Statistical Inference for Causal Effects in Experiments and Observational Studies

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Causal Inference

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Global contents of the course

Causal inferences play a predominant role in science. Yet the problems encountered in the process of trying to attain causal explanations are often severe, especially in the social and behavioral sciences. Basic elements of causal inference and the consequences for experimental and non-experimental research designs are covered in the course. Causal inference in observational studies and up-to-date statistical methods available in the search for causal knowledge in the social sciences and other disciplines will be emphasized.

Key references

For a solid study of the potential-outcome framework of causal inference, three books are very useful: The first book contains selected work of Donald Rubin and colleagues, the second provides a uniform treatment of the subject (partly no easy reading though — see, however, the last chapter: *Planning an observational study*), and the third book is a more recent and general one, covering the counterfactual approach, causal graphs, and instrumental variable modeling.

- Rubin, D.B. (2006). *Matched sampling for causal effects.* Cambridge: Cambridge University Press.
- Rosenbaum, P.R. (2002). *Observational studies* (2nd ed.). New York: Springer.
- Morgan, S.L., & Winship, C. (2007). *Counterfactuals and causal inference: Methods and principles for social research.* Cambridge: Cambridge University Press.

Practical guidelines for causal effect estimation can be found in the following important paper, published last year.

- Schafer, J.L., & Kang, J. (2008). Average causal effects from nonrandomized studies: A practical guide and simulated example. *Psychological Methods*, **13**, 279–313.

Provisional setup of the course

A selection will be made from the references listed below. An asterisk [*] behind a reference, along with the number of pages shown in the margin, indicates that this material might be part of the course. The other listed literature can be viewed as additional reading material. It should be noted that the size of the course is restricted to seven lectures only.

Lecture 1a
The scientific method; descriptive, relational and experimental orientations; the roots of causal inference; some historical background and current questions; general statistical aspects; basics of controlled experiments and observation studies; pitfalls of causal inference.

- Freedman, D., Pisani, R., & Purves, R. (1998). *Statistics* (3rd ed.). Controlled experiments and observational studies (pp. 3–28). New York: Norton. * 26

- Rosnow, R.L., & Rosenthal, R. (2004). *Beginning behavioral research: A conceptual primer* (5th ed.). Randomized experiments and causal inference (pp. 167–193). Upper Saddle River, NJ: Pearson Prentice Hall.

- Cochran, W.G. (1976). Early development of techniques in comparative experimentation. In D.B. Owen (Ed.), *On the history of statistics and probability* (pp. 1–25). New York: Dekker.

- Turner, S.P. (1997). "Net effects": A short history. In V.R. McKim & S.P. Turner (Eds.), *Causality in crisis? Statistical methods and the search for causal knowledge in the social sciences* (pp. 23–45). Notre Dame, IN: University of Notre Dame Press.

- Cox, D.R. (1992). Causality: Some statistical aspects. *Journal of the Royal Statistical Society, Series A*, **155**, 291–301.

Lecture 1b
Design of experiments; randomization; controlled experiments, quasi-experiments, and observational studies.

- Fisher, R.A. (1947). *The design of experiments* (4th ed.). The principles of experimentation, illustrated by a psycho-physical experiment (pp. 11–25). Edinburgh: Oliver and Boyd. (First edition published in 1935) * 15

- Salsburg, D. (2002). *The lady tasting tea: How statistics revolutionized science in the twentieth century* (pp. 1–8). New York: Freeman/Owl Book.

- Kirk, R.E. (2000). Randomized experiments. In A.E. Kazdin (Ed.), *Encyclopedia of psychology* (Vol. 6, pp. 502–505). Washington, DC/Oxford: American Psychological Association/Oxford University Press. * 4

- Cochran, W.G. (1974). The vital role of randomization in experiments and surveys. In J. Neyman (Ed.), *The heritage of Copernicus: Theories "pleasing to the mind"* (pp. 445–463). Cambridge, MA: The MIT Press.

- Rosnow, R.L., & Rosenthal, R. (2004). *Beginning behavioral research: A conceptual primer* (5th ed.). Categories of nonrandomized research (pp. 197–217). Upper Saddle River, NJ: Pearson Prentice Hall.

Lecture 2
Planning and analysis of observational studies; controlling bias in observational studies; matching, stratification and covariance adjustment.

- Cochran, W.G. (1983). *Planning and analysis of observational studies.* Variation, control, and bias (pp. 1–14). (L.E. Moses & F. Mosteller, Eds.). New York: Wiley. * 14

- Cochran, W.G. (1983). *Planning and analysis of observational studies.* Statistical introduction (pp. 15–31). (L.E. Moses & F. Mosteller, Eds.). New York: Wiley.

- Rubin, D.B. (1984). William G. Cochran's contributions to the design, analysis, and evaluation of observational studies. In P.S.R.S. Rao & J. Sedransk (Eds.), *W.G. Cochran's impact on statistics* (pp. 37–69). New York: Wiley.

- Rosenbaum, P.R. (2005). Observational study. In B.S. Everitt & D.C. Howell (Eds.), *Encyclopedia of statistics in behavioral science* (pp. 1451–1461). Chichester: Wiley. * 11

- Student (1931). The Lanarkshire milk experiment. *Biometrika*, **23**, 398–406. * 9

Lecture 3
Rubin's causal model — or the potential-outcome model —, missing values, and counterfactuals.

- Neyman, J. (1923/1990). On the application of probability theory to agricultural experiments. Essay on principles. Section 9 (with discussion). Translated and edited by D.M. Dabrowska & T.P. Speed. *Statistical Science*, **5**, 465–480. (Original work published in 1923)

- Rubin, D.B. (1974). Estimating causal effects of treatments in randomized and nonrandomized studies. *Journal of Educational Psychology*, **66**, 688–701. * 14

- Holland, P.W. (1986). Statistics and causal inference (with discussion). *Journal of the American Statistical Association*, **81**, 945–960. * 26

- Rubin, D.B. (2007). The design *versus* the analysis of observational studies for causal effects: Parallels with the design of randomized trials. *Statistics in Medicine*, **26**, 20–26. * 7

Lecture 4
Matching, stratification, and covariance adjustment.

- Cochran, W.G. (1983). *Planning and analysis of observational studies*. Matching (pp. 74–101). (L.E. Moses & F. Mosteller, Eds.). New York: Wiley. 28

- Rubin, D.B. (1973). Matching to remove bias in observational studies. *Biometrics*, **29**, 159–183.

- Rubin, D.B. (1973). The use of matched sampling and regression adjustment to remove bias in observational studies. *Biometrics*, **29**, 185–203.

- Rubin, D.B. (1977). Assignment to a treatment group on the basis of a covariate. *Journal of Educational Statistics*, **2**, 1–26.

- Rosenbaum, P.R. (2004). Matching in observational studies. In A. Gelman & X-L. Meng (Eds.), *Applied Bayesian modeling and causal inference from incomplete-data perspectives: An essential journey with Donald Rubin's statistical family* (pp. 15–24). Chichester: Wiley. ***** 10

Lecture 5
Propensity scores; logistic regression; propensity score stratification.

- Rosenbaum, P.R., & Rubin, D.B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, **70**, 41–55. ***** 15

- Rosenbaum, P.R., & Rubin, D.B. (1984). Reducing bias in observational studies using subclassification on the propensity score. *Journal of the American Statistical Association*, **387**, 516–524.

- Rosenbaum, P.R., & Rubin, D.B. (1985). Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *The American Statistician*, **39**, 33–38.

- Rosenbaum, P.R. (1986). Dropping out of high school in the United States: An observational study. *Journal of Educational Statistics*, **11**, 207–224. ***** 15

- Rosenbaum, P.R. (1996). Observational studies and nonrandomized experiments. In S. Ghosh & C.R. Rao (Eds.), *Handbook of Statistics: Vol. 13. Design and analysis of experiments* (pp. 181–197). Amsterdam: Elsevier.

- D'Agostino, R.B., Jr. (1998). Tutorial in biostatistics: Propensity score methods for bias reduction in the comparison of a treatment to a nonrandomized control group. *Statistics in Medicine*, **17**, 2265–2281. ***** 17

- Joffe, M.M., & Rosenbaum, P.R. (1999). Invited commentary: Propensity scores. *American Journal of Epidemiology*, **150**, 327–333. * 7

- Dehejia, R.H. (2004). Estimating causal effects in nonexperimental studies. In A. Gelman & X-L. Meng (Eds.), *Applied Bayesian modeling and causal inference from incomplete-data perspectives: An essential journey with Donald Rubin's statistical family* (pp. 25–35). Chichester: Wiley.

- Rubin, D.B. (2005). Causal inference using potential outcomes: Design, modeling, decisions. *Journal of the American Statistical Association*, **100**, 322–331.

- Yanovitzky, I., Zanutto, E., & Hornik, R. (2005). Estimating causal effects of public health education campaigns using propensity score methodology. *Evaluation and Program Planning*, **28**, 209–220. * 12

Lecture 6
Hidden bias and sensitivity analysis; average causal effect estimation revisited.

- Rosenbaum, P.R. (1991). Discussing hidden bias in observational studies. *Annals of Internal Medicine*, **115**, 901–905. * 5

- Rosenbaum, P.R. (2005). Sensitivity analysis in observational studies. In B.S. Everitt & D.C. Howell (Eds.), *Encyclopedia of statistics in behavioral science* (pp. 1809–1814). Chichester: Wiley. * 6

- Rubin, D.B. (2004). Teaching statistical inference for causal effects in experiments and observational studies. *Journal of Educational and Behavioral Statistics*, **29**, 343–367. * **25**

Lecture 7
Quantifying the impact of confounders on regression coefficients; from association to causation via regression and structural equation modeling.

- Cohen, J., Cohen, P., West, S.G., & Aiken, L.S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). Multiple regression/correlation and causal models (pp. 452–478). Mahwah, NJ: Erlbaum. * 27

- Frank, K.A. (2000). Impact of a confounding variable on a regression coefficient. *Sociological Methods & Research*, **29**, 147–194. * 48

- Frank, K.A., Sykes, G., Anagnostopoulos, D., Cannata, M., Chard, L., Krause, A., & McCrory, R. (2008). Does NBPTS certification affect the number of colleagues a teacher helps with instructional matters? *Educational Evaluation and Policy Analysis*, **30**, 3–30.

- Freedman, D. (1999). From association to causation: Some remarks on the history of statistics. *Statistical Science*, **14**, 243–258.

- Boomsma, A. (2006). *Het causaliteitsvraagstuk*. Ongepubliceerd manuscript, Rijksuniversiteit Groningen, Vakgroep Statistiek & Meettheorie.

- Sobel, M.E. (1996). An introduction to causal inference. *Sociological Methods & Research*, **24**, 353–379.

- Steyer, R., Gabler, S., Von Davier, A., Nachtigall, C., & Buhl, T. (2000). Causal regression models I: Individual and average causal effects. *Methods of Pschological Research-Online*, **5** (2), 39–71. [Online paper at `www.mpr-online.de`]

- Steyer, R., Gabler, S., Von Davier, A., & Nachtigall, C. (2000). Causal regression models II: Unconfoundedness and causal unbiasedness. *Methods of Psychological Research-Online*, **5** (3), 55–86. [Online paper at `www.mpr-online.de`]

- Steyer, R. (2005). Analyzing individual and average causal effects via structural equation models. *Methodology*, **1**, 39–54.

- Berk, R.A. (2004). *Regression analysis: A constructive critique* (pp. 81–102, 223–234). Thousand Oaks, CA: Sage.

Lecture 8
Practical guidelines for causal effect estimation

- Schafer, J.L., & Kang, J. (2008). Average causal effects from nonrandomized studies: A practical guide and simulated example. *Psychological Methods*, **13**, 279–313. ***** 35

Lecture 9
Instrumental variables, structural equation modeling, causal inference in the social sciences.

- Angrist, J.D., Imbens, G.W., & Rubin, D.B. (1996). Identification of causal effects using instrumental variables (with discussion). *Journal of the American Statistical Association*, **91**, 444–455.

- Heckman, J. (1997). Instrumental variables: A study of implicit behavioral assumptions in making program evaluations. *The Journal of Human Resources*, **32**, 441–462.

- Sobel, M.E. (2000). Causal inference in the social sciences. *Journal of the American Statistical Association*, **95**, 647–651.

- Sobel, M.E. (1995). Causal inference in the social and behavioral sciences. In G. Arminger, C.C. Clogg & M.E. Sobel (Eds.), *Handbook of statistical modeling for the social and behavioral sciences* (pp. 1–38). New York: Plenum Press.

- Winship, C., & Sobel, M. (2004). Causal analysis in sociological studies. In M.A. Hardy & A. Bryman (Eds.), *Handbook of data analysis* (pp. 481–503). London: Sage.

- Freedman, D.A. (2005). Linear statistical models for causation: A critical review. In B.S. Everitt & D.C. Howell (Eds.), *Encyclopedia of statistics in behavioral science* (Vol. 2, pp. 1061–1073). Chichester, UK: Wiley.

- Winship, C., & Morgan, S.L. (1999). The estimation of causal effects from observational data. *Annual Review of Sociology*, **25**, 659–707.

- Smith, R.B. (2003). Inferential causal models: Integrating quality & quantity. *Quality & Quantity*, **37**, 337–361.

Lecture 10
Epidemiologic principles of causation; statistical inference for causal effects. Second hour: *The memory of water*. A videotape of the BBC television program *Horizon* on testing the effect of homeopathic treatment.

- Hill, A.B. (1965). The environment and disease: Association or causation. *Proceedings of the Royal Society of Medicine*, **58**, 295–300. ***** 6

- Jewell, N.P. (2004). *Statistics for epidemiology* (pp. 93–122). Boca Raton, FL: Chapman & Hall/CRC.

- Woodward, M., (2005). *Epidemiology: Study design and data analysis* (2nd ed., pp. 1–31). Boca Raton, FL: Chapman & Hall/CRC.

- Astin, J.A., Harkness, E., & Ernst, E. (2000). The efficacy of "distant healing": A systematic review of randomized trials. *Annals of Internal Medicine*, **132**, 903–910.

- Courcey, K., Kaptchuk, T.J., Astin, J., Harkness, E., & Ernst, E. (2001). Distant healing [Letters to the editor and a reply]. *Annals of Internal Medicine*, **134**, 532–533.

- Van den Burg, W. (2003). 'Distant healing' lijkt soms te werken, maar onderzoek vertoont nog te veel tekorten. *Maandblad Geestelijke Volksgezondheid*, **58**, 481–484.

- Pearl, J. (2001). Causal inference in the health sciences: A conceptual introduction. *Health Services & Outcome Research Methodology*, **2**, 189–220.

- Finkelstein, M.O., & Levin, B. (2001). *Statistics for lawyers* (2nd ed., pp. 291–316). New York: Springer.

- BBC Two (2002). *The memory of water. Homeopathy: The Test.* Transcript and related material of the BBC television program *Horizon* (November 26, 2002) on testing the effect of homeopathic treatment. [Online available at `http://www/bbc.co.uk/science/horizon/2002/homeopathy.shtml`]

Lecture 11
The foundations of causal inference; graphical modeling and causal graphs. Second hour: Pearl (2001), *The art and science of cause and effect.*

- Pearl, J. (2001). The art and science of cause and effect. Epilogue in *Causality: Models, reasoning, and inference* (corr. ed., pp. 331–358). Cambridge, UK: Cambridge University Press. [Online material available at `http://singapore.cs.ucla.edu/jp\_home.html`]

- Scheines, R. (1997). An introduction to causal inference. In V.R. McKim & S.P. Turner (Eds.), *Causality in Crisis? Statistical methods and the search for causal knowledge in the social sciences* (pp. 185–199). Notre Dame, IN: University of Notre Dame Press.

- Scheines, R. (2002). Computation and causation. *Metaphilosophy*, **33**, 158–180.

- Pearl, J. (1997). The new challenge: From a century of statistics to the age of causation. *Computing Science and Statistics*, **29**, 415–423.

- Greenland, S., & Brumback, B. (2002). An overview of relations among causal modelling methods. *International Journal of Epidemiology*, **31**, 1030–1037.

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