

<b>ARE/ECN 240C</b>	<b>TIME SERIES ANALYSIS</b>	<b>Winter 2010</b>
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<b>Class Meets:</b>	T – R, <b>2:10 – 3:30pm</b> . Room: WICKSN 1038
<b>Office Hours:</b>	Mondays, 1 – 3pm; Wednesdays 10-11am, or by appointment

**Textbook:** Hamilton, J. D. (1994) *Time Series Analysis*, Princeton University Press, New Jersey. I will follow Hamilton's book rather closely. Regardless, this is a great book, worth having in your library. I will provide additional references for specific topics but these are easily available through the library or on the web.

**Assignments:** I plan to have 5 assignments, hopefully involving some computer work as well. The software programs that I plan to use are STATA, EViews and GAUSS. You should not be too stressed about this since most of the exercises will involve relatively simple manipulations of programs that I will have prepared for you.

**Resources:** Mostly, you should check the home page for the course. Additional readings for each topic can be found at the end of this document.

**Grading:** There will be three components to your grade, assignments (30%), midterm (30%) and final (40%).

**Planned Schedule:**

January 14	Problem Set 1 Due
January 28	Problem Set 2 Due
<b>February 4</b>	<b>Midterm</b>
February 11	Problem Set 3 Due
February 25	Problem Set 4 Due
March 11	Problem Set 5 Due
<b>March 18</b>	<b>FINAL</b>

## ***Course Outline:***

### TOPIC 0: REVIEW OF PROBABILITY THEORY

- Basic Definitions: sample space,  $\sigma$ -algebra, probability measure, probability space, random variable, distribution function, Borel-measurable functions, expected value.
- Modes of Convergence: convergence in probability, mean square, almost sure and convergence in law.
  - Mann-Wald Theorem
  - Cramer-Wold Theorem
  - Slutsky's Theorem
- Laws of Large Numbers:
  - Kolmogorov: I and II
  - Khinchine
- Central Limit Theorems:
  - Lindeberg-Levy
  - Lindeberg-Fuller
- The Delta Method

### TOPIC 1: INTRODUCTION TO UNIVARIATE, STATIONARY TIME SERIES

- Introduction: cross-section vs. time-series
- Preliminary Concepts:
  - Lag Operators
  - White noise, martingales and martingale difference sequences
  - Autocovariances and autocorrelations
  - Stationarity:
    - Weak stationarity
    - Strong stationarity
    - Random walks
  - Ergodicity and the Ergodic Theorem
  - Uniform-mixing and strong-mixing
- Central Limit Theorem for Martingale Difference Sequences
- Central Limit Theorem for Dependent Processes
  - The Beveridge-Nelson Decomposition
- Basic ARMA models:
  - MA, AR, and ARMA models
  - Common transformations and identification
  - Wold representation theorem
  - State-space representation

### TOPIC 2: LARGE SAMPLE ESTIMATION, HYPOTHESIS TESTING AND FORECASTING

- Maximum Likelihood, Extremum Estimation, Minimum Distance and GMM
  - Consistency
  - Asymptotic Normality
- MLE for ARMA models
  - AR ML: exact versus conditional likelihood
  - MA ML: exact versus conditional likelihood
  - ARMA ML
- Review of Numerical Optimization Routines
  - Newton's Method
  - Common algorithms: Newton-Raphson; Quadratic-Hill; Gauss-Newton/BHHH; Marquardt; DFP.
  - Elements of numerical optimization algorithms

- Statistical Inference
  - Wald, Likelihood Ratio and Lagrange Multiplier principles
  - Non-standard tests:
    - QMLE
    - Unidentified parameters under the null
    - Ljung-Box statistic
- The Bootstrap
  - Definition and Edgeworth Expansion
  - The Classical Bootstrap
  - Applications:
    - Bias reduction
    - Standard error estimation
    - Hypothesis testing
    - Confidence intervals
  - Bootstrap variations
  - Bootstrap for time series data
    - Parametric bootstrap
    - Block bootstrap
- Forecasting
  - ARMA models
  - Nonlinear models: Methods
    - Naïve
    - Exact
    - Monte Carlo
    - Bootstrap
  - Direct Forecasting
  - Tests of predictive ability

### TOPIC 3: UNIT ROOTS

- Detrending Methods: deterministic vs. stochastic trends
- Asymptotic distribution of the simple trend model
- Unit Roots
  - Preliminaries: Brownian motion
  - Functional central limit theorem:
    - Convergence in law of random functions
    - Convergence in probability of random functions
    - Continuous mapping theorem
  - The Dickey-Fuller distribution
  - Functional central limit theorem for dependent processes
    - The augmented Dickey-Fuller test: derivation
    - The Phillips-Perron test: derivation
  - Local-to-unity asymptotics

### TOPIC 4: COVARIANCE STATIONARY VECTOR TIME SERIES

- The VAR(p)
  - Presentation
  - Stationarity
  - Wold's theorem and the VMA representation
- Heteroskedasticity and Autocorrelation Variance Estimation
  - Newey-West estimator

- Granger causality and exogeneity
- MLE of vector processes
- Structural interpretation of VARs
  - The impulse response function
  - The variance decomposition
  - Identification and Interpretation
- Inference in VARs
- Estimation and Inference of Impulse Responses by Local Projections

#### TOPIC 5: GENERALIZED METHOD OF MOMENTS

- Introduction: classical method of moments
- GMM
  - Formulation
  - Optimal weighting matrix
  - Asymptotic distribution
  - Inference:
    - The J-statistic
    - Tests of subsets of orthogonality conditions
    - LR tests
  - MLE and GMM
    - Wald tests
    - LM tests
  - Extensions

#### TOPIC 6: COINTEGRATION

- Motivation: spurious regressions
- Definition:
  - Properties
  - Error correction representation
  - Granger representation theorem
  - Phillips triangular representation
  - Stock-Watson common trends representation
- Testing
  - Engle-Granger 2-step cointegration test
    - Corrections for serial correlation
- Full Information Maximum Likelihood analysis of cointegrated systems
  - Preliminaries: canonical correlations
  - Johansen's test
  - Concentrating the likelihood
  - Hypothesis testing

#### TOPIC 7: TIME SERIES MODELS FOR HIGHER MOMENTS AND TRANSITION DATA

- ARCH models
  - Relation to ARMA
  - MLE – GARCH
  - Testing for ARCH
  - Extensions
- ACD models
  - Specification

- Estimation
- ACH models
  - Presentation
  - Relation to ACD
  - Estimation
- ACI models
  - Presentation
  - Relation to ACD
  - Estimation

#### TOPIC 8: STATE SPACE MODELING AND THE KALMAN FILTER

- State Space Representation
- Kalman Filter
  - Overview
  - Algorithm
  - Forecasting
- MLE with the Kalman filter
- Asymptotic properties of MLE/QMLE

#### ***Additional Reading***

Almost all the material for the class comes from Hamilton's book so you need not worry about the reading list except when indicated in class. The references contained in Hamilton's book are quite comprehensive if you ever need to go deeper into a topic. The references below might be helpful if you have difficulty understanding the material. A \* indicates references I find particularly useful.

#### TOPIC 0: REVIEW OF PROBABILITY THEORY

- \*Amemiya, T. (1985), Advanced Econometrics. Cambridge: Harvard University Press. (Chapter 3). [Amemiya]
- Davidson, James (1994) Stochastic Limit Theory, Oxford: Oxford University Press.
- Davidson, Russell and James G. Mackinnon (1993), Estimation and Inference in Econometrics. New York: Oxford University Press. (Chapter 4) [Davidson and Mackinnon]
- \*Hamilton, Chapter 7.
- Hayashi, Fumio (2000) Econometrics. Princeton: Princeton University Press. (Chapter 2) [Hayashi]
- \*White, Halbert (1999) Asymptotic Theory for Econometricians, Revised Edition. San Diego: Academic Press. Chapters 2-5

#### TOPIC 1: INTRODUCTION TO UNIVARIATE, STATIONARY TIME SERIES

- Box, G.E.P. and G.M. Jenkins (1976), *Time Series Analysis: Forecasting and Control*, 2<sup>nd</sup> ed. San Francisco: Holden Day.
- Gouriéroux C. and A. Monfort (1997), *Time Series and Dynamic Models*. Cambridge: Cambridge University Press.
- \*Hamilton, Chapters 1-3.

- \*Sargent, T. J. (1987), *Macroeconomic Theory*. Boston: Academic Press. (Chapters 9-11).

#### TOPIC 2: ESTIMATION, INFERENCE AND FORECASTING

- \*Amemiya, Chapter 4.
- Berkowitz, Jeremy and Lutz Kilian (2000) "Recent Developments in Bootstrapping Time Series," *Econometric Reviews*, 19(1), 1-48.
- \*Cameron, A. Colin and Pravin Trivedi (2004) Microeconometrics: Methods and Applications, Chapter 11: *Bootstrap*. U.C. Davis, *mimeo*.
- Clements, Michael P. and David F. Hendry (1998) Forecasting Economic Time Series, Cambridge: Cambridge University Press.
- \*Davidson, R. and J. G. MacKinnon, Chapter 8.
- \*Diebold, F. X. and R. S. Mariano (1995) "Comparing Predictive Accuracy," *Journal of Economics and Business Statistics*, 13, 253-263.
- \*Engle, R. F. (1984), "Wald, Likelihood Ratio, and Lagrange Multiplier Tests in Econometrics," Ch. 13 in Handbook of Econometrics, Vol. II, eds. Z. Griliches and M.D. Intriligator, Amsterdam: North-Holland.
- Giacomini, R. and H. White (2004) "Tests of Conditional Predictive Ability," UCLA manuscript.
- \*Granger, C. W. J. and P. Newbold, (1986) Forecasting Economic Time Series. Academic Press.
- \*Granger, C. W. J. and Timo Terasvirta (1993) Modelling Nonlinear Economic Relationships, Oxford: Oxford University Press, Chapter 8.
- \*Greene, W. H. (1997) *Econometric Analysis*, 4<sup>th</sup> Edition. New Jersey: Prentice Hall. (Chapter 5).
- Hall, Peter (1992) The Bootstrap and Edgeworth Expansions, New York: Springer-Verlag.
- Horowitz, J. L. (2001) "The Bootstrap," Handbook of Econometrics, volume 5. Amsterdam: North-Holland.
- \*Hamilton, Chapters 4-5.
- \*Newey and McFadden (1994) "Large Sample Estimation and Hypothesis Testing," in The Handbook of Econometrics, v. 4. Amsterdam: North-Holland.
- \*West, K. D. (1996) "Asymptotic Inference about Predictive Ability," *Econometrica*, 64, 1067-1084.

#### TOPIC 3: UNIT ROOTS

- Brockwell, P.J. and R. A. Davis. Time Series: Theory and Methods. Springer-Verlag.
- Cavanagh, C. L., G. Elliott, and J. H. Stock (1995) "Inference in Models with Nearly Nonstationary Regressors," *Econometric Theory*, v11, 1131-1147.
- \*Davidson, J. (1994) Stochastic Limit Theory. Oxford; Oxford University Press.
- Dickey, D. A. and W. A. Fuller (1979), "Distribution Estimators for Autoregressive Time Series with a Unit Root," *Journal of the American Statistical Association*, 74, 437-431.
- Fuller, W. A. Introduction to Statistical Time Series. Wiley series in Probability and Statistics. John Wiley.
- \*Hamilton, Chapters 15-17.
- Phillips, P.C.B. (1986), "Time Series Regression with Unit Roots," *Econometrica*, 55, 227-302.

- \*Phillips, P.C.B. (1987) "Towards a Unified Asymptotic Theory for Autoregression," *Biometrika*, 74, 535-47
- Phillips, P.C.B. (1998), "New Tools for Understanding Spurious Regressions," *Econometrica*, 66, 1299-1236.
- \*Stock, J. H. (1994), "Unit Roots, Structural Breaks, and Trends," in *Handbook of Econometrics*, Vol. IV, eds. D. McFadden and R. F. Engle. Amsterdam: North-Holland.
- \* Tanaka, Katsuto, (1996) Time Series Analysis. New York: John Wiley (Chapter 3 and Chapter 9).

#### TOPIC 4: COVARIANCE STATIONARY VECTOR TIME SERIES

- Demiralp S. and K. D. Hoover, (2003), "Searching for the Causal Structure of a Vector Autoregression," *Oxford Bulletin of Economics and Statistics*, 65(0), 745-67.
- Den Haan, W. J. and A. Levin, (1997), " A Practioner's Guide to Robust Covariance Matrix Estimation," *Handbook of Statistics 15* (Chapter 12, 291-341)
- \*Den Haan, W. J. and A. Levin, (1996), " Inferences from Parametric and Non-Parametric Covariance Matrix Estimation Procedures," NBER Technical Working Paper 195. Both papers can be downloaded from: <http://weber.ucsd.edu/~wdenhaan/papers.html>
- \*Engle, R. F., D. F. Hendry, and J.-F. Richard, (1983), "Exogeneity," *Econometrica*, 51, 277-305.
- \*Granger, C. W. J. (1980), "Testing for Causality: A Personal Viewpoint," *Journal of Economic Dynamics and Control*, 2, 329-352
- Granger, C. W. J. (1989), *Modelling Economic Series*, Oxford: Oxford University Press.
- \*Hamilton, Chapters 10-11.
- \*Hendry, D. F. (1995), *Dynamic Econometrics*, Oxford: Oxford University Press.
- Hoover, K. D. and S. M. Sheffrin, (1992), " Causation, Spending, and Taxes: Sand in the Sandbox or Tax Collector for the Welfare State?" *American Economic-Review*; 82(1), 225-48.
- \*Jordà, O (2005) "Estimation and Inference of Impulse Responses by Local Projections," *American Economic Review*, March.
- Newey W. N. and K. D. West (1987), "A Simple Positive Semi-Definite Heteroskedasticity and Autocorrelation Consistent Covariance Matrix," *Econometrica*, 55, 703-708.
- \*Reinsel, G. C. (1993), *Elements of Multivariate Time Series Analysis*, New York: Springer-Verlag.
- Swanson, N. R. and C. W. J. Granger, (1997), "Impulse Response Functions Based on a Causal Approach to Residual Orthogonalization in Vector Autoregressions," *Journal of the American Statistical Association*, 92(437), 357-367.

#### TOPIC 5: GENERALIZED METHOD OF MOMENTS

- \*Hamilton, Chapter 14.
- \*Hayashi, Chapters 3-4.
- \*Wooldridge, Jeff (2002) Econometric Analysis of Cross Section and Panel Data, chapter 14

#### TOPIC 6: COINTEGRATION

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

- \*Johansen, S. (1995), *Likelihood-Based Inference in Cointegrated Vector-Autoregressive Models*, Oxford: Oxford University Press.
- Hamilton, Chapters 19-20.
- \*Sims, C. A., J. H. Stock and M. W. Watson, (1990), "Inference in Time Series Models with some Unit Roots," *Econometrica*, 58, 113-44.
- Watson, M. W. (1994), "Vector Autoregressions and Cointegration," in *Handboof of Econometrics*, Vol. IV, eds. D. McFadden and R. F. Engle. Amsterdam: North-Holland.

#### TOPIC 7: TIME SERIES MODELS FOR HIGHER MOMENTS AND TRANSITION DATA

- Bergin, Paul R. and Òscar Jordà (2001) "Measuring Monetary Policy Interdependence," *Journal of International Money and Finance*, v. 23, n. 5, 761-83..
- Engle, Robert F. (1995) ARCH. Selected Readings, Oxford: Oxford University Press.
- Engle, Robert F. and Jeffrey R. Russell (1998) "Autoregressive Conditional Duration: A New Model for Irregularly Spaced Transaction Data," *Econometrica*, V. 66, N. 5, 1127-1162.
- \*Hamilton, James D. and Òscar Jordà (2002) "A Model for the Federal Funds Target," *Journal of Political Economy*, vol. 110, n. 5, 1135-1167.
- \*Hamilton, Chapter 21.
- Jordà, Oscar Holly Liu and Jeffrey Williams (2002) "Non-institutional Market Making Behavior: The Dalian Futures Exchange," U.C. Davis, *mimeo*.
- \*Marcellino, Massimiliano and Òscar Jordà (2002) "Modelling High-Frequency FX Data Dynamics," *Macroeconomic Dynamics*, v.7, 618-635.

#### TOPIC 8: STATE SPACE MODELING AND THE KALMAN FILTER

- \*Hamilton, Chapter 13.
- \*Hamilton, J. D. (1994), "State-Space Models," in *Handbook of Econometrics*, Vol. IV, R. F. Engle and D. L. McFadden, eds. Amsterdam: North-Holland.
- Harvey, Andrew C. (1989), *Forecasting Structural Time Series Models and the Kalman Filter*. Cambridge: Cambridge University Press.