GARCH and Q-GARCH models have been programmed-up in RATS and are available from Estima's FTP site or dial-up bulletin board.

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