14.384. Time Series Analysis
Fall, 2021
Anna Mikusheva

Instructor: Anna Mikusheva (amikushe@mit.edu, Office hours: Tuesdays, noon-1pm, E52-526)

Teaching Assistant: Sylvia Klosin (klosins@mit.edu, Office hours: Mondays, 5:30-6:30pm, E52-548)

Course Description. The course provides a survey of the theory and application of time series methods in econometrics. Topics covered will include univariate stationary and non-stationary models, vector autoregressions, frequency domain methods, models for estimation and inference in persistent time series, structural breaks. We will cover structural VARs and Factor models. We discuss different methods for estimation and inference including simulated method of moments, Maximum likelihood and Bayesian approach. The empirical applications in the course will be drawn primarily from macroeconomics and Finance.

Goals. The main objective of this course is to develop the skills needed to do empirical research in fields operating with time series data sets. The course aims to provide students with techniques and receipts for estimation and assessment of quality of economic models with time series data. Special attention will be placed on limitations and pitfalls of different methods and their potential fixes. The course will also emphasize recent developments in Time Series Analysis and will present some open questions and areas of ongoing research.

Course structure. The content is delivered through pre-recorded lectures. Videos and supporting lecture notes are available on this web-site and will be released one week in advance. There will be mandatory live-small group in-person discussions with professor (once a week, 30-minutes, in E52-532). The small group discussions will be scheduled on Tuesdays/Thursdays 10.30am-noon, in E52-532. Group assignments will be announced at the beginning of the semester. Recitations (Wednesday, 5.30-7pm, in person, E51-361) will be devoted to solving problems from problem sets, attendance is recommended.

Problem sets. There will be 7 problem sets and a take home final exam. The students are required to submit solutions through Gradescope, or e-mail them to the TA. The problem sets will emphasize different aspects of the course, including theory and estimation procedures we discuss in class. I strongly believe that the best way to learn the techniques is by doing. Almost every problem set will include an applied task that may include computer programming. I do not restrict you in your choice of computer language. I also do not require you to write all programs by yourself from scratch. You may use user-written parts of codes you find on the Internet, but I do require that you understand the program you use and properly document it with all needed citations of original sources.

Collaboration with other students on problem sets is encouraged, however, the problem sets should be written independently.

Grading. Final grade is based on problem sets and the take-home final exam. All problems are equally weighted.

Textbooks and Readings. The primary text is Hamilton (1994), which is somewhat outdated. A fantastic reference on current state of the field is the method lectures "What New in Econometrics-Time Series" delivered by James H. Stock and Mark W. Watson during NBER Summer Institute 2008. The slides and videos of the lectures are available on the web http://www.nber.org/minicourse_2008.html (Links to an external site.). Most of the readings for the later parts of the course are journal articles. The course overviews a large literature, so not all topics are treated in the same depth. The lecture notes will be self-contained. The previous years lecture notes are available through MIT OpenCourseWare.

The Department of Economics values an inclusive environment. If you need a disability accommodation to access this course, please communicate with us early in the semester. If you have your accommodation letter, please meet with the faculty so that we can understand your needs and implement your approved accommodations. If you have not yet been approved for accommodations, please contact Student Disability Services at <uaap-sds@mit.edu> to learn about their procedures. We encourage you to do so early in the term to allow sufficient time for implementation of services/accommodations that you may need.

Books:

Required:

Hamilton, James D., *Time Series Analysis*, Princeton University Press, 1994, ISBN 0691042896, MIT library call number QA280.H264.

Recommended:

Brockwell Peter, J. and Davis Richard A. (1991), *Time Series: Theory and Methods*, New York: Springer-Verlag, ISBN 0387974296, Call number QA280.B76.

Canova, Fabio, *Methods for Applied Macroeconomic Research*, Princeton University Press, 2007.

DeJong, David N. and Chetan Dave (2007), *Structural Macroeconometrics*, Princeton University Press.

Hall P. and Heyde C.C. (1980), *Martingale Limit Theory and Its Application*, New York: Academic Press, ISBN 0123193508, MIT call number QA274.5.H34.

Zvi Griliches and Michael D. Intriligator (eds.) (1983-2001), *Handbook of Econometrics, Vol. IV*, Elsevier Science Publishing Company, ISBN 0444861882, MIT call number HB139.H36.

Lütkepohl, H. (1993), *Introduction to Multiple Time Series Analysis*, New York: Springer-Verlag, ISBN 0387569405, MIT call number QA280.L87.

Course Outline

Asterisked references are more important to the course. The following is a tentative list of topics that will be covered in this course. I reserve the right to add or delete topics as the course progresses.

I. Introduction. Stationary time series.

- **Introduction to stationary time series:** *ARMA, limit theory for stationary time series, causal relationships, HAC. Lectures 1-3.*

*Hamilton, Chs. 1-5, 7, 8.

*Newey, W.K. and West, K.D. (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.

Kiefer, N. and Vogelsang, T. (2002). "Heteroskedasticity-autocorrelation robust testing using bandwidth equal to sample size," *Econometric Theory* **18**, 1350-1366.

Ibragimov, R. and U. Mueller (2010) "t-statistic based correlation and heteroscedasticity robust inference," *Journal of Business and Economic Stat,* **28**, 453-468.

- **Frequency Domain Analysis**: *spectra; filters; nonparametric estimation. Lectures 4-5.*

*Hamilton, Ch. 6.

Brockwell and Davis, Chaps. 4 and 10.

*Baxter, M. and King, R. (1999). "Measuring business cycles: approximate band-pass filters for economic time series," *Review of Economics and Statistics*, **81**, 575-593.

Berk, K.N. (1974). "Consistent autoregressive spectral estimates," *Annals of Statistics* **2**, 489-502.

Hodrick, R. and Prescott, E. (1997). "Post-war US business cycles: an empirical investigation," *Journal of Money Banking and Credit* **29**, 1-16.

Christiano, L.J., and Fitzgerald, T.J. (1999). "The band pass filter," NBER Working Paper 7257, httpf/www.nber.orglpapers/w7257.

Cogley, Timothy & Nason, James M., (1995). "Effects of the Hodrick-Prescott filter on trend and difference stationary time series Implications for business cycle research," *Journal of Economic Dynamics and Control*, **19**(1-2), 253-278.

- **Model selection and information criteria:** *consistent estimation of number of lags, discussion of non-uniformity and post-selection inferences. Lectures 6-7.*

Ng, S. and Perron, P. (2005). "A note on the selection of time series models," *Oxford Bulletin of Economics and Statistics* **67:1**, 115-134.

*Leeb, H. and Potscher, B.M. (2005). "Model selection and inference: facts and fiction," *Econometric Theory* **21**, 21–59.

*Leeb, H. and Potscher, B.M. (2003). "The finite-sample distribution of post-model-selection estimators and uniform versus nonuniform approximations," *Econometric Theory* **19**, 100–142.

Hansen, B. (2005). "Challenges for econometric model selection," *Econometric Theory* **21**, 60-68.

*Belloni, A., V. Chernozhukov and C. Hansen (2013) "Inference on Treatment Effects After Selection Amongst High-Dimensional Controls (with an Application to Abortion and Crime)," *The Review of Economic Studies*

II. GMM, IV and related issues *(lectures 8-10)*

- **GMM:** *GMM estimation and asymptotic theory, testing in GMM setting, simulated method of moments and time series specifics: estimation of covariance structure, initial condition problem,.*

*Hamilton, Chap. 14

DeJong and Dave, Ch. 7

*Hansen, L.P. (1982). "Large sample properties of GMM estimators," *Econometrica* 50, 1029-1054.

*Hansen, L.P. and Singleton, K. (1982). "Generalized instrumental variables estimation of nonlinear rational expectations models," *Econometrica* **50**, 1269-1286. (*corrigenda*, 1984).

- **Weak IV:** *what is weak IV, alternative asymptotic theory, how to detect weak IV, procedures robust to weak IV, unsolved problems. Lectures 8-9.*

Andrews, D.W.K., M. Moreira, and J.H. Stock (2006). "Optimal Two-Sided Invariant Similar Tests for Instrumental Variables Regression", *Econometrica* **74**, 715-752.

Andrews, D.W.K. and J.H. Stock (2007). "Inference with Weak Instruments," *in Advances in Economics and Econometrics, Theory and Applications: Ninth World Congress of the Econometric Society, Vol. III, ed. by R. Blundell, W. K. Newey, and T. Person. Cambridge, UK: Cambridge University Press.*

Kleibergen, F.R. and S. Mavroeidis (2008), "Weak Instrument Robust Tests in GMM and the New Keynesian Phillips Curve," *manuscript, Brown University*.

Staiger, D. and J.H. Stock (1997), "Instrumental Variables Regression with Weak Instruments," *Econometrica* **65**, no. 3, 557-586

*Stock, J.H., M. Yogo, and J. Wright (2002), "A Survey of Weak Instruments and Weak Identification in Generalized Method of Moments," *Journal of Business and Economic Statistics*, **20**, 518 – 529.

*Stock, J.H. and J. Wright (2000), "GMM With Weak Identification," Econometrica 68, 1055 – 1096.

Yogo, M. (2004), "Estimating the Elasticity of Intertemporal Substitution when the Instruments are Weak," *Review of Economics and Statistics* **86**, 797-810.

III. Mutivariate stationary analysis

- **VAR**: *definition, estimation: OLS, ML, Granger causality, Impulse response functions and variance decompositions. Lectures 11-12*

  *Hamilton, Chaps. 10, 11

  *Lütkepohl, H. (2005), Chaps. 2, 3

Watson, M. (1994). "Vector autoregressions and cointegration," *Handbook of Econometrics*, vol IV, chapter 47.

Stock, J.H. and Watson, M.W. (2001). "Vector autoregressions," *Journal of Economic Perspectives* **15:**4, 101-116.

Wright, J.H. (2000). "Confidence intervals for univariate impulse responses with a near unit root," *Journal of Business and Economic Statistics* **18**, 368-373.

Killian, L. (1998). "Small sample confidence intervals for impulse response functions," *Review of Economics and Statistics*, 218-230.

Mikusheva, A. (2011) "One-dimensional inferences in autoregressive models in a potential presence of a unit root," *Econometrica,*

- **Structural VARs:** *Identification, short term restrictions, long-term restrictions, external instruments***.** *Lecture 13-14.*

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

*Blanchard, O.J. and Quah, D. (1989). "Dynamic effects of aggregate demand and supply disturbances," *American Economic Review* 7**9**, 655-673.

Blanchard, O.J. (1989). "A traditional interpretation of economic fluctuations," *American Economic Review* **79**, 1146-1164.

King, R.G., Plosser, C. I., Stock, J.H. and Watson, M.W. (1991). "Stochastic trends and economic fluctuations," *American Economic Review* **81**, 819-840.

Cooley, T. and LeRoy, S. (1985). "A theoretical macroeconomics: A critique," *Journal of Monetary Economics* **16**, 283-308.

Braun, P. and Mittnik, S. (1993). "Misspecification in VAR and their effects on impulse responses and variance decompositions," *Journal of Econometrics*, 59, 319-341.

Cooley, T. and Dwyer, M. (1998). "Business cycle analysis without much theory: A look at structural VARs," *Journal of Econometrics* **83**, 57-88.

Wright, J.H. (2011) "What does Monetary Policy do to Long-Term Interest Rates at the Zero Lower Bound?" *working paper*

Moon, H.R., F. Schorfheide, E. Granziera, and M. Lee(2009), "Inference for VARs Identified with Sign Restrictions," manuscript, University of Pennsylvania.

Christiano, Eichenbaum, and Vigfusson (2006) What happens after a technology shock?

Chari, Kehoe, and McGrattan (2008) Are structural VARs with long-run restrictions useful in developing business cycle theory? *Journal of Monetary Economics*, **55**, 1337-1352

- **Factor model and FAVAR:** *Motivation, Principal components, choosing number of static and dynamic factors, structural FAVAR, IV regression with factors, asset pricing factors. Lectures 15-16.*

*Stock, J.H. and Watson, M.W. (2005). "Implications of dynamic factor models for VAR analysis," NBER Working Paper 11467.

Bernanke, B.S. and Boivin, J. (2003). "Monetary policy in a data-rich environment," *Journal of Monetary Economics* **50**: 525-546.

*Bernanke, B.S., Bovian, J. and Eliasz, P. (2005). "Measuring the effects of monetary policy: a factor-augmented vector autoregressive (FAVAR) approach," *Quarterly Journal of Economics* **120**: 387-422.

*Forni, M., Giannoni, D., Lippi, M. and Reichlin, L. (2007), "Opening the black box: structural factor models with large cross-sections," European Central Bank, working paper #712.

Chamberlain, G. and Rothschild, M. (1983). "Arbitrage, factor structure and mean-variance analysis of large asset markets," *Econometrica* **51**, 1281-1304.

Forni, M., Hallin, M., Lippi, M. and Reichlin, L. (2000), "The generalized factor model: identification and estimation," *Review of Economics and Statistics* 82: 540–554.

Bai, J., and Ng, S. (2002). "Determining the number of factors in approximate factor models," *Econometrica* **70**: 191-221.

Bai, J. and Ng, S. (2007). "Determining the number of primitive shocks in factor models," *Journal of Business Economics and Statistics* **25**: 52-60.

*Bai, J. and Ng, S. (2010). "Instrumental variable estimation in a data rich environment," *Econometric Theory* **26**: 1577-1606.

*Kleibergen (2010) "Reality checks for and of factor pricing" unpublished manuscript

IV. Univariate non-stationary processes

- **Asymptotic theory of empirical processes**: *Lecture 17*

*Hamilton, Sections 17.1-17.3

Hall and Heyde, Chaps. 3, 4, and 5 and the Appendix.

- **Univariate unit roots and near unit root problem:** *unit root testing, confidence sets for persistence, tests for stationarity. Lectures 18-19*

*Hamilton, Ch. 17

*Stock, J.H. (1994). "Unit roots and trend breaks in econometrics," *Handbook of Econometrics*, Vol. IV, 2740-2841 (sections 1-4).

Dickey, D.A. and Fuller, W.A. (1979). "Distribution of the estimators for autoregressive time series with a unit root," *Journal of the American Statistical Association* 7**4**, 427-431.

Campbell, J.Y. and Perron, P. (1991). "Pitfalls and opportunities: what macroeconomists should know about unit roots," *NBER Macroeconomics Annual*, Vol. 6., pp. 141-201.

Andrews, D.W.K. (1993). "Exactly median-unbiased estimation of first order autoregressive/unit root models," *Econometrica* **61(1)**, 139-165.

Hansen, B.E. (1999). "The grid bootstrap and the autoregressive model," *Review of Economics and Statistics* **81(4)**, 594-607.

*Phillips, P.C.B. (1987). "Toward a unified asymptotic theory for autoregression," *Biometrika* **74(3)**, 535-547.

Stock, J. (1991). "Confidence intervals for the largest autoregressive root in US macroeconomic time series," *Journal of Monetary Economics* **28**, 435-459.

Mikusheva, A. (2007). "Uniform inference in autoregressive models," *Econometrica,* **75(5).**

- **Structural breaks and non-linearity:** *testing for breaks with known and unknown dates, multiple breaks, estimating number of breaks. Lecture 22.*

*Hamilton (1994), Ch. 22.

*Andrews, D.W.K. (1993). "Tests for parameter instability and structural change with unknown change-point," *Econometrica* **61**, 821-856.

*Hansen, B.E. (2001). "The new econometrics of structural change: dating breaks in U.S. labor productivity," *Journal of Economic Perspectives* **15**, 117-128.

*Perron, P. (1989). "The great crash, the oil price shock, and the unit root hypothesis," *Econometrica* **57**, 1361-1401.

Andrews, D.W.K. and Ploberger, W. (1994). "Optimal tests when a nuisance parameter is present only under the alternative," *Econometrica* **62**, 1383-1414.

Bai, J. S. (1997). "Estimating multiple breaks one at a time," *Econometric Theory* **13**, 315-352.

Bai, J. and Perron, P. (1998). "Estimating and testing linear models with multiple structural changes," *Econometrica* **66**, 47-78.

Bai, J., Lumsdaine, R.L. and Stock, J.H. (1998). "Testing for and dating common breaks in multivariate time series," *Review of Economic Studies* **65**, 395-432.

Zivot, E. and Andrews, D.W.K. (1992). "Further evidence on the great crash, the oil price shock, and the unit root hypothesis," *Journal of Business and Economic Statistics* **10**, 251-270.

V. Multivariate non-stationary

- **Multivariate unit roots and co-integration:** *estimating cointegration relations, canonical form. limit theory, Stambaugh correction, nuisance parameter problem, conservative procedures, conditional procedures Lectures 20-21*

Stock, J.H. (1987). "Asymptotic properties of least squares estimators of cointegrating vectors," *Econometrica* **55**, 1035-1056.

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

*Watson, M. W. (2008), "Cointegration", *The New Palgrave Dictionary of Economics.* Second Edition. Eds. Steven N. Durlauf and Lawrence E. Blume. Palgrave Macmillan. The New Palgrave Dictionary of Economics Online. http://www.dictionaryofeconomics.com/article?id=pde2008_U000024

*Stambaugh, R.F. (1999). "Predictive regressions," *Journal of Financial Economics* **54**, 375-421.

Jansson M. and Moreira, M.J. (2006) "Optimal inference in regression models with nearly integrated regressors," *Econometrica* **74(3)**, 681-715.

VI. Likelihood methods

- **Kalman filter and its applications:** *State-Space models, time varying coefficients. Lecture 23*

*Hamilton (1994), Ch. 13

Canova (2007), Ch. 6

*Hamilton, J.D. (1989). "A new approach to the economic analysis of nonstationary time series and the business cycle," *Econometrica* **57**, 357-384.

VII. Bayesian methods. *Lectures 24-26.*

- **Bayesian concepts:**

*Hamilton, 1994, section 12.3

- **Markov Chain Monte Carlo (MCMC):** *Metropolis-Hastings, Gibbs sampler, data augmentation*

*Chib, S. and Greenberg, E. (1995). "Understanding the Metropolist-Hastings algorithm," *American Statistician* **49(4)**, 327-335.

*Chib, S. and Greenberg, E. (1996). "Markov chain Monte Carlo simulation methods in econometrics," *Econometric Theory* **12**, 409-431.

*Chib, S. (2001). "Markov chain Monte Carlo methods: computation and inference," in: Heckman, J.J., Leamer, E. (Eds.), *Handbook of Econometrics, Vol. 5*. Amsterdam: North-Holland, 3564–3634, Chapter 5.