SS 222C: Econometrics
California Institute of Technology
Spring 2006

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Lecture: MW 2:30-3:55 p.m., 210 Baxter
Office Hours: By appointment or open door if available
Secretary: Patricia Hamad (Phone 396-3586, 112 Baxter)

Course Description: The course covers the *basic* methods and theory of modern time series econometrics while it is also intended to provide a foundation for applied research. The goal of the course is that the student acquires knowledge of the relevant concepts necessary to be able to understand the empirical and theoretical econometric literature as exposed in the leading journals. The course deals with the analysis of, univariate and multivariate, stationary and non-stationary, and linear and nonlinear, time series models. Topics such as forecasting, unit roots, VAR, cointegration, ARCH, bootstrap theory, quantiles, will also be covered. More advanced time series econometrics will be treated in SS223C (Spring 2006). The substantive applications in the course will draw from macroeconomics and finance. All the topics covered in the course are relevant to empirical applications. Prerequisites: SS222A and SS222B.

Grading: There will be 8 weekly homework sets, a take-home mid-term exam, and a take-home final exam with the following valuations in terms of your final grade: Homework (60%), Mid-term (20%), and Final (20%).

In order to pass the course (i.e., C or higher), all homework assignments as well as the mid-term and the final must be completed with a grade of at least 50%. In short, no skipping any homework assignment or exam.

The 8 homework sets will be based on material covered during the week either in lectures or in the reading assignment. Homework sets will have both analytical and computational problems. The computational problems will involve either simulation exercises or exercises involving analysis of real data sets. Weight of each homework set (to be indicated) may vary according to the length and difficulty.

The mid-term exam will be based on material from the first half of the course. The mid-term will take place during the official Caltech Midterm Examination Period (April 26-May 2). The exam will be handed out on Wednesday, April 26, 2006, 4 pm, after class, and must be returned to me (or under my door) by 10 am, Monday, May 1. You may take as much time as you wish to complete the exam (i.e., not timed). I will try to have the exams graded and returned on Wednesday, May 3 at the beginning of class.

The final exam will be based on material from the entire course, but will emphasize material covered in the second half of the class. The final will take place during the official Caltech Final Examinations for Graduate Students (May 31-June 2). You can pick up the exam from my mailbox after 10 am, Wednesday May 31, 2006. I will also email you the final exam in pdf, at 10 am, the same day. The exam must be returned to me (or under my door) by 5 pm Friday June 2. Again, you may take as much time as you want for the exam. Your graded final will be returned to you in your mailboxes in envelops or you can pick up from me in my office by appointment in the following week.

Collaboration Policy: You may collaborate on the homework sets. However, you must write up your own solutions. No copying. You are on your own for the mid-term and final exams. No collaboration on exams.

Course Outline: This course covers various issues in analysis of weakly dependent time series processes, nonstationary time series, nonlinear models, volatility, quantiles, and forecasting. The course contains essentially three parts. The first concerns the standard theory of stationary stochastic processes. This includes the characterization and estimation in the time domain as well as the frequency domain (spectral analysis). Also covered are vector autoregressive models including the analysis of causality and variance decomposition. We also highlight the importance of the concept of the spectral density function at the zero frequency. The second part of the course concerns the analysis of nonstationary data. We start

with some basic concepts for continuous time processes to introduce the Wiener process. We take a close look at the asymptotic distribution theory in the leading case of an AR(1) model and especially the case with an autoregressive unit root. Tests related to unit root processes are discussed. We also discuss the characterization, estimation and tests in cointegrated systems, including the problem of the decomposition of a time series in common permanent and idiosyncratic temporary components. The third part of the course concerns the recently developed topics such as forecasting, specification, testing, and estimation of nonlinear time series models and their diagnostic checking, volatility modeling, estimation and forecasting of the conditional quantile, and bootstrap for time series.

1. Stationary Time Series I

   (a) Introduction to the theory of time series: Definitions of stationarity, Autocorelations and autocovariances, Wold decomposition theorem, Autocovariance generating function, Autoregressive moving-average models, Invertibility, Autocovariance functions

   (b) Building linear time series models: Identification, Diagnostic checking, Model selection and information criteria

   (c) Estimation of ARMA models: Limiting distribution of the sample mean and the autocovariances, Estimation of autoregressive models, Estimation of moving-average models, Asymptotic results (weak and strong laws of large numbers, central limit theorems) for dependent processes and Martingale difference series

   (d) Forecasting: Using ARMA models

   (e) Spectral analysis: Spectral density function for stationary stochastic processes, Filters, Spectral density function at frequency zero, Estimation, HAC and Robust standard errors for the linear model estimated by OLS and for GMM estimators

   (f) Vector autoregressive processes: Causality, Impulse response, Variance decomposition

2. Non-stationary Time Series

   (a) Unit root: Trends, Wiener process, Functional central limit theorem, Testing for a unit root, Asymptotic distributions, Dickey-Fuller tests, Phillips-Perron tests

   (b) Cointegration: Granger representation, Error correction model, Tests for cointegration, Estimation of models with cointegration, Results for static OLS regressions, Asymptotically optimal single equation methods, Asymptotically optimal full system methods, Permanent and transitory components in economic time series

3. Stationary Time Series II

   (a) Conditional Variance: ARCH, GARCH, Testing, Estimation, QML, Consistency, Asymptotic distribution, Forecasting, Multivariate models

   (b) Forecasting: Tests for accuracy of forecasts, Forecast comparisons, Forecast combination, Density forecasts, Large model and parameter reduction methods

   (c) Nonlinear time series models: Testing, Estimation, Diagnostics, Forecasting

REFERENCES

The primary textbooks are Hamilton (1994) and Granger and Newbold (1986). The later sections of the course contains material not covered (at least not well) in these textbooks and draws heavily on articles. Only a few of the papers listed below under a topic will be covered; one role of this syllabus is to list additional references for those wishing to delve into specific topics in greater detail. In any event, the lectures will be self-contained. Primary readings are denoted by *.

Textbooks

*Granger, C.W.J. and P. Newbold (1986), *Forecasting Economic Time Series*, 2ed., Academic Press.

*Hamilton, J.D. (1994), *Time Series Analysis*, Princeton University Press.

General references for Topic 1 (Stationary Time Series I)

*Granger, C.W.J. and P. Newbold (1986), *Forecasting Economic Time Series*, 2ed., Academic Press.

*Hamilton, J.D. (1994), *Time Series Analysis*, Princeton University Press.

White, Halbert (2001), *Asymptotic Theory for Econometricians*, 2ed., Academic Press.

Hansen, Bruce (2006), *Lecture Notes*, www.ssc.wisc.edu/~bhansen

Davidson, R. and J. MacKinnon (2004), *Econometric Theory and Methods*, Oxford University Press.

Hayashi, Fumio (2000), *Econometrics,* Princeton University Press.

Davidson, J. (1994), *Stochastic Limit Theory*, Oxford University Press. (A thorough but accessible treatment of central limit theorems and convergence on function spaces.)

Newey, W.K. and D.L. McFadden (1994), "Large Sample Estimation and Hypothesis Testing", in R.F. Engle and D.L. McFadden (eds.), *Handbook of Econometrics,* Vol. 4, 2113-2247, North Holland.

Enders, W. (1995), *Applied Econometric Time Series*, John Wiley.

Mills, T. C. (1990), *Time Series Techniques for Economists*, Cambridge University Press.

Mills, T. C. (1993), *The Econometric Modelling of Financial Time Series*, Cambridge University Press.

Box, G. E. and G. M. Jenkins (1976), *Time Series Analysis : Forecasting and Control*, 2nd edition, Holden-Day.

Brillinger, D.R, (1981), *Time Series Data Analysis and Theory*, second edition. New York: Holt, Rinehart and Winston (A classic text for spectral estimation and filtering, with an engineering/statistics orientation.)

Brockwell, P. J. and R. A. Davies (1991), *Time Series : Theory and Methods*, 2nd ed., Springer-Verlag. (An advanced survey of time series techniques from the point of view of engineers and statisticians. Perhaps the most complete treatment of linear time series models [univariate and vector ARMA models].)

Lutkephohl, H. (1993), *Introduction to Multiple Time Series Analysis*, 2nd ed., Springer-Verlag.

Hall, P. and C.C. Heyde (1980), *Martingale Limit Theory and its Applications.* New York: Academic Press, 1980. (The classic treatment of martingales and convergence on function spaces.)

Harvey, A.C. (1993), *Time Series Models*, Second Edition. Cambridge: MIT Press, 1993. (A concise overview of time series tools, with an emphasis on modeling, numerical implementation and the Kalman filter, and not much distribution theory.)

Gourieroux, C. and A. Monfort (1996), *Time Series and Dynamic Models*, Cambridge University Press.

Priestley, M. B. (1981), *Spectral Analysis and Time Series*, Academic Press.

Model selection and information criteria

*Hansen, Bruce (2006), *Lecture Notes*, www.ssc.wisc.edu/~bhansen

Geweke, J. and R. Meese (1981), Estimating Regression Models of Finite but Unknown Order, International Economic Review 22, no. 1, 55-70.

Heteroskedasticity and autocorrelation consistent (HAC) variance estimation

*White, H. (1980), *Econometrica*

*Newey, W.K. and K.D. West (1987), A Simple Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix, *Econometrica* 55, 703-708.

Andrews, D.W.K. (1991), Heteroskedasticity and Autocorrelation Consistent Covariance Matrix Estimation, *Econometrica* 59, 817-858.

Hayashi, Fumio (2000), *Econometrics,* Princeton University Press.

Andrews, D.W.K. and J.C. Monahan (1992), An Improved Heteroskedasticity and Autocorrelation Consistant Covariance Matrix Estimator, *Econometrica* 60, 953-966.

den Haan, W.J. and A. Levin (2000), Robust Covariance Matrix Estimation with Data-Dependent VAR Prewhitening Order, NBER Technical Working Paper #255.

den Haan, W.J. and A. Levin, A Practitioners Guide to Robust Covariance Matrix Estimation, *Handbook of Statistics* 15, Ch 12, 291-341.

Kiefer, N. and T. Vogelsang (2002), Heteroskedasticity-Autocorrelation Robust Testing Using Bandwidth Equal to Sample Size, *Econometric Theory* 18, 1350-1366.

Kiefer, N.M., T.J. Vogelsang, and H. Bunzel (2000), "Simple Robust Testing of Regression Hypotheses", *Econometrica,* 68(3), 695 - 714

Vector Autoregressions

*Hamilton (1994)

Lutkepohl, H., *Introduction to Multiple Time Series Analysis*, Second Edition. New York: Springer-Verlag, 1993, ch. 3.7

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

Stock, J.H. and M.W. Watson (2001) Vector Autoregressions, *Journal of Economic Perspectives* 15 (Fall 2001), 101 116.

Watson, M.W. (1994), Vector Autoregressions and Cointegration, *Handbook of Econometrics*, v. IV, 2844-2915 (section 3).

Enders, W. (1995), *Applied Econometric Time Series*, John Wiley.

Unit Root and Cointegration

References for Topic 2 (Non-stationary Time Series)

*Hamilton (1994)

Banerjee, A., J. Dolado, J.W. Galbraith and D.F. Hendry (1994), *Co-Integration, Error Correction and the Econometric Analysis of Non-Stationary Data*, Oxford University Press.

Engle, R.F. and C.W.J. Granger (1991), *Long-Run Economic Relationships,* Oxford University Press.

Fuller, W. A. (1976), *Introduction to Statistical Time Series*, John Wiley & Sons.

Hatanaka, M. (1996), *Time-Series-Based Econometrics: Unit Roots and Cointegration.* Oxford: Oxford University Press, 1996. (Another perspective on the unit roots/cointegration literature, well organized and reasonably comprehensive.)

Johansen, S. (1995), *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models,* Oxford University Press.

White, Halbert (2001), *Asymptotic Theory for Econometricians*, 2ed., Academic Press, Chapter 7.

Chan, N.H., and Wei, C.Z. (1988), Limiting Distributions of Least Squares Estimates of Unstable Autoregressive Processes, *Annals of Statistics* 16, March 1988, 367-401.

Stock, J.H. (1994), Unit Roots and Trend Breaks, *Handbook of Econometrics*, v. IV

Andrews, D.W.K. and H.-Y. Chen (1994), Approximately Median-Unbiased Estimation of Autoregressive Models, *Journal of Business and Economic Statistics*, 12, 187-204.

Dickey, D.A., and W.A. Fuller (1979), Distribution of the Estimators for Autoregressive Time Series With a Unit Root, *Journal of the American Statistical Association* 74, no. 366, 427-431.

Elliott, G., T.J. Rothenberg, and J.H. Stock (1996), Efficient Tests for an Autoregressive Unit Root, *Econometrica* 64, 813-836.

Nelson, C.R., and C.I. Plosser (1982), Trends and Random Walks in Macroeconomic Time Series, *Journal of Monetary Economics*, 129-162.

Ng, S. and P. Perron (2001), Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power, *Econometrica* 6, 15191554.

*Phillips, P.C.B. (1987), Time Series Regression with Unit Roots, *Econometrica*, 55, 277-302.

Stock, J.H. (1991), Confidence Intervals for the Largest Autoregressive Root in U.S. Economic Time Series, *Journal of Monetary Economics* 28, no. 3, 435-460.

*Engle, Robert F., and C.W.J. Granger (1987), Co-Integration and Error Correction: Representation, Estimation and Testing, *Econometrica* 55, 251-276.

Watson, M.W. (1994), Vector Autoregressions and Cointegration, *Handbook of Econometrics*, v. IV, 2844-2915 (sections 1 and 2).

Elliott, G. (1998), The Robustness of Efficient Cointegration Estimators when Regressors Almost Have Unit Roots, *Econometrica* 66, 149-158.

Haug, A.A. (1996), Tests for Cointegration: A Monte Carlo Comparison, *Journal of Econometrics* 71.

*Johansen, S. (1988), "Statistical Analysis of Cointegration Vectors", *Journal of Economic Dynamics and Control*, 12, 231-255.

*Johansen, S. (1991), "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models", *Econometrica,* 59(6), 1551-1580.

Phillips, P.C.B. and S. Ouliaris (1990), Asymptotic Properties of Residual Based Tests for Cointegration, *Econometrica*, 58, 165-94.

Saikkonen, P. (1991), Asymptotically Efficient Estimation of Cointegrating Regressions, *Econometric Theory*, 7, 1-21.

Sims, C.A., J.H. Stock, and M.W. Watson (1990), Inference in Linear Time Series Models with Some Unit Roots, *Econometrica* 58, 113-144.

Stock, J.H. (1987), Asymptotic Properties of Least Squares Estimators of Cointegrating Vectors, *Econometrica* 55, 1035-1056.

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Hendry, D.F. (1995), *Dynamic Econometrics*, Oxford University Press.

Granger C.W.J. and T.-H. Lee (1989), "Investigation of Production, Sales and Inventory Relationships Using Multicointegration and Nonsymmetric Error Correction Models", *Journal of Applied Econometrics*, 4, S145-159

Granger C.W.J. and T.-H. Lee (1989), "Multicointegration", *Advances in Econometrics: Cointegration, Spurious Regression, and Unit Roots*, edited by Thomas B. Fomby and George F. Rhodes, Jr., Vol. 8, 71-84, JAI Press Inc.

Engle, R.F. and D. McFadden (1993), *Handbook of Econometrics*, Volume 4, North Holland.

ARCH

*Hamilton (1994), Chapter 21

*Tsay, R.S. (2005), *Analysis of Financial Time Series*, 2ed., Wiley.

*Campbell, J.Y., A.W. Lo, and A.C. MacKinlay (1997), *The Econometrics of Financial Markets,* Princeton University Press. Chapter 12

Bollerslev, T., R.F. Engle, and D.B. Nelson (1994), ARCH Models, *Handbook of Econometrics*, v. IV, 2959-3038.

Engle, R.F. (1995), *ARCH Selected Readings,* Oxford University Press.

Gourieroux, C. and J. Jasiak (2001), *Financial Econometrics,* Princeton University Press.

Forecasting

*Granger and Newbold (1986)

Bates, J.M. and C.W.J. Granger (1969), "The Combination of Forecasts", *Operations Research Quarterly,* 20, 451-468. Also see Granger and Newbold (1986, Chapter 9)

*Diebold, F. X. and R. Mariano. 1995. Comparing predictive accuracy. *Journal of Business and Economic Statistics* 13: 253-265.

*Diebold, F. X., T. Gunther and A.S. Tay (1998), "Evaluating Density Forecasts with Applications to Finance and Management", *International Economic Review*, 39, 863-883.

Diebold, F. X., J. Hahn and A.S. Tay (1999), "Multivariate Density Forecast Evaluation and Calibration in Financial Risk Management: High Frequency Returns on Foreign Exchange", *Review of Economics and Statistics*, 81, 661-673.

*Giacomini, R. and H. White (2005), "Conditional Tests for Predictive Ability", UCLA and UCSD.

Granger, C. W. J. (1969), "Investigating Causal Relations by econometric Models and Cross-Spectral Methods", *Econometrica,* 37, 424-438.

Granger, C.W.J. (1969), "Prediction with a Generalized Cost of Error Function", *Operational Research Quarterly,* 20, 199-207.

Granger, C. W. J. (1980), "Testing for Causality: A Personal Viewpoint", *Journal of Economic Dynamics and Control*, 2, 329-352.

Granger, C. W .J. (1988), "Some Recent Developments in a Concept of Causality", *Journal of Econometrics*, 39, 199-211.

Granger, C.W.J. (1989), "Invited Review: Combining Forecasts - Twenty years Later", *Journal of Forecasting* 8, 167-173.

Granger, C.W.J. (1999), *Empirical Modeling in Economics,* Cambridge University Press.

*Granger, C.W.J. (1999), "Outline of Forecast Theory Using Generalized Cost Functions", *Spanish Economic Review* 1, 161-173.

Granger, C.W.J. (2002), "Some Comments on Risk", *Journal of Applied Econometrics*, 17, 447-456.

Granger, C. W .J. (2003), "Time Series Concepts for Conditional Distributions", *Oxford Bulletin of Economics and Statistics*, 65, 689-701.

Granger, C. W .J. (2005), "The Past and Future of Empirical Finance: Some Personal Comments", *Journal of Econometrics*, 129, 35-40.

Granger, C.W.J. and Ramanathan, R. (1984), "Improved Methods of Combining Forecasts", *Journal of Forecasting* 3, 197-204.

Granger, C.W.J. and M.H. Pesaran (2000), "Economic and Statistical Measures of Forecast Accuracy", *Journal of Forecasting,* 19, 537-560.

*West, K.D. (1996), "Asymptotic Inference about Predictive Ability", *Econometrica,* 64 1067-1084.

*Timmermann, A. (2005), "Forecast Combinations", forthcoming in *Handbook of Economic Forecasting*, Elliott, G., Granger, C.W.J., and Timmermann, A. (ed.), North Holland.

Stock, J.H. and M.W. Watson (2004), Forecasting with Many Predictors, forthcoming, *The Handbook of Economic Forecasting.*

White, H. (2000), "A Reality Check for Data Snooping", *Econometrica*, 68, 1097-1126.

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*Campbell, J.Y., A.W. Lo, and A.C. MacKinlay (1997), *The Econometrics of Financial Markets,* Princeton University Press. Chapter 12

Fan, J. and Q. Yao (2003), *Nonlinear Time Series: Nonparametric and Parametric Methods*, Springer Verlag.

Granger, C. W. J. and T.-H. Lee (1999), "The Effect of Aggregation on Nonlinearity", *Econometric Reviews*, 18(3), 259-269.

*Granger, C.W.J. and T. Teräsvirta (1993), *Modelling Nonlinear Economic Relationships,* Oxford University Press.

Lee, T.-H., H. White and C. W. J. Granger (1993), "Testing for Neglected Nonlinearity in Time Series Models: A Comparison of Neural Network Methods and Alternative Tests", *Journal of Econometrics*, 56, 269-290.

*Hong, Y. (1999), "Hypothesis Testing in Time Series via the Empirical Characteristic Function: A Generalized Spectral Density Approach," *Journal of American Statistical Association*, 84, 1201-1220.

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Hong, Y. and T.-H. Lee (2003b), "Diagnostic Checking for Adequacy of Nonlinear Time Series Models", *Econometric Theory*, 19(6), 1065-1121