

## **Econometrics IV: Time Series Econometrics**

### **Course Outline 2006**

This is the first semester of what was until recently a two-course sequence in time series econometrics. (This academic year, the Spring semester course Econ 557b will not be taught, so we will again attempt to cover some of the material in that course in the first semester). The Fall course provides an introduction to time series methods in econometrics and emphasizes stationary time series, although some aspects of trend behavior and detrending are covered, and we will discuss some aspects of unit root theory and cointegration. Both time domain and frequency domain methods are discussed, and Bayesian as well as classical approaches are included. The treatment relies on asymptotic theory for linear processes, martingales and martingale approximations. We will overview a large literature, so not all topics are treated in the same depth. Theory, computations and some empirical applications are discussed.

No specific text is recommended. However, Hamilton's (1994)<sup>1</sup> book, Fuller (1996) and Gouriéroux and Monfort (1997) are recommended as useful references. Hamilton's coverage is broad and relevant to econometrics, the book is easy to read and it includes much introductory material, but is now a bit dated. Fuller's book provides an accessible statistical treatment of the subject, is a useful revision of an earlier (1976) edition, and was the first text to discuss unit root theory. Gouriéroux and Monfort (1997) is a translation of an excellent modern French textbook of time series that covers a wide literature and is oriented towards econometrics. Lutkepohl and Kratzig (2004) is a new textbook of applied time series econometrics that emphasizes practicalities and covers methods that are popular in empirical economic applications. Brockwell and Davis (1991) is a very successful time series text that is commonly used in North American graduate statistics courses. This book is more technical than the above texts and stresses univariate models, but is well expository, covers most of the traditional stationary time series topics and comes with some computer software. Lutkepohl's (1993) book and his new (2005) text provide excellent coverage and exposition of VAR and Bayesian VAR modelling methods, together with some small scale practical applications to macro data. Davidson (1994) is a good general reference source on limit theory for econometrics including functional laws, emphasizing mixing and weak dependence. Taniguchi and Kakizawa (2000) gives a modern treatment of time series asymptotics from a stochastic process perspective and includes some useful special topics like large deviation expansions, saddlepoint approximations and higher order asymptotics.

In addition, some older lecture notes and my 1998 IMF Lectures will be available. These cover some of the topics we will talk about in lectures. Past take home exams are available on the web and some solution sets are available. With these, the course should be self-contained.

A take home examination will be given at the end of the course and students have the option of taking this or doing an applied paper instead.

The following is a general outline of how we will proceed through the course material. This year I will make further adjustments to incorporate material on nonstationary time series.

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<sup>1</sup> See Section 0 in the Reading Guide below for general references.

<b>Week</b>	<b>Content</b>
1	Ideas and approaches to time series. Primary concerns and methods of inference: Classical, Bayesian and prequential approaches. Role of unit roots and cointegration in econometric modeling.
2&3	Bayesian and classical asymptotics for time series. Heuristic ideas and implications for inference and modelling. Model selection. Trend Elimination.
4 &5	Ergodic theory, implications and applications. Notions of weak dependence.
6	The Wold decomposition and forecasting. Conditional expectations and Hilbert projections.
7	The Phillips-Solo device & shortcuts to time series asymptotics. Strong laws and CLT's for time series.
8	Martingales and time series applications of the martingale convergence theorem
9	Vector Autoregressions and Bayesian VARs. Impulse response and forecast error variance asymptotic theory
10-11	Frequency domain approaches and spectral regression. Spectral density and long run variance estimation.
12	Long memory models and econometric methods. More on unit roots and cointegration.
<b>December</b>	<b><i>Take Home examination paper or applied econometrics paper</i></b>

## Reading Guide

Time series is a vast subject. The following list covers only that part of the subject that relates most closely to econometric research. The list is subdivided into topics that are relevant to material we intend to discuss, if only briefly in some cases, during the course.

### 0. General References<sup>2</sup>

- Aoki, M. (1987) *State Space Modeling of Time Series*. New York: Springer.
- Anderson, T.W. (1971) *The Statistical Analysis of Time Series*. New York: Wiley.
- Banerjee, A., J. Dolado, J.W. Galbraith and D.F. Hendry (1993) *Cointegration, Error-Correction and the Econometric Analysis of Non-Stationary Data*. Oxford: Oxford University Press.
- Bierens, H. J. (1996) *Topics in Advanced Econometrics: Estimation, testing and specification of cross section time series models*. Cambridge: Cambridge University Press.
- Box, G.E.P. and G.M. Jenkins (1976) *Time Series Analysis: Forecasting and Control*, 2nd ed. San Francisco: Holden Day.
- \* Brillinger, D.R. (1981) *Time Series: Data Analysis and Theory*, 2nd ed. San Francisco: Holden Day.
- \* Brockwell, P.J. and R.A. Davis (1986) *Time Series: Theory and Methods*. New York: Springer (2nd ed., 1991).
- Clements M. P. and D. F. Hendry (1998) *Forecasting Economic Time Series*. Cambridge: Cambridge University Press.
- \* Davidson, J. (1995) *Stochastic Limit Theory* Oxford: Oxford University Press.
- Dhrymes, P. (1989) *Topics in Advanced Econometrics*. New York: Springer Verlag.
- Fan, J. and Q. Yao (2003) *Nonlinear Time Series. Nonparametric and Parametric Methods*. New York: Springer.
- \* Fuller, W.A. (1996) *Introduction to Statistical Time Series, 2nd Edition*. New York: Wiley.
- Fishman, G. (1969) *Spectral Methods in Econometrics*. Cambridge: Harvard University Press.
- \* Gouriéroux C. and A. Monfort (1997). “Time Series and Dynamic Models”. Cambridge: Cambridge University Press.
- Granger, C.W.T. and P. Newbold (1987) *Forecasting Economic Time Series, 2nd edition*. New York: Academic Press.
- Grenander, U. and M. Rosenblatt (1957) *Statistical Analysis of Stationary Time Series*. New York: Wiley.

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<sup>2</sup> Asterisked references are more important to the course.

- \* Hall, P. and C.C. Heyde (1980) *Martingale Limit Theory and its Applications*. New York: Academic Press.
- Hannan, E.J. (1970) *Multiple Time Series*. New York: Wiley.
- Hannan, E.J. and M. Deistler (1988) *Statistical Theory of Linear Systems*. New York: Wiley.
- \* Hamilton, J.D. (1994) *Time Series Analysis*. Princeton: Princeton University Press.
- Harvey, A.C. (1993) *Time Series Models*. Hemel Hempstead: Harvester Wheatsheaf.
- Harvey, A.C. (1990) *Forecasting Structural Time Series Models and the Kalman Filter*. New York: Cambridge University Press.
- Hendry, D. F. (1995) *Dynamic Econometrics*. Oxford: Oxford University Press.
- Hsiao, C. (2003) *Analysis of Panel Data*. (2'nd Ed.) Cambridge: Cambridge University Press.
- Hylleberg, S. (1992) *Modelling Seasonality*. Oxford: Oxford University Press.
- \* Lutkepohl, H. (1993) *Introduction to Multiple Time Series Analysis*, 2nd ed. New York: Springer Verlag.
- \* Lutkepohl, H. (2005) *A New Introduction to Multiple Time Series Analysis*, New York: Springer Verlag.
- \* Lutkepohl, H. and M. Kratzig (2004) *Applied Time Series Econometrics*, Cambridge University Press.
- Matyas, L. (1999). *Generalized Methods of Moments Estimation*., Cambridge: Cambridge University Press.
- McCabe, B. and A. Tremayne (1992) *Elements of Modern Asymptotic Theory with Statistical Applications*, Manchester: Manchester University Press.
- Mills, T. C. (1990) *Time Series Techniques for Economists*. Cambridge: Cambridge University Press
- Ouliaris, S. and P. C. B. Phillips (1994) *COINT 2.0: Gauss Procedures for Cointegrated Regressions*, Aptech systems.
- Potscher B. and I. Prucha, “Dynamic Nonlinear Econometric Models” New York: Springer.
- Priestley, M.B. (1981) *Spectral Analysis and Time Series*. Vol. 1, New York: Academic Press.
- Rao, B.B. (1994) *Cointegration for the Applied Economist*. St. Martin's Press.
- Reinsel, G. (1993) *Elements of Multivariate Time Series Analysis*. New York: Springer.
- Solo V. (1986) *Topics in Advanced Time Series Analysis* in G. Del Pino and R. Rebolledo (Eds.) *Lectures in Probability and Statistics*. New York: Springer Verlag.
- Taniguchi, M. and Y. Kakizawa (2000). *Asymptotic Theory of Statistical Inference for Time Series*. New York: Springer Verlag.

- Tong, H. (1990) *Non-Linear Time Series: A Dynamical System Approach*. Oxford: Clarendon Press.
- Watson, M. (1995) "Vector Autoregressions and Cointegration." In R.F. Engle and D. McFadden, eds., *Handbook of Econometrics*, Vol. 4. Amsterdam: North Holland.
- West, M. and P.J. Harrison (1989) *Bayesian Forecasting and Dynamic Models*. New York: Springer-Verlag.
- White, H. (1994) *Estimation, Inference and specification Analysis*. Cambridge: Cambridge University Press.
- White, H. (2002) *Easymptotic Theory for Econometricians*. (Revised Edition) San Diego: Academic Press.
- Whittle, P. (1984) *Prediction and Regulation*, 2nd ed. Oxford: Blackwell.
- Wooldridge, J. M. (1995) "Estimation and Inference for Dependent Processes" in R. F. Engle and D. L. McFadden *Handbook of Econometrics Vol IV*. Amsterdam: North Holland.
- Yaglom, A.M. (1962) *An Introduction to the Theory of Stationary Random Functions*. New York: Dover.

## 1. Ideas and Approaches

- \* Phillips P. C. B. (1989 & 1995) Lecture notes

Phillips, P.C.B. (1992) "Unit Roots." In P. Newman, M. Milgate and J. Eatwell, eds., *The New Palgrave Dictionary of Money and Finance*, 726-730.

Phillips, P.C.B. (1995) "Unit Roots and Cointegration: Recent Books and Themes for the Future," *Journal of Applied Econometrics*

Phillips P. C. B. (1998) "Econometric Analysis of Nonstationary Data", IMF Lectures

Phillips P. C. B. (2003) "Laws and Limits of Econometrics", *Economic Journal*, Vol. 113, No. 486, March, 2003, pp. C26-C52..

## 2. Classical and Bayesian Asymptotics for time series and Model Selection

Chen, C. F. (1985). "On asymptotic normality of limiting density functions with Bayesian implications," *Journal of the Royal Statistical Society, Series B*, 47, 540--546.

Hartigan, J. A. (1983). *Bayes Theory*. New York: Springer-Verlag.

Heyde, C. C. and I. M. Johnstone (1979). "On asymptotic posterior normality for stochastic processes," *Journal of the Royal Statistical Society*, 41, 184--189.

Le Cam, L. and G. L. Yang (1990). *Asymptotics in Statistics: Some Basic Concepts*. New York: Springer

- \* Phillips, P.C.B. (1996) "Econometric Model Determination " *Econometrica*, 64, 763-812.
  - \* Phillips, P. C. B. and W. Ploberger (1996). "An asymptotic theory of Bayesian inference for time series," *Econometrica*, 64, 381-413.
- Ploberger W. and P. C. B. Phillips (2003) "Empirical Limits for Time Series Econometric Models", *Econometrica*, Vol. 71, No. 2, pp. 627-673.
- \* Schwarz, G. (1978) "Estimating the dimension of a model," *Annals of Statistics*, 6:461-464.
- Sweeting, T. J. and A. O. Adekola (1987). "Asymptotic posterior normality for stochastic processes revisited," *Journal of the Royal Statistical Society, Series B*, 49, 215--222.

### 3. Strict Stationarity and Ergodic Theory

- Cramer, H. and M.R. Leadbetter (1967) *Stationary and Related Stochastic Processes*. New York: Wiley.
- \* Dhrymes (1989) *op. cit.*
- Rozanov, Y.A. (1967) *Stationary Random Processes*. San Francisco: Holden Day.
- \* Stout, W.F. (1974) *Almost Sure Convergence*. New York: Academic Press.
- Walters, P. (1982) *An Introduction to Ergodic Theory*. New York: Springer.

### 4. Projections and the Wold Decomposition

- Anderson (1971) *op. cit.*
- \* Brockwell and Davis (1993) *op. cit.*
  - \* Hannan (1970) *op. cit.*
- Whittle (1984) *op. Cit.*

### 5. Weak Dependence and Mixing Processes

- \* Davidson J. (1995) *op. cit.*
- Gallant A. R. and H. White (1988) *A Unified Theory of Estimation and Inference for Nonlinear Dynamic Models*. New York: Basil Blackwell.
- Ibragimov, I.A. and Y.V. Linnik (1971) *Independent and Stationary Sequences of Random Variables*. Groningen: Wolters-Noordhoff.

Potscher B. and I. Prucha (1997) *op. cit.*

- \* White, H. (2002) *op. cit.*

White, H. and I. Domowitz (1984) "Nonlinear Regression with Dependent Observations," *Econometrica*, 52:143-162.

## 6. BN Decomposition and Phillips-Solo Device

- \* Beveridge, S. and C. R. Nelson (1981). "A new approach to decomposition of economic time series into permanent and transitory components with particular attention to measurement of the 'business cycle'," *Journal of Monetary Economics*, 7, 151--174.
- \* Phillips, P.C.B. and V. Solo (1992) "Asymptotics for Linear Processes," *Annals of Statistics*, 20:971-1001.

## 7. Martingales, Martingale Convergence Theory and Strong Laws for Dependent Sequences

Billingsley, P. (1979) *Probability and Measure*. New York: Wiley.

Doob, J.L. (1953) *Stochastic Processes*. New York: Wiley.

- \* Hall, P. and C.C. Heyde (1980) *Martingale Limit Theory and its Application*. New York: Academic Press.
- McLeish, D.L. (1975) "A Maximal Inequality and Dependent Strong Laws," *Annals of Probability*, 3:829-839.
- \* Phillips, P.C.B. and V. Solo (1992) *op. cit.*

## 8. Central Limit Theory for Dependent Variables

Davidson J. (1995) *op. cit.*

- \* Hall and Heyde (1980) *op. cit.*
- \* Phillips and Solo (1992) *op. cit.*
- White, H. (1984) *op. cit.*

## 9. Spectrum, HAC and Long Run Variance Matrix Estimation

- \* Andrews, D.W.K. (1991) "Heteroskedasticity and Autocorrelation Consistent Covariance Matrix Estimation," *Econometrica*, 817-858.
- Andrews, D.W.K. and J.C. Monahan (1992) "An Improved Heteroskedasticity and autocorrelation Consistent Covariance Matrix Estimator," *Econometrica*, 60, 953-966.

- Den Haan, W.J., and A. Levin, 1997, "A practitioner's guide to robust covariance matrix estimation," in Handbook of Statistics 15, G.S. Maddala and C.R. Rao, eds., Elsevier (Amsterdam), pp.299-342.
- Den Haan, W.J., and A. Levin, 2000, "Robust covariance matrix estimation with data-dependent prewhitening order", Working Paper 2000-11, University of California, San Diego
- \* Hannan, E. J. (1970) *op. cit.*
- Lee, C. C. and P. C. B. Phillips (1994) "An ARMA-prewhitened long run variance estimator", Yale University, mimeographed.
- Newey, W.K. and K.D. West (1987) "A Simple Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix," *Econometrica*, 55, 703-708.
- Parzen, E. (1957) "On Consistent Estimates of the Spectrum of a Stationary Time Series," *Annals of Mathematical Statistics*, 28:329-348.
- Phillips, P. C. B., Y. Sun and S. Jin (2006) "Spectral Density Estimation and Robust Hypothesis Testing using Steep Origin Kernels without Truncation", *International Economic Review*.
- Phillips, P. C. B., Y. Sun and S. Jin (2006) "Long Run Variance Estimation and Robust Regression Testing using Sharp Origin Kernels with No Truncation" (with Yixiao Sun and Sainan Jin), *Journal of Statistical Planning and Inference*, 2006 (forthcoming)
- \* Priestley (1981) *op. cit.*
- Robinson, P.M. (1998), "Inference-without-smoothing in the Presence of Nonparametric Autocorrelation," *Econometrica*, 66, 1163-1182.
- Sul, D., C-Y Choi and P. C. B. Phillips (2005) "Prewhitening Bias in HAC Estimation", Oxford Bulletin of Economics and Statistics, # 1436
- Sun, Y., P. C. B. Phillips, and S. Jin (2006) "Optimal Bandwidth Selection in Heteroskedasticity-Autocorrelation Robust Testing" Cowles Foundation Discussion Paper.
- White, H. (1980) "A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test of Heteroskedasticity," *Econometrica*, 48, 817-838.
- White, H. (2002) *op. cit.*

## 10. Spectral Regression Theory

- Corbae, D., S. Ouliaris and P. C. B. Phillips (2002) "Band Spectral Regression with Trending Data". *Econometrica*, 70, 1067-1110.
- \* Hannan, E. J. (1963) "Regression for Time Series" in M. Rosenblatt (Ed.) *Time Series Analysis*, New York: Wiley.
- \* Hannan (1970) *op. cit.*



Phillips, P. C. B. (1997) "New developments on Hannan Regression", Ted Hannan Lecture, Australasian meetings of Econometric Society, Melbourne.

Robinson, P.M. (1991) "Automatic frequency domain inference on semiparametric and nonparametric models," *Econometrica*, 59, 1329-1364.

Xiao, Z. and P. C. B. Phillips, (1998). "Higher Order Approximations for Frequency Domain Time Series Regression", *Journal of Econometrics*, Vol. 86, 1998, pp. 297-336

## 11. VAR'S, BVAR's, Impulse Response Analysis

Cooley, T.B. and S.F. LeRoy (1985) "Atheoretical Macroeconometrics: A Critique," *Journal of Monetary Economics*, 16:283-308.

\* Hamilton (1994) Chs. 11, 12.

Litterman, R.B. (1986) "Forecasting with Bayesian Vector Autoregressions: Five Years of Experience," *Journal of Business and Economic Statistics*, 4:25-38.

Litterman, R.B. and L. Weiss (1985) "Money, Real Interest Rates, and Output: A Reinterpretation of Postwar U.S. Data," *Econometrica*, 53:129-156.

\* Lutkepohl, H. (1990) "Asymptotic Distributions of Impulse Response Functions and Forecast Error Variance Decompositions of Vector Autoregressive Models," *Review of Economics and Statistics*, 72:116-125.

\* Lutkepohl, H. (1993) *op.cit.*, Ch. 5.

Phillips, P.C.B. (1995a) "Bayesian Model Selection and Prediction with Empirical Applications," *Journal of Econometrics*, 69, 289-332

Phillips, P.C.B. (1995b) "Bayesian Prediction: A Response," *Journal of Econometrics*, 69, 351-365.

\* Phillips, P.C.B. (1998) "Impulse response and forecast error asymptotics in nonstationary VAR's," *Journal of Econometrics*, 83, 21-56.

Runkle, D. (1987) "Vector Autoregressions and Reality," *Journal of Business and Economic Statistics*, 5(4):437-432.

\* Sims, C.A. (1980) "Macroeconomics and Reality," *Econometrica*, 48:1-48.

Todd, R.M. (1990) "Vector Autoregression Evidence on Monetarism: Another Look at the Robustness Debate," *Federal Reserve Bank of Minneapolis Quarterly Review*, 19-37.

Todd, R.M. (1995) "Improving Economic Forecasting with Bayesian Vector Autoregression," *Federal Reserve Bank of Minneapolis Quarterly Review*, 4:18-29.

Zellner, A. and C.K. Min (1992) "Bayesian Analysis, Model Selection and Prediction," University of Chicago, Mimeographed.

## 12. Long Memory Models and Econometric Methods

- \* Baillie, R. T. (1996). "Long memory processes and fractional integration in econometrics". *Journal of Econometrics*, 73, 5-59.
- Baillie, R. T. and T. Bollerslev (1994). "Long memory in the forward premium". *Journal of International Money and Finance*, 13, 565-571.
- Geweke J. and S. Porter-Hudak (1983) "The estimation and application of long memory time series models". *Journal of Time Series Analysis*, 4, 221-237.
- Granger, C. W. J. (1980). "Long memory relationships and the aggregation of dynamic models". *Journal of Econometrics*, 14, 227-238.
- \* Granger, C. W. J. and R. Joyeux (1980). "An introduction to long memory time series models and fractional differencing". *Journal of Time Series Analysis*, 1, 15-39.
- \* Hosking, J. R. M. (1981). "Fractional differencing". *Biometrika*, 68, 165-176.
- Kunsch, H. (1986). "Discrimination between monotonic trends and long-range dependence". *Journal of Applied Probability*, 23, 1025-1030.
- Mandelbrot, B. B. and J. W. Van Ness (1968). "Fractional Brownian motions, fractional Brownian noises and applications". *SIAM Review*, 10, 422-437.
- Mandelbrot, B. B. and J. Wallis (1968). "Noah, Joseph and operational hydrology". *Water Resources Research*, 4, 909-918.
- \* Phillips, P. C. B. (1999) "Discrete Fourier Transforms of Fractional Processes". Cowles Foundation Discussion Paper #1243, Yale University.
- Phillips, P. C. B. & K. Shimotsu (2004) "Local Whittle Estimation in Nonstationary and Unit Root Cases," *Annals of Statistics*, 32, 656-692.
- Phillips, P. C. B. (2006) "Unit Root Log Periodogram Regression", *Journal of Econometrics*,
- \* Robinson, P. M. (1995) "Log periodogram regression of time series with long range dependence". *Annals of Statistics*, 23, 1048-1072.
- Robinson, P. M. (1995) "Gaussian semiparametric estimation of time series with long range dependence". *Annals of Statistics*, 23, 1630-1661.
- Shimotsu, K. & Phillips, P. C. B (2005) "Exact Local Whittle Estimation of Fractional Integration" *Annals of Statistics*, 33, 1890-1933
- Shimotsu, K. & Phillips, P. C. B (2006) "Local Whittle Estimation of Fractional Integration and Some of its Variants", *Journal of Econometrics*.
- Sowell, F. B. (1986). "Fractionally integrated vector time series". Ph.D. dissertation (Duke University, Durham, NC).
- Sowell, F. B. (1992). "Maximum likelihood estimation of stationary univariate fractionally integrated time series models". *Journal of Econometrics*, 53, 165-188.

Sun, Y. and P. C. B. Phillips (2003). "Nonlinear Log-Periodogram Regression for Perturbed Fractional Processes", *Journal of Econometrics*, Vol. 115, No. 2, pp. 355-389.

*Journal of Econometrics*, Vol. 73 (1996) [special issue].