Princeton University **Spring 2021**
Department of Economics **ECO 513**

Advanced Econometrics: Time Series Models

Syllabus: Version 1 (January 25, 2021)

Instructors:	Mikkel Plagborg-Moller, mikkelpm@princeton.edu Christopher Sims, sims@princeton.edu
Zoom lectures:	Tue/Thu 10.40am–12.10pm
Office hours:	By appointment
Website:	`https://princeton.instructure.com/courses/2055`

Description. Concepts and methods of time series analysis and their applications to economics. Time series models to be studied include simultaneous stochastic equations, VAR, ARIMA, and state-space models. Methods to analyze trends, second-moment properties via the auto covariance function and the spectral density function, methods of estimation and hypothesis testing and of model selection will be presented. Kalman filter and applications as well as unit roots, cointegration, ARCH, and structural breaks models are also studied.

Prerequisites. ECO 517 and 518, or equivalent. Students from outside the Economics PhD program should contact the instructors to obtain permission to take the course.

Material. There is no required textbook for the course. Handouts will be made available on the website. Attached to this syllabus is a list of optional readings that are useful for a deeper understanding of the material in the first half of the course.

Some students might find it useful to have a textbook as an additional reference. Good reference books include:

Brockwell, P. J., and Davis, R. A. (1991). *Time Series: Theory and Methods*. 2nd edition, Springer. (Beautiful mathematical treatment of the classic theory of covariance stationary time series, but not aimed at economists.)

Hamilton, J. D. (1994). *Time Series Analysis*. Princeton University Press. (Comprehensive reference for time series econometrics methods developed before the mid-1990s.)

Hayashi, F. (2000). *Econometrics*. Princeton University Press. (Accessible treatment of GMM and stochastic limit theory for time series data.)

Herbst, E. P., and Schorfheide, F., (2015). *Bayesian Estimation of DSGE Models*. Princeton University Press. (Recent reference on Bayesian inference in structural time series models.)

Kilian, L., and Lütkepohl, H. (2017). *Structural Vector Autoregressive Analysis*. Cambridge University Press. (Recent reference on SVAR methods.)

Lectures. The class will meet online on Zoom twice a week. Recordings of the meetings will be made available on the course website afterwards.

Homework. Problem sets will be posted on the course website approximately every one or two weeks. Problem sets should be submitted online in PDF form. Students are encouraged to collaborate on the problem sets, but answers and computer code must be typed up independently. The problem sets will be graded coarsely, i.e., a full score will be given as long as the work demonstrates dedication and thoughtfulness. We reserve the right to subtract points for sloppy exposition, including unreadable code. If you find a grading error, please resubmit your problem set along with a one-paragraph explanation; we reserve the right to re-grade the entire problem set.

Exams. The course will feature a midterm and a final exam. Both will be in the form of take-home exams to be submitted online. No collaboration is allowed on the midterm or final.

Grading. The final course grade will be a monotonic function of the simple average of the point scores in each half of the course. In each half, the point score is given by a weighted average of (i) the average problem set score (25% weight) and (ii) the midterm/final exam score (75% weight).

Code of conduct. All course activities, including class meetings and homework assignments, are subject to the university's academic code and code of conduct as detailed in the "Rights, Rules, Responsibilities" publication.

Accommodations for students with disabilities. Students must register with the Office of Disability Services (ODS) (ods@princeton.edu; 258-8840) for disability verification and determination of eligibility for reasonable academic accommodations. Requests for academic accommodations for this course need to be made at the beginning of the semester, or as soon as possible for newly approved students, and again at least two weeks in advance of any needed accommodations in order to make arrangements to implement the accommodations. Please make an appointment to meet with the instructor in order to maintain confidentiality in addressing your needs. No accommodations will be given without authorization from ODS, or without advance notice.

Important dates. These dates are preliminary. Changes will be announced via course email.

Feb 2 (Tue): First class with M. Plagborg-Moller

Mar 11 (Thu): Last class with M. Plagborg-Moller

Date TBA: Take-home midterm exam

Mar 18 (Thu): First class with C. Sims

Apr 27 (Tue): Last class with C. Sims

Date TBA: Take-home final exam

Course outline: Feb 2 – Mar 11. The following outline is preliminary and may change without warning.

1. Refresher: Stationary models.
    i) Strict/covariance stationarity, projection.
    ii) Lag operators, linear filters, VARMA.
    iii) Wold decomposition.
    iv) Likelihood factorization, estimation.
    v) Model selection.
2. Spectral analysis.

i) Spectrum of linear filter.

ii) Estimation: sieve-VAR, periodogram smoothing.

3. Causal identification in macroeconomics.

i) SVMA, SVAR, invertibility.

ii) Identification through exclusion restrictions.

iii) Local Projection versus VAR estimation of impulse responses.

iv) Identification under potential non-invertibility.

v) Identification using instruments/proxies.

vi) Recoverability.

vii) Partial identification through sign/magnitude restrictions.

viii) Identification through non-Gaussianity/heteroskedasticity.

4. Inference with weakly dependent data.

i) Central Limit Theorem, martingale difference sequences, mixing.

ii) Applications to GMM, moment matching.

iii) Bootstrap.

5. Long-run variance estimation.

i) VAR-HAC.

ii) Spectral estimators.

iii) Kernel estimators.

6. Dynamic factor models.

i) State space approach.

ii) Principal components.

iii) Inference on number of factors.

Optional reading list

Introductory readings are listed first and marked with a star (*). Other readings are included for your reference. Original contributions are not always cited when good handbook/textbook references are available. The reading list is preliminary and may change without warning.

1 Stationary models

Models, prediction, estimation

* Hayashi: chapters 6.1–6.4.

* Kilian and Lütkepohl: chapters 2.1–2.5.

  Brockwell and Davis: chapters 1.1–1.5, 2.1–2.9, 3.1–3.5, 5.1–5.5, 5.7, 11.1–11.4.

  Hamilton: chapters 2–4, 10–12.

  Herbst and Schorfheide: chapters 3.1–3.2.

  Kilian and Lütkepohl: chapters 2, 5.

Model selection

* Kilian and Lütkepohl: chapter 2.6.

  Brockwell and Davis: chapter 9.

  Claeskens, G., and Hjort, N. L. (2008). *Model Selection and Model Averaging.* Cambridge University Press. Chapters 1–4.

  Geweke, J., and Meese, R. (1981). "Estimating regression models of finite but unknown order." *International Economic Review* 22(1), 55–70.

  Hansen, B. E. (2005). "Challenges for Econometric Model Selection." *Econometric Theory* 21(1), 60–68.

  Leeb, H., and Pötscher, B. M. (2005). "Model Selection and Inference: Facts and Fiction." *Econometric Theory* 21(01), 21–59. Sections 1–2.

Applications

Bernanke, B. S., and Kuttner, K. N. (2005). "What Explains the Stock Market's Reaction to Federal Reserve Policy?" *Journal of Finance* 60(3), 1221–1257.

Sims, C. A. (1972). "Money, Income, and Causality." *American Economic Review* 62(4), 540–552.

Stock, J. H., and Watson, M. W. (2003). "Forecasting Output and Inflation: The Role of Asset Prices." *Journal of Economic Literature* 41(3), 788–829.

2 Spectral analysis

Representation theory and inference

* Hamilton: chapter 6.

Brockwell and Davis: chapters 4, 10.1–10.5, 11.6.

Berk, N. (1974). "Consistent Autoregressive Spectral Estimates." *Annals of Statistics* 2(3), 489–502.

Hannan, E. J. (1970). *Multiple Time Series*. John Wiley & Sons. Chapters III.2–3, III.5.

Applications

Dew-Becker, I., and Giglio, S. (2016). "Asset Pricing in the Frequency Domain: Theory and Empirics." *Review of Financial Studies* 29(8), 2029–2068.

King, R. G., and Watson, M. W. (1996). "Money, Prices, Interest Rates and the Business Cycle." *Review of Economics and Statistics* 78(1), 35–53.

Qu, Z., and Tkachenko, D. (2012). "Frequency Domain Analysis of Medium Scale DSGE Models with Application to Smets and Wouters (2007)." In *Advances in Econometrics, Volume 28: DSGE Models in Macroeconomics – Estimation, Evaluation and New Developments*, edited by Balke, N., Canova, F., Milani, F., and Wynne, M. A., Emerald Group Publishing, 319–385.

Sala, L. (2015). "DSGE Models in the Frequency Domain." *Journal of Applied Econometrics* 30(2), 219–240.

Sargent, T. J., and Surico, P. (2011). "Two Illustrations of the Quantity Theory of Money: Breakdowns and Revivals." *American Economic Review* 101(1), 109–128.

Watson, M. W. (1993). "Measures of Fit for Calibrated Models." *Journal of Political Economy* 101(6), 1011–1041.

3 Causal identification in macroeconomics

Exclusion restrictions, instruments/proxies

* Montiel Olea, J. L., and Plagborg-Møller, M. (2020). "Local Projection Inference is Simpler and More Robust Than You Think." *Econometrica*, forthcoming.

* Stock, J. H., and Watson, M. W. (2018). "Identification and Estimation of Dynamic Causal Effects in Macroeconomics Using External Instruments." *Economic Journal* 128(610), 917–948.

Kilian and Lütkepohl: chapters 4, 7–12, 15.

Barnichon, R., and Brownlees, C. (2019). "Impulse Response Estimation By Smooth Local Projections." *Review of Economics and Statistics* 101(3), 522–530.

Blanchard, O., and Quah, D. (1989). "The Dynamic Effects of Aggregate Demand and Supply Disturbances." *American Economic Review* 79(4), 655–673.

Jordà, O. (2005). "Estimation and Inference of Impulse Responses by Local Projections." *American Economic Review* 95(1), 161–182.

Montiel Olea, J. L., Stock, J. H., and Watson, M. W. (2020). "Inference in SVARs Identified with External Instruments." *Journal of Econometrics*, forthcoming.

Plagborg-Møller, M. (2019). "Bayesian Inference on Structural Impulse Response Functions." *Quantitative Economics* 10(1), 145–184.

Plagborg-Møller, M., and Wolf, C. K. (2020). "Local Projections and VARs Estimate the Same Impulse Responses." *Econometrica*, forthcoming.

Rubio-Ramírez, J. F., Waggoner, D. F., and Zha, T. (2010). "Structural vector autoregressions: Theory of identification and algorithms for inference." *Review of Economic Studies* 77(2), 665–696.

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

Uhlig, H. (2005). "What are the effects of monetary policy on output? Results from an agnostic identification procedure." *Journal of Monetary Economics* 52(2), 381–419.

Invertibility, recoverability

Chahrour, R., and Jurado, K. (2021). "Recoverability and Expectations-Driven Fluctuations." Manuscript, Duke University.

Fernández-Villaverde, J., Rubio-Ramírez, J. F., Sargent T. J., and Watson, M. W. (2007). "ABCs (and Ds) of Understanding VARs." *American Economic Review* 97(3), 1021–1026.

Forni, M., Gambetti, L., and Sala, L. (2019). "Structural VARs and noninvertible macroeconomic models." *Journal of Applied Econometrics* 34(2), 221–246.

Lippi, M., and Reichlin, L. (1994). "VAR analysis, nonfundamental representations, Blaschke matrices." *Journal of Econometrics* 63(1), 307–325.

Plagborg-Møller, M., and Wolf, C. K. (2020). "Instrumental Variable Identification of Dynamic Variance Decompositions." Manuscript, Princeton University.

Sign/magnitude restrictions

* Baumeister, C., and Hamilton, J. D. (2015). "Sign Restrictions, Structural Vector Autoregressions, and Useful Prior Information." *Econometrica* 83(5), 1963–1999.

Gafarov, B., Meier, M., and Montiel Olea, J. L. (2018). "Delta-Method Inference for a Class of Set-Identified SVARs." *Journal of Econometrics* 203(2), 316–327.

Giacomini, R., and Kitagawa, T. (2020). "Robust Bayesian Inference for Set-Identified Models." *Econometrica*, forthcoming.

Wolf, C. K. (2020). "SVAR (Mis)Identification and the Real Effects of Monetary Policy." *American Economic Journal: Macroeconomics* 12(4), 1–32.

Identification through non-Gaussianity/heteroskedasticity

* Kilian and Lütkepohl: chapter 14.

Gouriéroux, C., Monfort, A., and Renne, J.-P. (2017). "Statistical inference for independent component analysis: Application to structural VAR models." *Journal of Econometrics* 196(1), 111–126.

Gouriéroux, C., Monfort, A., and Renne, J.-P. (2020). "Identification and Estimation in Non-Fundamental Structural VARMA Models." *Review of Economic Studies* 87(4), 1915–1953.

Rigobon, R. (2003). "Identification Through Heteroskedasticity." *Review of Economics and Statistics* 85(4), 777–792.

Applications

* Ramey, V. A. (2016). "Macroeconomic Shocks and Their Propagation." In *Handbook of Macroeconomics, Volume 2A*, edited by Taylor, J. B., and Uhlig, H., Elsevier, chapter 2, 71–162.

Forni, M., Gambetti, L., Lippi, M., and Sala, L. (2017). "Noisy News in Business Cycles." *American Economic Journal: Macroeconomics* 9(4), 122–152.

Gertler, M., and Karadi, P. (2015). "Monetary Policy Surprises, Credit Costs, and Economic Activity." *American Economic Journal: Macroeconomics* 7(1), 44–76.

Mertens, K., and Ravn, M. O. (2010). "Measuring the Impact of Fiscal Policy in the Face of Anticipation: A Structural VAR Approach." *Economic Journal* 120(544), 393–413.

Mertens, K., and Ravn, M. O. (2013). "The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States." *American Economic Review* 103(4), 1212–1247.

4 Inference with weakly dependent data

Abstract theory

* Hayashi: chapters 2, 6.5.

Brockwell and Davis: chapters 6–7.

Hamilton: chapter 7.

Davidson, J. (1994). *Stochastic Limit Theory*. Oxford University Press. Chapters 13–14, 24.

GMM, moment matching

* Hayashi: chapters 7.1–7.4.

Cocci, M. D., and Plagborg-Møller, M. (2019). "Standard Errors for Calibrated Parameters." Manuscript, Princeton University.

Hansen, L. P., Heaton, J., and Yaron, A. (1996). "Finite-Sample Properties of Some Alternative GMM Estimators." *Journal of Business & Economic Statistics* 14(3), 262–280.

Hansen, L. P., and Heckman, J. J. (1996). "The empirical foundations of calibration." *Journal of Economic Perspectives* 10(1), 87–104.

Hansen, L. P., and Singleton, K. (1991). "Computing Semiparametric Efficiency Bounds for Linear Time Series Models." In *Nonparametric and semiparametric methods in econometrics and statistics: Proceedings of the Fifth International Symposium in Economic Theory and Econometrics*, edited by Barnett, W. A., Powell, J., and Tauchen, G. E., Cambridge University Press, chapter 15, 388–411.

Kydland, F., and Prescott, E. (1996). "The computational experiment: an econometric tool." *Journal of Economic Perspectives* 10(1), 69–85.

Nakamura, E., and Steinsson, J. (2018). "Identification in Macroeconomics." *Journal of Economic Perspectives* 32(3), 59–86.

Newey, W. K., and McFadden, D. L. (1994). "Large sample estimation and hypothesis testing." In *Handbook of Econometrics, Volume IV*, edited by Engle, R. F., and McFadden, D. L., Elsevier, chapter 36, 2111–2245.

Bootstrap

* Kilian and Lütkepohl: chapters 12.1–12.5.

Brüggemann, R., Jentsch, C., and Trenkler, C. (2016). "Inference in VARs with conditional heteroskedasticity of unknown form." *Journal of Econometrics* 191(1), 69–85.

Gonçalves, S., and Kilian, L. (2004). "Bootstrapping autoregressions with conditional heteroskedasticity of unknown form." *Journal of Econometrics* 123(1), 89–120.

Horowitz, J. L. (2001). "The Bootstrap." In *Handbook of Econometrics, Volume 5*, edited by Heckman, J. J., and Leamer, E., Elsevier, chapter 52, 3159–3228.

Kilian, L. (1998). "Small-sample Confidence Intervals for Impulse Response Functions." *Review of Economics and Statistics* 80(2), 218–230.

Applications

Christiano, L., Eichenbaum, M., and Evans, C. (2005). "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy* 113(1), 1–45.

Hansen, L. P., and Singleton, K. J. (1982). "Generalized Instrumental Variable Estimation of Nonlinear Rational Expectation Models." *Econometrica* 50(5), 1269–1286.

Mankiw, N. G., Reis, R., and Wolfers, J. (2004). "Disagreement about Inflation Expectations." In *NBER Macroeconomics Annual 2003, Volume 18*, edited by Gertler, M., and Rogoff, K., National Bureau of Economic Research, 209–248.

Mavroeidis, S., Plagborg-Møller, M., and Stock, J. H. (2014). "Empirical Evidence on Inflation Expectations in the New Keynesian Phillips Curve." *Journal of Economic Literature* 52(1), 124–188.

5 Long-run variance estimation

Theory

* Hayashi: 6.5–6.6.

* Lazarus, E., Lewis, D. J., Stock, J. H., and Watson, M. W. (2018). "HAR Inference: Recommendations for Practice." *Journal of Business and Economic Statistics* 36(4), 541–559. See also comments and rejoinder in the same journal issue.

Brockwell and Davis: chapters 10.1–10.5, 11.6.

Andrews, D. W. K. (1991). "Heteroskedasticity and autocorrelation consistent covariance matrix estimation." *Econometrica* 59(3), 817–858.

Andrews, D. W. K., and Monahan, J. C. (1992). "An Improved Heteroskedasticity and Autocorrelation Consistent Covariance Matrix Estimator." *Econometrica* 60(4), 953–966.

Den Haan, W. J., and Levin, A. (1997). "A practitioner's guide to robust covariance matrix estimation." In *Handbook of Statistics, Volume 15*, edited by Maddala, G. S., and Rao, C. R., North-Holland, 299–342.

Dou, L. (2020). "Optimal HAR Inference." Manuscript, Chinese University of Hong Kong, Shenzhen.

Ibragimov, R., and Müller, U. K. (2010). "t-Statistic Based Correlation and Heterogeneity Robust Inference." *Journal of Business and Economic Statistics* 28(4), 453–468.

Jansson, M. (2004). "The Error in Rejection Probability of Simple Autocorrelation Robust Tests." *Econometrica* 72(3), 937–946.

Kiefer, N. M., and Vogelsang, T. J. (2005). "A New Asymptotic Theory for Heteroskedasticity–Autocorrelation Robust Tests." *Econometric Theory* 21(6), 1130–1164.

Lazarus, E., Lewis, D. J., and Stock, J. H. (2019). "The Size-Power Tradeoff in HAR Inference." Manuscript, Harvard University.

Müller, U. K. (2007). "A theory of robust long-run variance estimation." *Journal of Econometrics* 141(2), 1331–1352.

Müller, U. K. (2014). "HAC Corrections for Strongly Autocorrelated Time Series." *Journal of Business & Economic Statistics* 32(3), 311–322.

Newey, W. K., and West, K. D. (1987). "A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix." *Econometrica* 55(3), 703–708. *Review of Economic Studies* 61(4), 631–653.

Pötscher, B. M. (2002), "Lower Risk Bounds and Properties of Confidence Sets for Ill-Posed Estimation Problems with Applications to Spectral Density and Persistence Estimation, Unit Roots, and Estimation of Long Memory Parameters." *Econometrica* 70(3), 1035–1065.

Sun, Y. (2014). "Let's Fix It: Fixed-b Asymptotics versus Small-b Asymptotics in Heteroscedasticity and Autocorrelation Robust Inference." *Journal of Econometrics* 178(3), 659–677.

Sun, Y., Phillips, P. C. B., and Jin, S. (2008). "Optimal Bandwidth Selection in Heteroskedasticity–Autocorrelation Robust Testing." *Econometrica* 76(1), 175–194.

Applications

Dew-Becker, I. (2017). "How Risky Is Consumption in the Long-Run? Benchmark Estimates from a Robust Estimator." *Review of Financial Studies* 30(2), 631–666.

6 Dynamic factor models

Estimation and inference

* Stock, J. H., and Watson, M. W. (2016). "Dynamic Factor Models, Factor-Augmented Vector Autoregressions, and Structural Vector Autoregressions in Macroeconomics." In *Handbook of Macroeconomics, Volume 2A*, edited by Taylor, J. B., and Uhlig, H., Elsevier, chapter 8, 415–525. Sections 1–3, 5–6.

Bai, J. (2003). "Inferential Theory for Factor Models of Large Dimensions." *Econometrica* 71(1), 135–171.

Bai, J., and Ng, S. (2008), "Large Dimensional Factor Analysis." *Foundations and Trends in Econometrics* 3(2), 89–163.

Doz, C., Giannone, D., and Reichlin, L. (2012). "A Quasi-Maximum Likelihood Approach for Large, Approximate Dynamic Factor Models." *Review of Economics and Statistics*, 94(4), 1014–1024.

Forni, M., Giannone, D., Lippi, M. and Reichlin, L. (2009). "Opening the Black Box: Structural Factor Models with Large Cross Sections." *Econometric Theory* 25(5), 1319–1347.

Forni, M., Hallin, M., Lippi, M., and Reichlin, L. (2000). "The Generalized Dynamic-Factor Model: Identification and Estimation." *Review of Economics and Statistics* 82(4), 540–554.

Stock, J. H., and Watson, M. W. (2002). "Forecasting Using Principal Components From a Large Number of Predictors." *Journal of the American Statistical Association* 97(460), 1167–1179.

Determining the number of factors

Bai, J., and Ng, S. (2002). "Determining the Number of Factors in Approximate Factor Models." *Econometrica* 70(1), 191–221.

Onatski, A. (2009). "Testing Hypotheses About The Number of Factors in Large Factor Models." *Econometrica* 77(5), 1447–1479.

Applications

Bernanke, B. S., Boivin, J., and Eliasz, P. (2005). "Measuring the effects of monetary policy: a factor-augmented vector autoregressive (FAVAR) approach." *Quarterly Journal of Economics* 120(1), 387–422.

Bok, B., Caratelli, D., Giannone, D., Sbordone, A. M., and Tambalotti, A. (2017). "Macroeconomic Nowcasting and Forecasting with Big Data." *Annual Review of Economics* 10, 615–643.