**Spatial Econometrics and Modeling**

**GEO 4169 & 6168; LAS 4935 & 6938**

**Dr. Robert Walker**

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**Class meeting times: When & Where: R | Periods 2-4 8:30AM – 11:30AM, Turlington 3006**

**Office Hours: 10:00 AM – 12:00 AM Thursday**

This course addresses spatial statistical models from both theoretical and empirical perspectives. It shows students how to assess the presence of spatial autocorrelation in their data and how to specify appropriate regression models that produce reliable results when spatial autocorrelation is present. Students learn to implement a variety of spatial models developed by econometricians and spatial analysts in geography. Spatial Lag and Spatial Error models are addressed, as are situations with complex autocorrelation patterns affecting dependent variables, independent variables, and error terms simultaneously. Also considered is the geostatistical method, Kriging, as well as approaches to modelling under conditions of non-stationarity, specifically Geographically Weighted Regression.

The instructional premise of the course is that statistical techniques should not be approached via a "cook-book," but instead by considering the underlying estimation and probability theory. We will spend time at the outset dusting off a few mathematical preliminaries to gain notational facility with matrix algebra and an intuitive understanding of basic probabilistic concepts. We will develop estimation techniques based on the so-called "maximum likelihood function" and on Bayes Theorem. We will use them to fit a set of models of interest, namely spatial regression models for both continuous and discrete dependent variables. Students will be introduced to an extensive spatial-econometrics library, with MATLAB scripts written for a wide variety of statistical situations, such as panel analysis, truncated dependent variables, etc. The course will be conducted primarily in MATLAB and GeoDa, both available from UF APPs. We will have occasion to use R as well for applications of spatial regression. The course is open to both advanced undergraduate and graduate students. Grades will be determined by homework and tests, and graduate students will write and present a research paper.

The instructor believes that computation provides not just analytical power but also an effective pedagogical device. Thus, we will be using MATLAB to write our own estimation scripts to reinforce the course's theoretical foundations. For example, we will solve the so-called "normal equations" directly in but a few MATLAB statements, in both a-spatial and spatial formats. Further, we will have occasion to write our own Markov Chain Monte Carlo (MCMC) simulation scripts, incorporating experimental data in likelihood functions that we specify ourselves. We will observe first-hand the convergence properties of the Gibbs Sampler by executing codes developed in exercises. MATLAB enables us to "see" results immediately and understand how Bayesian point estimates of parameters arise from histograms based on as large a sample as we wish to draw in Monte Carlo simulation.

**Grading for Graduates**: The course is presented in lecture format, with some practical lab-oriented instruction in computational methods. Grades for graduate students will be assessed on the basis of homework assignments, tests (mid-term and final), presentations, and a class paper; here, the distribution of points is 10% for homework (4 assignments each worth 2.5 points), 30% for each test, 20% for the paper, 5% for the presentation of Objectives and Data, and 5% for presentation of Analysis and Findings. Homework can be done in groups working together; tests are to be completed on the basis of individual effort.

**Grading for Undergraduates:** Grades for undergraduates are determined on the basis of homework assignments and tests (mid-term and final), with homework accounting for 40% (10 points for each of 4 assignments), and the two tests, 30% each. Homework can be done in groups working together; tests are to be completed on the basis of individual effort. No paper requirement for undergraduates.

**Grading Scale**

| Graduate | | Undergraduate |
|---|---|---|
| 96.0 - 100 | A | 87.0 -100 |
| 87.0 - 95.99 | A- | 84.0 - 86.99 |
| 84.0 - 86.99 | B+ | 81.0 – 83.99 |
| 80.0 - 83.99 | B | 78.0 – 80.99 |
| 78.0 - 79.99 | B- | 75.0 – 77.99 |
| 75.0 - 77.99 | C+ | 72.0 – 74.99 |
| 70.0 - 74.99 | C | 69.0 – 71.99 |
| 68.0 - 69.99 | C- | 66.0 - 68.99 |
| 65.0 - 67.99 | D+ | 63.0 - 65.99 |
| 60.0 – 64.99 | D | 60.0 – 62.99 |
| 55.0 – 59.99 | D- | 50.0 – 59.99 |
| 0.0 – 54.99 | E | 0.0 – 49.99 |

**Class Paper (Only for Graduate Students):** The class paper should be at least 10 pages long excluding figures and references. No larger than a 12 point font and margins no greater than 1 inch. I expect to see the student demonstrate facility with the methods taught in the course. There should be a motivation for the analysis undertaken that is rooted in appropriate literature. Following this, I expect to see a presentation of the data used, and a discussion of the model selection process detailing why the methods were chosen. Finally, I expect to see conclusions based on model results, and an explicit reference back to the original motivation for the work. That is, conclusions should not be simply a numerical presentation of regression results, but a verbal and descriptive discussion presented within the original motivation of the paper.

**Pre-requisites:** The graduate pre-requisite for the class is GEO 6161, Intermediate Quantitative Methods, or equivalent. The undergraduate pre-requisite for the class is GEO 4167C or equivalent. Students must be motivated by an interest in spatial analysis and a willingness to do the work. I will not lecture on advanced mathematics, but I will show how it is used by economists and geographers to arrive at key results. I do hope to advance student knowledge of matrix notation, insofar as it is used as a shorthand for describing data-sets, and as the basic set-up for estimating regression models. That is, I do not expect students to become experts in solving systems of equations by brute force. I do hope that they will learn the easy route of doing such solutions with software like MATLAB. Bottom-line: You do not need to have a strong math background to succeed in this class. You simply need to be a good student, which you no doubt are.

**Testing:** The two tests will be administered as open book, take home tests. The second test will be handed out on the last day of class. If you find this conflicts with your reading days, please let me know in advance. I will not give early tests to accommodate personal travel. Graduate Students will have 2 days to complete each test.

**Readings**: I draw my readings from a wide cross-section of literature, books, published articles, etc. These readings are meant to provide background, and I do not expect you to digest the materials in their entirety, as they can be quite mathematical. But you will have them in your virtual archives for future reference as you go on to apply what you learn. The prime textual information will come from my lectures. It will often be the case that I will call attention to some aspect of the readings, and elaborate the main points in my class presentations. I will do my best to make my class notes available on the Canvas system. Note that I do rely with some regularity on a book by LeSage and Pace entitled *An Introduction to Spatial Econometrics*. It is available as an electronic resource at UF Libraries.

Information on current UF grading policies for assigning grade points can be found in the following link:

https://catalog.ufl.edu/UGRD/academic-regulations/grades-grading-policies/

**Course Policies and Useful Information:**

*Class Attendance and Make-Up Policy*

Class attendance is expected. Excused absences are consistent with university policies in the undergraduate catalog (https://catalog.ufl.edu/ugrad/current/regulations/info/attendance.aspx) and require appropriate documentation. Makeups for the Mid-term and Final will be provided for students who miss either exam due to extreme, documented circumstances. Late homework assignments will also be accepted under similar circumstances. Students should arrange with the instructor for makeup material, and the student will receive one week to prepare for any makeup assignment, if circumstances allow it.

*Students Requiring Accommodations* Students with disabilities requesting accommodations should first register with the Disability Resource Center (352-392-8565, www.dso.ufl.edu/drc/) by providing appropriate documentation. Once registered, students will receive an accommodation letter which must be presented to the instructor when requesting accommodation. Students with disabilities should follow this procedure as early as possible in the semester.

*Course Evaluation* Students are expected to provide feedback on the quality of instruction in this course by completing online evaluations at https://evaluations.ufl.edu. Evaluations are typically open during the last two or three weeks of the semester, but students will be given specific times when they are open. Summary results of these assessments are available to students at https://evaluations.ufl.edu/results/.

*Class Demeanor* Students are expected to arrive to class on time and behave in a manner that is respectful to the instructor and to fellow students. Please avoid the use of cell phones and restrict eating to outside of the classroom. Opinions held by other students should be respected in discussion, and conversations that do not contribute to the discussion should be held at minimum, if at all.

*Materials and Supplies Fees* There are no additional fees for this course.

*University Honesty Policy* UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (https://www.dso.ufl.edu/sccr/process/student-conducthonor-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor in this class.

*Counseling and Wellness Center* Contact information for the Counseling and Wellness Center: http://www.counseling.ufl.edu/cwc/Default.aspx, 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

*U Matter, We Care*: If you or a friend is in distress, please contact umatter@ufl.edu or 352 392-1575 so that a team member can reach out to the student.

**Class Calendar**

**Week 1** Aug 23-25 Introduction

**Week 2** Aug 28-Aug 31 Data Arrays and Matrix Algebra. Intro to MATLAB

**Week 3** Sep 4-8 Principles of Probability (Inference, Bias) Intro to GeoDa

Assignment 1. Data arrays and matrices in MATLAB. Due the following Thursday

**Week 4** Sep 11-15 Ordinary Least Squares and Spatial Representation

*Derivation of Normal Equations: Multidimensional Minimization with Calculus*

*Identifying Bias*

*Spatial Weights Matrices*

Assignment 2. Using GeoDa for Moran's I. Due the following Thursday

**Week 5** Sep 18-22 Spatial Regression, Preliminaries

*Motivation: Heterogeneity, Omitted Variables, Time Dependence*

*The Data Generating Process*

*Maximum Likelihood Principle*

Chapters 1 & 2 of LeSage and Pace

GeoDa/MATLAB applications

**Week 6** Sep 25-29 Standard Spatial Models and the MATLAB Library

*Spatial Autoregressive Regression Model (SAR)*

*Spatial Error Model (SEM)*

*Spatial Autoregression Model (SAC)*

*Spatial Durbin Model (SDM)*

LeSage and Pace: Section 3.1 of Chapter 3 Section 6.1 Chapter 6

Assignment 3. Spatial regressions with MATLAB

**Week 7** Oct 2-6 Model Selection and goodness-of-fit

*Anselin's Decision Tree*

*LeSage and Pace: The Nesting Power of the Spatial Durbin Model*

Test 1, Take Home on Thursday, Return the Following Thursday All Materials Week 1-7

**Week 8** Oct 9-13 Model Extensions

*Limited Dependent Variables (Tobit, Probit, Logit) and Space*

*Panel Analysis and Space*

*Issues with Endogeneity and Space*

**Week 9** Oct 16-20 Grad Student Presentations: Objectives and Data.

**Week 10** Oct 23-27 Bayesian Estimation: Closed Form Solutions; Markov Chains

*Zellner's solution for the mean of a random variable*

*Markov Chains and Equilibrium Distributions: Existence and Uniqueness*

*Markov Chains for Continuous State Space*

Readings assigned from: Zellner, A., 1971. *An Introduction to Bayesian Inference in Econometrics*. John Wiley & Sons: New York.

Readings assigned from Çinlar, E., 1975. *Introduction to stochastic processes*. Prentice-Hall. *Englewood Cliffs, NJ*.

Continuous State Space: https://www.colorado.edu/amath/sites/default/files/attached-files/2_28_2018.pdf

**Week 11** Oct 30- Nov 3 Markov Chain Monte Carlo (MCMC) Simulation

*Transforming Kernels into Probability Densities*

*Applications Scripting of MCMC simulation in MATLAB*

*Proof that MCMC Simulation converges to correct Posterior*

*Gibbs Sequences with Joint Distributions (Beta-Binomial)*

Navarro, D. and Perfors, A., 2011. The Metropolis-Hastings Algorithm. *Course Material for COMPSCI, 3016*. (http://compcogsci-3016.djnavarro.net/technote_metropolishastings.pdf

Hohendorff, J.M. and Rosenthal, J., 2005. An introduction to Markov Chain Monte Carlo. *University of Toronto, Department of Statistics, supervised reading report (http://www. probability. ca/jeff/grad. html)*.

Casella, G. and George, E.I., 1992. Explaining the Gibbs sampler. *The American Statistician*, *46*(3), pp.167-174.

**Week 12** Nov 6-10 Bayesian regression with the Gibbs Sampler

*Estimation of SAR, SEM, SAC, & SDM using Gibbs Sampler*

*Burn-in specification and number of draws*

*Converting Histograms into Point Estimates of Location & Scale Parameters*

Chapter 5 in LeSage and Pace

Assignment 4. Bayesian spatial regressions with MATLAB. Due the following Tuesday

**Week 13** Nov 13-17 Kriging

*Variance Structures: Variance, Covariance, and Semi-Variance*

*Lagrangian Minimization Problem: Formal Statement and Derivation following* Cressie, N., 2015. *Statistics for spatial data*. John Wiley & Sons & Bailey, T.C. and Gatrell, A.C., 1995. *Interactive spatial data analysis* (Vol. 413, No. 8). Essex: Longman Scientific & Technical.

*Applications*

Oliver, M., Webster, R. and Gerrard, J., 1989. Geostatistics in physical geography. Part I: theory. *Transactions of the Institute of British Geographers*, pp.259-269.

Oliver, M., Webster, R. and Gerrard, J., 1989. Geostatistics in physical geography. Part II: applications. *Transactions of the Institute of British Geographers*, pp.270-286.

**Week 14** Nov 27 – Dec 1 Geographically Weighted Regression

*Stationarity*

*Non-parametric Monte Carlo Significance Testing: First Principles of Inference*

Brunsdon, C., Fotheringham, S. and Charlton, M., 1998. Geographically weighted regression. *Journal of the Royal Statistical Society: Series D (The Statistician)*, *47*(3), pp.431-443.

**Week 15** Dec 6-9 Grad Student Presentations: Findings.

Test 2 Administered. Take Home.

All course materials from Week 7 to Week 15.

Due the following Thursday.

## COURSE RESOURCES


Anselin, L. 1988. *Spatial Econometrics Methods and Models*. The Netherlands: Kluwer Academic Publishers.

Anselin, L. 2005. *Exploring Spatial Data with GeoDa: A Workbook*. Center for Spatially Integrated Social Science, Spatial Analysis Laboratory (hhtp://sal.uiuc.edu)

Binmore, K.G. 1982. *Mathematical Analysis: A Straightforward Approach* (2nd edition). Cambridge: Cambridge University Press.

Çinlar, E., 1975. Introduction to stochastic processes Prentice-Hall. *Englewood Cliffs, NJ*.

Cressie, N., 2015. *Statistics for spatial data*. John Wiley & Sons

Greene, W.H. 2000. *Econometric Analysis*, 4th ed. New Jersey: Prentice Hall

Griffith, D.A., Amrhein, C.G. 1991. *Statistical Analysis for Geographers*. Englewood Cliffs, New Jersey: Prentice Hall.

LeSage, J. P. and Pace, R. K. 2009. *Introduction to Spatial Econometrics*. Boca Raton, FL: CRC Press.

Miller, R.E. 2000. *Optimization: Foundations and applications*. New York: John Wiley & Sons, Inc.

Zellner, A. 1971. *An Introduction to Bayesian Inference in Econometrics*. New York: John Wiley & Sons, Inc.