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ECONOMETRIC MODELLING WITH TIME SERIES: SPECIFICATION, ESTIMATION AND TESTING

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Everything should be made as simple as possible, but not simpler.

Albert Einstein

Econometric modelling with time series: Specification, Estimation, and Testing is a graduate textbook covering a broad range of topics in time series econometrics. The book is unique and valuable in three aspects. First, the book tries to bridge the gap between the purely theoretical view of time series analysis such as the one offered by Hamilton (1994) and applied approach offered by Enders (2015). Indeed, every chapter in approximately 30 pages provides enough theoretical background and rigorous asymptotic theory which is followed by two empirical examples, usually one taken from economics and one from finance. Second, the focus of the book is on maximum likelihood estimation which makes it stand out among other books on time series analysis. Third, authors offer solutions for all examples and exercises from the book in three different software: GAUSS, MATLAB, and R. Most of empirical examples are also available in RATS. In order to follow the content of the book with ease, mathematical and statistical knowledge is required from the reader, including a basic understanding

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of econometrics. The book aims at advanced master students, graduate students, and researchers in the field.

With a focus on maximum likelihood, this book provides a general framework for specifying, estimating and testing time series econometric models. Maximum likelihood framework helps the reader understand properties and interrelationships of the estimators and test statistics usually proposed in econometrics. However, the book also discusses other estimation methods. The advantage of this approach is that authors build models from scratch by defining maximum likelihood function and then gradually moving forward. The same approach is taken when writing code in GAUSS, MATLAB, and R, which is a great way to learn time series econometrics more deeply. A downside of this approach is that it requires a basic understanding of software and basic programming skills.

Time series econometrics is extremely rich subject, and this book does an excellent job of covering many topics. The book has 21 chapters organized into six parts followed by four appendices. In total, the book has 887 pages. Chapters in every of these six parts are well organized in a very comprehensible way. They all start with the introduction and end with applications and exercises. All the chapters are connected, especially with the chapters of the Part one of the book. While it is advisable to read the chapters in their intended order, skipping chapters is made easier by the authors because they consistently refer to the related chapters. This makes this book a book to come back to over and over again and browse through it with ease. For readers with a previous knowledge on the topic, many chapters could be read separately. For example, readers interested in vector autoregression (VAR) models could jump straight to chapters 13 and 14 without a problem.

Part one consists of four chapters and lays out the basic maximum likelihood framework to which authors refer in the remainder of the book. Part one is mostly theoretical, defines concepts for later use, and covers standard topics from introductory econometrics course at the graduate level. **First** chapter serves as the basis for the understanding of the chapters that follow. It lays out the maximum likelihood principle and stresses its role in deriving a number of estimators used in econometrics. It presents how the maximum likelihood estimator is derived by maximizing the likelihood function given certain conditions.

In the **second** chapter, authors derive statistical properties of maximum likelihood estimators while differentiating between large and small samples. The chapter starts with preliminaries including a weak law of large numbers, rates of convergence and central limit theorem. Further, it discusses regularity conditions and properties of the likelihood function. It covers asymptotic properties (consistency, normality, and efficiency) and finite sample properties (unbiasedness, sufficiency, invariance and non-uniqueness). Many of these properties are examined by methods based on Monte Carlo simulations and series expansions. The chapter

ends with two examples: portfolio diversification problem as a very good applied example and bimodal likelihood as a theoretical example.

In the **third** chapter, numerical estimation methods, namely iterative algorithms are presented for obtaining the maximum likelihood estimator when no analytical expressions are available. Methods provided are Newton methods, Quasi-Newton methods, line searching and optimization based on function evaluation. Various approaches of computing standard errors are also offered. This is an excellent chapter since there is enough theory and applied advice for practitioners which is rare in the rest of the econometric modelling literature.

Fourth chapter reviews basic concepts in hypothesis testing. It discusses three general hypothesis testing procedures in detail: the Likelihood Ratio test, the Wald test, and the Lagrange Multiplier test. The chapter discusses asymptotic distribution and the three test statistics are compared by their tendency to reject the null hypothesis which should be interesting to the researchers. As a useful addition, size and power of the three tests are discussed.

Part two presents standard econometric analysis within the maximum likelihood framework and its advantages. Namely, it is applied to the estimation and testing of regression models. In the **fifth** chapter authors deal with linear models i.e. ordinary least squares (OLS). It provides a specification of various examples of linear regression models and steps for their estimation and testing. There is a special emphasis on identification problem and instrumental variables estimation. The chapter shows that for a single equation models, the maximum likelihood estimator is equivalent to OLS estimator. The chapter ends with two excellent applications: a static version of the Taylor rule and Klein macroeconomic model.

In the chapter **six** authors discuss nonlinear least squares models in which nonlinearity comes from a functional form i.e. nonlinearities in the specification of the conditional mean. Other, more common types of nonlinearities are discussed later on in the book, specifically in chapters nineteen to twenty-one. This chapter presents a fairly standard discussion about nonlinear least squares models and it includes some good examples of relaxing the assumption of normal disturbances in nonlinear models such as robust estimation of capital asset pricing model and stochastic frontiers models.

Chapter **seven** reviews autocorrelated models, autoregressive (AR), moving-average (MA) and autoregressive-moving-average (ARMA) models, with the main focus on univariate models. It provides a discussion on estimation techniques, distribution theory and testing. The authors use a somewhat different notation for ARMA models than in the usual econometric modelling literature. Namely, they represent models with ARMA parts in terms of shocks. The chapter ends with a very good example of liquidity and hedge funds model.

Chapter **eight** is a short and straightforward chapter that focusses on weighted least squares estimation of heteroskedastic regression models. The point of this chapter is not in modeling nonlinearities in the variance because generalized autoregressive conditional heteroscedasticity (GARCH) models are considered in the Chapter 20. The point is in testing different models of heteroscedasticity i.e. testing the hypothesis of time varying, heteroskedastic variance. While the chapter certainly has its value, it discusses topics which are not very common in the time series analysis.

Conditions to implement the maximum likelihood framework outlined in the first chapter may not always be satisfied so four mostly theoretical chapters in **Part three** address these particular situations. **Ninth** chapter explains in detail so called quasi-maximum likelihood estimation which is appropriate when probability distribution is incorrectly specified. It also stresses the difference between maximum likelihood and quasi-maximum likelihood estimators.

Tenth chapter discusses in detail generalized method of moments (GMM) which is appropriate when joint probability distribution of the data is unknown. The differences between maximum likelihood estimator and GMM estimator are outlined, as well as the conditions under which they are the same. Furthermore, authors explain both advantages and disadvantages of GMM estimation throughout the chapter. Estimation procedures and properties of GMM estimator are explained in detail.

Eleventh chapter specifies the use of nonparametric procedures when neither the distribution nor the functional form of the moments of the distribution are specified. It is used to model either the distribution of variables or the relationships between them. The cost and the gain of using nonparametric estimator is presented. Concepts of the Kernel density estimator and the Nadaraya-Watson Kernel regression estimator are introduced and explained in detail.

Finally, the **twelfth** chapter presents simulation estimation methods that are used when the likelihood is intractable. In economics and finance, these are the situations of continuous–time models with discrete data i.e. factor GARCH models or ARMA models with discrete random variables. The chapter discusses requirements for the successful implementation of these simulation methods, the properties of the simulation estimator and provides algorithms for computing the simulation estimators – indirect inference, efficient method of moments (EMM) and simulated generalized method of moments (SMM). Although authors do not discuss frequently used Bayesian numerical methods in this chapter, they do offer references that can provide an introduction to those methods.

Authors then proceed to examine stationary and nonstationary time series models in Part four and Part five through six chapters altogether. **Part four** begins with **thirteenth** chapter and the general class of dynamic models known as sta-

tionary time series models. The chapter introduces single equation ARMA models and multivariate extensions, VARMA models, including its important special case, VAR model. Authors emphasize a connection between stationarity and invertibility properties of time series models which allow the conversion of AR into infinite MA process (or VAR into VMA) and vice versa, respectively. Estimation, optimal lag choice, and testing are addressed. As an important special case of VARMA models, VAR is discussed in more details. Specifically, VAR analysis is organized around Granger causality, impulse response functions (IRF-s), and variance decomposition analysis. There is no discussion about historical decomposition in VAR, which is sometimes used in applied work. Although historical decomposition produces results similar to variance decomposition, it presents them in a different way, serving as an interesting way of analyzing the importance of different shocks, so its absence from this book is unfortunate. Regarding IRF-s, the advantage of the maximum likelihood approach used in this book is that it gives standard errors of estimates, while commonly used Choleski decomposition gives only point estimates. In the end, the chapter gives two applications: Barro's rational expectations model and Campbell-Shiller present value model, both of which are interesting and non-standard examples. However, it seems that more detailed discussion on the interpretation of IRF results is postponed until Chapter 14. As another disadvantage, there is no significant discussion on confidence intervals, which is an important part of the VAR analysis.

Part four then proceeds with **fourteenth** chapter which discusses structural vector autoregression models, so-called SVAR-s and different types of identifying restrictions (short-run, long-run, a combination of short- and long-run restrictions and sign restrictions). An excellent discussion on sign restrictions in SVAR-s is rarely seen in peer textbooks. It gives a very simple and convenient explanation followed by a practical checklist to apply sign restrictions in the analysis. Authors specify SVAR models, provide details on its estimation, identification, and testing. This chapter includes many interesting examples and ends with two applications: a macroeconomic model of oil price shocks as an example for both short- and long-run restrictions and a portfolio SVAR model of Australia as a finance example with long-run restrictions only. Both examples are very useful and informative.

Chapter **fifteen** introduces latent factor models i.e. linear factor models where the factors are treated as latent. The assumption that the explanatory variable is observed is now relaxed. This is basically a chapter on so-called state-space models, very frequent in economics and finance. The chapter focuses on the Kalman filter used to rewrite the likelihood in terms of the observable variables which makes the estimation and testing by maximum likelihood feasible. This chapter is actually a great addition to the Chapter 3 on numerical optimization algorithms. It offers many useful and motivating examples and two applications at the end of the chapter: Hodric-Prescott filter example and factor model of spreads with money

shocks. The chapter provides many practical advice for the applied research including parameter restrictions which is often necessary to estimate the model, but it is not common in peer textbooks. This chapter can match Kim and Nelson (1999) book which is a classical reference for state space models.

Part five focusses on nonstationary time series models. In chapter **sixteen** nonstationary distribution theory is laid out. The difference between stationary case and nonstationary cases with either stochastic or deterministic trends is outlined. Also, some important asymptotic results for nonstationary time series are presented. This chapter introduces concepts of Brownian motion, functional central limit theorem, continuous mapping theorem and stochastic integral theorem. It ends with two interesting applications: the case of estimating an AR(1) model when the true model is I(1), and the problem of misspecifying the trend.

The chapter on nonstationary time series models is followed by a comprehensive discussion of unit root testing in chapter **seventeen** and cointegration analysis in chapter **eighteen**. Chapter seventeen explains detrending approaches in details. However, other related topics, such as autocorrelation and structural breaks, are only briefly discussed. The first application of this chapter is very useful since it shows that unit root tests based on GLS detrending provide a substantial power advantage over those based on OLS detrending.

Chapter on cointegration is an excellent chapter that focuses on Johansen and vector error correction (VECM) models. It offers many useful theoretical details, but also provides tips for estimation as well as motivating and very useful examples (e.g. graphical detection of the rank). Rank selection based on the information criteria as well as the effects that heteroscedasticity has on the trace test i.e. the test of cointegration will be much appreciated by the researchers.

Finally, **Part six** addresses nonlinear time series models. **Nineteenth** chapter deals with models that are nonlinear in mean. They include threshold models, artificial neural network models, and bilinear models, for all of which specification, estimation and testing based on maximum likelihood methods are provided. Markov switching model, nonparametric autoregression model, and nonlinear impulse responses are also discussed. Researchers interested in modelling some extreme events such as jumps or asymmetric adjustments across cycles will benefit greatly from this chapter, including its two applications.

Twentieth chapter deals with nonlinearities in variance in terms of the autoregressive conditional heteroscedasticity (ARCH) class of models, mostly used to model the volatility of the returns on financial assets. The chapter starts off by presenting statistical properties of asset returns and then introduces the ARCH class of models. Many extensions of ARCH models are discussed and, more importantly, given examples for to help researchers decide on the appropriate model for their own studies. The chapter provides estimation and testing procedures and

ends with additional two interesting applications. For example, one application introduces SVAR GARCH model which is very useful. Estimation of such a model requires advanced programming skills, so codes provided for different software are extremely useful.

Twenty-first chapter explains discrete time series models that deal with discrete or truncated time series data. Different models and estimation techniques are explained for different types of discrete data – for qualitative data so called qualitative response models, for ordered data an ordered probit model, for count data Poisson regression model and the model for the duration data. Just like in the previous chapters, interesting examples follow theoretical explanations that help readers better understand the content.

To conclude, one of the greatest **advantages** of this book is that it effectively connects econometric modelling theory with its applications. It provides great examples for easier understanding that can serve as an inspiration for the readers' own research. In addition, the structure of the book, the organization of the text and the clarity of exposition makes it easy for readers to follow and understand the content. There are many useful estimation tips, but also warnings regarding certain misspecifications. In addition, authors provide some basic guidelines regarding GAUSS and MATLAB programming languages which help readers to get familiar with them. However, it should be noted that this is a challenging textbook not intended for an undergraduate level econometrics. The book requires certain mathematical and statistical knowledge, covers advanced topics, and it does not aim for a wide audience. It should be noted as well that certain topics have been omitted from this book (such as bootstrapping often used in maximum likelihood estimations). Nonetheless, authors provide references for those omitted topics in the Preface of the book which is again very helpful. All things considered, this book represents a comprehensive discussion on the topic of econometric modeling, one that reader can always revisit to find inspiration for future research.

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