STAT 69500 — Causal Inference Under the Rubin Causal Model

Spring 2025

CRN: 31649

Credit Hours: 3

Lectures: Tuesday & Thursday / 9:00 - 10:15 AM / SC G014

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Course Website: Brightspace (https://purdue.brightspace.com/d2l/login)

Course Textbook: Imbens G.W., Rubin D.B. (2015). *Causal Inference for Statistics, Social, and Biomedical Sciences*. Cambridge University Press. ISBN 978-0-521-88588-1.

Course Description: How can we draw causal inferences from data? From the dawn of civilization a great deal of intellectual effort has gone into addressing this question. More recently, scientists recognized that statistics can yield powerful insights into causal inference. One simple and powerful statistical framework for causal inference is the Rubin Causal Model. This framework is founded on the potential outcomes framework that was first formalized for randomized experiments in the 1923 doctoral dissertation of Jerzy Neyman, and the groundbreaking work by Donald Rubin in the 1970s on causal inference in experiments and observational studies. This course will cover frequentist and Bayesian statistical methodologies for drawing causal inferences from randomized experiments and observational studies under the modern Rubin Causal Model. The distinct perspective adopted in this course corresponds to the foundation for conventional inferential techniques, and can be effectively applied to address complex real-life problems in causal inference that are not amenable to standard techniques. The methodologies taught in this course possess a broad scope of application, ranging from the physical, life, social, and management sciences, among other domains. Conceptual understanding, not necessarily memorization or theoretical derivations of equations, is required and emphasized throughout the course. Topics include: the fundamental components of the Rubin Causal Model (Science, Learning, Decisions), Fisherian randomization-based causal inference, Neymanian repeated sampling-based causal inference, causal inferences for classical randomized experiments and multiple treatment factors, rerandomization, multi-armed bandit algorithms, drawing causal inferences from linear regression models, the Bayesian paradigm for causal inference, the design and analysis of observational studies (propensity score subclassification and matching, sensitivity analyses), design and machine learning for Big Observational Data, drawing causal inferences in the presence of treatment noncompliance/nonadherence (instrumental variables analysis, the Tripartite Framework), and principal stratification. Specific topics and the course outline are subject to change as the semester progresses. All topics will be motivated by

real-life problems from the physical, life, social, and management sciences, as well as technology and engineering domains.

Learning Outcomes:

- Acquire fluency in the principles and techniques for causal inference under the Rubin Causal Model.
- Apply frequentist and Bayesian methodologies to solve real-life causal inference problems.
- Utilize Python or R for statistical visualization, computation, design of experiments and observational studies, and analysis.
  - Python is freely available for download here. Free manuals are available here.
  - `R` is freely available for download here. Free manuals are available here.
  - Assistance for `R` is available at the virtual Statistical Software Help Desk.

Prerequisites: At least one introductory graduate-level statistics course (e.g., STAT 511) and familiarity with computing, or permission of the instructor. Students should have some programming experience using a language such as Python or `R`. The ability to write, debug, and execute programs in at least one of the above languages is required. Graduate-level courses in probability and statistics such as STAT 512, STAT 514, 516, 517, 525, 526, and 528 are recommended.

Course Outline:

- **Week 1: Introduction to experiments, observational studies, and the Rubin Causal Model (Chapters 1 - 2)**
  - **Lecture 1 (1-14-2025)**: Introduction to the Rubin Causal Model and its history.
  - **Handout (Due 1-16-2025)**: Background survey.
  - **Lecture 2 (1-16-2025)**: The Science for the Rubin Causal Model.
  - **Assignment 1 (Due 1-30-2025)**
- **Week 2: Assignment mechanisms and randomization-based causal inference (Chapters 3 - 5)**
  - **Lecture 3 (1-21-2025)**: Assignment mechanisms and their typical assumptions.
  - **Lecture 4 (1-23-2025)**: Fisherian randomization tests and intervals for treatment effects in completely randomized designs.
- **Week 3: Repeated sampling-based causal inference (Chapter 6)**
  - **Lecture 5 (1-28-2025)**: The Neymanian perspective of causal inference.
  - **Lecture 6 (1-30-2025)**: Fisherian and Neymanian causal inferences for treatment factors with more than two levels. Contrasts of potential outcomes.
  - **Assignment 2 (Due 2-13-2025)**
- **Week 4: Causal inferences for classical randomized experiments (Chapters 9 - 10)**

  - **Lecture 7 (2-4-2025)**: Randomized complete block designs for one treatment factor with more than two levels. Paired comparison designs for one treatment factor with two levels.
  - **Lecture 8 (2-6-2025)**: The Neyman-Fisher controversy of 1935 and its consequences for causal inference.
  - **Project Description: Due 2-27-2025**.
- **Week 5: Causal inferences for multiple treatment factors**
  - **Lecture 9 (2-11-2025)**: The Science of the 2^2 factorial design.
  - **Lecture 10 (2-13-2025)**: Learning factorial effects in the 2^2 factorial design.
  - **Assignment 3 (Due 2-27-2025)**
- **Week 6: Model-based causal inferences (Chapters 7 - 8, 11)**
  - **Lecture 11 (2-18-2025)**: Linear regression methods for completely randomized experiments.
  - **Lecture 12 (2-20-2025)**: The Bayesian paradigm for causal inference in studies with unconfounded assignment mechanisms. Case studies of model-based causal inferences.
- **Week 7: Complex assignment mechanisms**
  - **Lecture 13 (2-25-2025)**: The general rerandomization framework to design and analyze experiments with many covariates.
  - **Lecture 14 (2-27-2025)**: Multi-armed bandits in the online service industry.
  - **Written Project Progress Report: Due 3-27-2025**.
  - **Assignment 4 (Due 4-3-2025)**
- **Week 8: Propensity scores and their utility for causal inference in observational studies (Chapters 12 - 14)**
  - **Lecture 15 (3-4-2025)**: The need to design observational studies to reduce bias in their causal inferences.
  - **Lecture 16 (3-6-2025)**: Propensity scores and their properties. Estimating propensity scores for the design of observational studies.
- **Week 9: Propensity score-based design of observational studies (Chapters 14 - 18)**
  - **Lecture 17 (3-11-2025)**: Propensity score subclassification and matching.
  - **Lecture 18 (3-13-2025)**: Assessing covariate balance.
- **Week 10: Spring Break**
- **Week 11: Advanced design methodologies and supplementary analyses for observational studies (Chapters 21 - 22)**
  - **Lecture 19 (3-25-2025)**: Assessing unconfoundedness.
  - **Lecture 20 (3-27-2025)**: Sensitivity analyses and bounds.
  - **Project Progress Report Presentation: Due 4-17-2025**.
- **Week 12: Design and machine learning for Big Observational Data**
  - **Lecture 21 (4-1-2025)**: Machine learning-based causal inference for randomized experiments.

  - **Lecture 22 (4-3-2025)**: Distributed design for Big Observational Data.
  - **Assignment 5 (Due 4-24-2025)**
- **Week 13: Causal inference for experiments with one-sided noncompliance/nonadherence (Chapter 23)**
  - **Lecture 23 (4-8-2025)**: The Science of one-sided noncompliance/nonadherence, and intention-to-treat analyses. Instrumental variable analyses for experiments with one-sided noncompliance/nonadherence.
  - **Lecture 24 (4-10-2025)**: Bayesian analyses for experiments with one-sided noncompliance/nonadherence.
- **Week 14: Causal inference for experiments with two-sided noncompliance/nonadherence (Chapters 24 - 25)**
  - **Lecture 25 (4-15-2025)**: The Science of two-sided noncompliance/nonadherence, and instrumental variables analyses.
  - **Lecture 26 (4-17-2025)**: Presentations on progress of projects.
  - **Final Project Report and Presentation: Due 5-9-2025**
- **Week 15: The Tripartite Framework and principal stratification**
  - **Lecture 27 (4-22-2025)**: Bayesian analyses for experiments with two-sided noncompliance/nonadherence.
  - **Lecture 28 (4-24-2025)**: Estimates in causal inference: Broadening the perspective. Principal stratification in causal inference
- **Week 15: Case studies of noncompliance/nonadherence and principal stratification**
  - **Lecture 29 (4-29-2025)**: Analysis of the Gerber and Green (2000) field experiment.
  - **Lecture 30 (5-1-2025)**: Principal stratification analyses for treatment discontinuation in clinical trials.
- **Week 16**: Project presentations.

Course Work and Requirements:

	Percentage of Grade
Assignments	50%
Group Project	50%

- *Assignments* will be posted on Brightspace on Thursdays, and will be due on Thursdays before 9:00 AM (Eastern). The specific posting and due dates for the assignments are listed in the Course Outline above. **No late assignments will be accepted. The grade for any late assignment in which no alternative arrangement has been made will be zero**. Requests for due date extensions must be submitted to the instructor via e-mail at least three days prior to the original due date. The instructor will notify the student whether the request is accepted or denied. Assignments must be submitted directly to the instructor's e-mail prior to their respective due dates and times. Jupyter Notebook should be used for assignment submission. Additional, specific instructions will be provided

when the assignments are uploaded to Brightspace. There will be approximately five assignments accounting for 50% of your course grade. The lowest assignment score will be dropped. You may discuss the assignments with other students, but, unless stated otherwise, you *must* write your own solution independently, and you *must* provide the names of students with whom you had significant discussions.

- *The group project* will constitute the remaining 50% of your course grade. Specific details on the project will be given in a separate handout.

For your assignments, projects, and presentations, please note the Purdue Honors Pledge: "As a Boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together - we are Purdue." '

Course Policies

Addressing Questions via E-mail: Please feel free to e-mail questions to the instructor, but reserve those that involve extensive computation or mathematical expressions for office hours. If your question involves programming, please be sure to e-mail a minimal working example of your code to the instructor.

Incompletes: Incompletes will only be given under emergency circumstances (e.g., a serious auto accident, death of family member, etc). See the Grief Absence Policy for further information. Incompletes will not be given to students failing the course.

Grading: The grading scale is predetermined so as to eliminate competition with other students, and to ensure that you always know your grade in the class. Grades will not be curved.

Grade	Numerical range
A	90.00-100.00
B	80.00-89.99
C	70.00-79.99
D	60.00-69.99
F	0.00-59.99

Evaluation: Student feedback is essential for any course to be successful. Feedback questionnaires will be included in each assignment. These evaluations should be taken seriously, and will be addressed directly by the instructor.

Re-grading: All grade disputes must submitted *directly* to Dr. Sabbaghi's e-mail. Discussions or arguments for re-grades will *not* be done in person. A student has until one week after receiving his/her grade to dispute the grade.

When disputing a grade, you should state the question, the dispute, and the number of points you feel you should have received for the question. If you do not state the number of points you think are reasonable for the re-grade, zero points will be give as the re-grade. Please note that when you ask for a question to be re-graded, the entire assignment may be re-graded, and there is a possibility of losing points.

Dropping the Course: The instructor reserves the right to *not* sign anyone out of the course once the deadline for dropping without the instructor's signature has passed. Please take care to pay attention to these dates.

Generative AI Tools: Advances in generative artificial intelligence (AI) provide students with unparalleled access to information and problem-solving capabilities. However, with these advantages come the responsibilities of ethical use and academic integrity.

In this course, our approach to AI tools like ChatGPT revolves around adaptability, collaboration, and a focus on learning. Firstly, integrity guides our use of AI tools, ensuring ethical and responsible application in line with established standards. Secondly, AI tools should complement learning rather than substitute critical thinking or genuine engagement. Thirdly, upholding academic integrity is crucial, and you should utilize AI as a tool to augment understanding and creativity, avoiding plagiarism or misrepresentation. Additionally, exploring AI's impact within our field is encouraged, but its incorporation in assignments must align with the course guidelines.

Let's responsibly engage with AI tools, leveraging their capabilities while upholding ethical standards, fostering collaboration, and enriching our learning experiences. To preserve our class culture, any violation of our established policy, including academic integrity breaches, will be addressed thoughtfully and may involve reporting violations.

The formal guidelines for the responsible use of generative AI tools are outlined below.

- Original Work: You should ensure that assignments submitted are original and based on your understanding. While AI can assist in research or provide general guidance, it should not produce work on behalf of you.
- Citation: Any content, ideas, or assistance obtained through AI tools must be appropriately cited, similar to any other reference or source. You will need to go and find the relevant citations from the primary literature (e.g., journal articles).
- Collaboration: If you collaborate with AI tools (and you are encouraged to do so in this course), then you must specify the nature and extent of this collaboration in your submission. This includes providing details of the prompts used to generate the AI responses.
- Data Privacy: You should be cautious when sharing personal or sensitive information with AI platforms, and you should be familiar with the terms of service for any third-party AI tools.

Misuse of AI tools in coursework, which includes but is not limited to producing unoriginal work, uncited use of AI-generated content, or unauthorized assistance on assessments, will be considered a breach of academic integrity. Consequences will follow Purdue's policies on academic dishonesty as detailed in this syllabus, which may include grade penalties, course failure, and/or more severe disciplinary actions.

Students are encouraged to reflect on their experiences using AI tools and to openly discuss any ethical or academic concerns. Periodic class discussions or forums might be held to address advances in AI and their implications in different domains.

The promise of AI in enhancing learning and research is vast, but it must be used judiciously. Responsible use not only ensures academic honesty but also maximizes genuine learning and skill development. Students are urged to approach AI as a supplementary tool, not a replacement for their unique intellectual capacities and insights.

Academic Dishonesty: Purdue prohibits "dishonesty in connection with any University activity. Cheating, plagiarism, or knowingly furnishing false information to the University are examples of dishonesty." [Part 5, Section III-B-2-a, University Regulations] Furthermore, the University Senate has stipulated that "the commitment of acts of cheating, lying, and deceit in any of their diverse forms (such as the use of substitutes for taking examinations, the use of illegal cribs, plagiarism, and copying during examinations) is dishonest and must not be tolerated. Moreover, knowingly to aid and abet, directly or indirectly, other parties in committing dishonest acts is in itself dishonest." [University Senate Document 72-18, December 15, 1972].

Academic integrity is one of the highest values that Purdue University holds. You are encouraged to alert university officials to potential breeches of this value by either e-mailing `integrity@purdue.edu`, calling 765-494-8778, or contacting the Office of the Dean of Students (`https://www.purdue.edu/odos/`). While information may be submitted anonymously, the more information that is submitted provides the greatest opportunity for the university to investigate the concern. More details are available on the course Brightspace table of contents, under University Policies.

Incidents of academic misconduct in this course will be addressed by the course instructor and referred to the Office of Student Rights and Responsibilities (OSRR, `https://www.purdue.edu/odos/osrr/`) for review at the university level. Any violation of course policies as it relates to academic integrity will result minimally in a failing or zero grade for that particular assignment, and at the instructor's discretion may result in a failing grade for the course. In addition, all incidents of academic misconduct will be forwarded to OSRR, where university penalties, including removal from the university, may be considered. Use of instructor solution manuals or related resources will not be tolerated.

Attendance and Participation: Students: You are expected to attend lectures and engage in class/group projects. You are expected to be prepared and participate. On the rare occasion that a student is extremely close to the cut-off value between letter grades, attendance and class participation may help.

Classroom engagement is extremely important and associated with your overall success in the course. When conflicts or absences can be anticipated, such as for many University sponsored activities and religious observations, you should inform the instructors of the situation as far in advance as possible. You should also meet with the instructor to discuss the absence and how, if possible, learning outcomes associated with any missed class activities may be addressed. If you are involved in a group project, you are strongly encouraged to inform your group members as well. For unanticipated or emergency absences when advance notification is not possible, you should contact the instructor as soon as possible by e-mail, by phone, through Brightspace, or the Department of Statistics main office. When you are unable to make direct contact with the instructor and unable to leave word with the Department of Statistics because of circumstances beyond your control, and in cases of bereavement, quarantine, or isolation, you or your representative should contact the Office of the Dean of Students via e-mail or phone at 765-494-1747. The instructor will try to accommodate you either by excusing you or by allowing you an extension when possible.

Ultimately, you are responsible for all required coursework and bear full responsibility for any academic consequences that may result due to your absence. The link on Attendance and Grief Absence policies is: https://www.purdue.edu/advocacy/students/absences.html. The link to the implications of the attendance policy is: https://catalog.purdue.edu/content.php?catoid=13&navoid=16335.

Instructor: You can expect that I will attend lectures. I will arrive in the classroom prior to the start of lecture, and will end lecture on time. You can expect that I will be prepared for lecture, try my best to convey the information for the course, and show respect for all students.

If I am unable to attend lecture you will know in advance, and I will either cancel class or provide a guest instructor. I will be present for my office hours, and available for scheduled appointments.

The amount of material covered in each lecture is governed by the speed with which we complete the material. Every group of students is different, and I would rather teach the material well (and have you learn it) than speed through the topics for the purpose of covering a preset number of topics. Accordingly, the course outline is subject to change as the course progresses.

Grief Absence Policy for Students: Purdue University recognizes that a time of bereavement is very difficult for a student. The University therefore provides the following rights to students facing the loss of a family member through the Grief Absence Policy for Students (GAPS). Students will be excused for funeral leave and given the opportunity to earn equivalent credit and to demonstrate evidence of meeting the learning outcomes for missed assignments or assessments in the event of the death of a member of the student's family.

Counseling and Psychological Services Information: Purdue University is committed to advancing the mental health and well-being of its students. If you find yourself beginning to feel some stress, anxiety, and/or feeling slightly overwhelmed, try Well-Track Boost. Sign in and find information and tools at your fingertips, available to you at any time. If you need support and information about options and resources, please see the Office of the Dean of Students for drop-in hours (Monday - Friday, 8:00 AM - 5:00 PM). If you're struggling and need mental health services: Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of mental health support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at 765-494-6995 during and after hours, on weekends and holidays, or by going to the CAPS office of the second floor of the Purdue University Student Health Center (PUSH) during business hours. If you find yourself struggling to find a healthy balance between academics, social life, stress, etc. sign up for free one-on-one virtual or in-person sessions with a Purdue Wellness Coach at RecWell. Student coaches can help you navigate through barriers and challenges toward your goals throughout the semester. Sign up is completely free and can be done on BoilerConnect. If you have any questions, please contact Purdue Wellness at evans240@purdue.edu.

University Emergency Information: A safety briefing will be conducted on the first day of class. In the event of a major campus emergency or temporary suspension of

classes course requirements, deadlines, and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances beyond the instructors' control. Relevant changes to this course will be posted onto the course website or can be obtained by contacting the instructor via e-mail or phone. You are expected to read your Purdue e-mail on a frequent basis.

Violent Behavior Policy: Purdue University is committed to providing a safe and secure campus environment for members of the university community. Purdue strives to create an educational environment for students and a work environment for employees that promote educational and career goals. Violent behavior impedes such goals. Therefore, violent behavior is prohibited in or on any University Facility or while participating in any university activity.

Use of Copyrighted Materials: Among the materials that may be protected by copyright law are the lectures, notes, recordings, and other material presented in class or as part of the course. Always assume the materials presented by the instructor are protected by copyright unless the instructor has stated otherwise. Students enrolled in, and authorized visitors to, Purdue University courses are permitted to take notes, which they may use for individual/group study or for other non-commercial purposes reasonably arising from enrollment in the course or the University generally.

Notes taken in class are, however, generally considered to be "derivative works" of the instructor's presentations and materials, and they are thus subject to the instructor's copyright in such presentations and materials. No individual is permitted to sell or otherwise barter notes, either to other students or to any commercial concern, for a course without the express written permission of the course instructor. To obtain permission to sell or barter notes, the individual wishing to sell or barter the notes must be registered in the course or must be an approved visitor to the class. Course instructors may choose to grant or not grant such permission at their own discretion, and may require a review of the notes prior to their being sold or bartered. If they do grant such permission, they may revoke it at any time, if they so choose.

Students with Disabilities: Purdue University is required to respond to the needs of the students with disabilities as outlined in both the Rehabilitation Act of 1973 and the Americans with Disabilities Act of 1990 through the provision of auxiliary aids and services that allow a student with a disability to fully access and participate in the programs, services, and activities at Purdue University.

Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic behaviors based on disability, you are welcome to let the instructors know so that they can discuss options. You are also encouraged to contact the disability resource center at `drc@purdue.edu` or by phone 765-494-1247. If you have a disability that requires special academic accommodation, please make an appointment to speak with the instructors within the first three (3) weeks of the semester in order to discuss any adjustments. It is important to talk about this at the beginning of the semester. It is the student's responsibility to notify the Disability Resource Center (`https://www.purdue.edu/drc/`) of an impairment/condition that may require accommodations and/or classroom modifications. More details are available on the course Brightspace page under Accessibility Information.

Nondiscrimination: Purdue University is committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. More details are available on the course Brightspace table of contents, under University Policies. Purdue University's nondiscrimination policy can be found at https://www.purdue.edu/home/ea_eou_statement/.

Purdue University prohibits discrimination against any member of the University community on the basis of race, religion, color, sex, age, national origin or ancestry, genetic information, marital status, parental status, sexual orientation, gender identity and expression, disability, or status as a veteran. The University will conduct its programs, services and activities consistent with applicable federal, state and local laws, regulations and orders and in conformance with the procedures and limitations as set forth in Executive Memorandum No. D-1, which provides specific contractual rights and remedies. Any student who believes they have been discriminated against may visit www.purdue.edu/report-hate to submit a complaint to the Office of Institutional Equity. Information may be reported anonymously.