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Time Series Econometrics

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Preface

Over the past decades, time series analysis has experienced a proliferous increase of applications in economics, especially in macroeconomics and finance. Today these tools have become indispensable to any empirically working economist. Whereas in the beginning the transfer of knowledge essentially flowed from the natural sciences, especially statistics and engineering, to economics, over the years theoretical and applied techniques specifically designed for the nature of economic time series and models have been developed. Thereby, the estimation and identification of structural vector autoregressive models, the analysis of integrated and cointegrated time series, and models of volatility have been extremely fruitful and far-reaching areas of research. With the award of the Nobel Prizes to Clive W. J. Granger and Robert F. Engle III in 2003 and to Thomas J. Sargent and Christopher A. Sims in 2011, the field has reached a certain degree of maturity. Thus, the idea suggests itself to assemble the vast amount of material scattered over many papers into a comprehensive textbook.

The book is self-contained and addresses economics students who have already some prerequisite knowledge in econometrics. It is thus suited for advanced bachelor, master's, or beginning PhD students but also for applied researchers. The book tries to bring them in a position to be able to follow the rapidly growing research literature and to implement these techniques on their own. Although the book is trying to be rigorous in terms of concepts, definitions, and statements of theorems, not all proofs are carried out. This is especially true for the more technically and lengthy proofs for which the reader is referred to the pertinent literature.

The book covers approximately a two-semester course in time series analysis and is divided in two parts. The first part treats univariate time series, in particular autoregressive moving-average processes. Most of the topics are standard and can form the basis for a one-semester introductory time series course. This part also contains a chapter on integrated processes and on models of volatility. The latter topics could be included in a more advanced course. The second part is devoted to multivariate time series analysis and in particular to vector autoregressive processes. It can be taught independently of the first part. The identification, modeling, and estimation of these processes form the core of the second part. A special chapter treats the estimation, testing, and interpretation of cointegrated systems. The book also contains a chapter with an introduction to state space models and the Kalman filter. Whereas the books is almost exclusively concerned with linear systems, the last chapter gives a perspective on some more recent developments in the context of nonlinear models. I have included exercises and worked out examples to deepen the teaching and learning content. Finally, I have produced five appendices which summarize important topics such as complex numbers, linear difference equations, and stochastic convergence.

As time series analysis has become a tremendously growing field with an active research in many directions, it goes without saying that not all topics received the attention they deserved and that there are areas not covered at all. This is especially true for the recent advances made in nonlinear time series analysis and in the application of Bayesian techniques. These two topics alone would justify an extra book.

The data manipulations and computations have been performed using the software packages EVIEWS and MATLAB.[1] Of course, there are other excellent packages available. The data for the examples and additional information can be downloaded from my home page www.neusser.ch. To maximize the learning success, it is advised to replicate the examples and to perform similar exercises with alternative data. Interesting macroeconomic time series can, for example, be downloaded from the following home pages:

Germany: www.bundesbank.de
Switzerland: www.snb.ch
United Kingdom: www.statistics.gov.uk
United States: research.stlouisfed.org/fred2

The book grew out of lectures which I had the occasion to give over the years in Bern and other universities. Thus, it is a concern to thank the many students, in particular Philip Letsch, who had to work through the manuscript and who called my attention to obscurities and typos. I also want to thank my colleagues and teaching assistants Andreas Bachmann, Gregor Bäurle, Fabrice Collard, Sarah Fischer, Stephan Leist, Senada Nukic, Kurt Schmidheiny, Reto Tanner, and Martin Wagner for reading the manuscript or part of it and for making many valuable criticisms and comments. Special thanks go to my former colleague and coauthor Robert Kunst who meticulously read and commented on the manuscript. It goes without saying that all errors and shortcomings go to my expense.

Bern, Switzerland/Eggenburg, Austria Klaus Neusser
February 2016

[1]EVIEWS is a product of IHS Global Inc. MATLAB is a matrix-oriented software developed by MathWorks which is ideally suited for econometric and time series applications.

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Notation and Symbols

r	number of linearly independent cointegration vectors
α	$n \times r$ loading matrix
β	$n \times r$ matrix of linearly independent cointegration vectors
$\xrightarrow{\text{d}}$	convergence in distribution
$\xrightarrow{\text{m.s.}}$	convergence in mean square
$\xrightarrow{\text{p}}$	convergence in probability
corr(X, Y)	correlation coefficient beween random variables X and Y
γ_X, γ	covariance function of process $\{X_t\}$, covariance function
ρ_X, ρ	correlation function of process $\{X_t\}$, correlation function
ACF	autocorrelation function
J	long-run variance
α_X, α	partial autocorrelation function of process $\{X_t\}$
PACF	partial autocorrelation function
n	dimension of stochastic process, respectively dimension of state space
$\sim$	is distributed as
sgn	sign function
tr	trace of a matrix
det	determinant of a matrix
$\\|\\|$	norm of a matrix
$\otimes$	Kronecker product
$\odot$	Hadamard product
vec(A)	stakes the columns of A into a vector
vech(A)	stakes the lower triangular part of a symmetric matrix A into a vector
GL(n)	general linear group of $n \times n$ matrices
$\mathcal{O}(n)$	group of orthogonal $n \times n$ matrices
L	lag operator

$\Phi(\mathrm{L})$	autoregressive polynomial
$\Theta(\mathrm{L})$	moving-average polynomial
$\Psi(\mathrm{L})$	causal representation, $\mathrm{MA}(\infty)$ polynomial
Δ	difference operator, $\Delta = 1 - \mathrm{L}$
p	order of autoregressive polynomial
q	order of moving-average polynomial
ARMA(p,q)	autoregressive moving-average process of order (p, q)
ARIMA(p,d,q)	autoregressive integrated moving-average process of order (p, d, q)
d	order of integration
I(d)	integrated process of order d
VAR(p)	vector autoregressive process of order p
$\mathbb{Z}$	integer numbers
$\mathbb{R}$	real numbers
$\mathbb{C}$	complex numbers
$\mathbb{R}^n$	set of n-dimensional vectors
$\imath$	imaginary unit
cov(X, Y)	covariance beween random variables X and Y
$\mathbb{E}$	expectation operator
$\mathbb{V}$	variance operator
$\Psi(1)$	persistence
$\mathbb{P}_T X_{T+h}$	linear least-squares predictor of X_{T+h} given information from period 1 up to period T
$\widetilde{\mathbb{P}}_T X_{T+h}$	linear least-squares predictor of X_{T+h} using the infinite remote past up to period T
P	Probability
$\{X_t\}$	stochastic process
$\mathrm{WN}(0, \sigma^2)$	white noise process with mean zero and variance σ^2
$\mathrm{WN}(0, \Sigma)$	multivariate white noise process with mean zero and covariance matrix Σ^2
$\mathrm{IID}(0, \sigma^2)$	identically and independently distributed random variables with mean zero and variance σ^2
$\mathrm{IID\,N}(0, \sigma^2)$	identically and independently normally distributed random variables with mean zero and variance σ^2
X_t	time indexed random variable
x_t	realization of random variable X_t
$f(\lambda)$	spectral density
$F(\lambda)$	spectral distribution function
I_T	periodogram
$\Psi(\mathrm{e}^{-\imath\lambda})$	transfer function of filter Ψ
VaR	value at risk