Mini-course on Stochastic Choice

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These lectures will discuss various models that generate stochastic choices. Randomness in choice is motivated both theoretically (since it naturally appears as a consequence of varying utility, information, or attention) as well as empirically (since individual choices typically exhibit variability, both in experimental and field data). I will mostly discuss the recently flourishing literature in decision theory, but I will also make connections to the discrete choice literature in econometrics. Both static and dynamic models will be discussed.

Lecture 1: Random Utility

- Random Utility/Discrete Choice
- Axioms
- Special Cases
- Random Expected Utility (REU)

Lecture 2: Other Static Models

- Learning
- Attention
 - Optimal Attention
 - Random Attention
- Deliberate Randomization

Lecture 3: Dynamic Models

- Dynamic Random Utility
- Dynamic Discrete Choice
- Decision Times

References

- AGRANOV, M., AND P. ORTOLEVA (2017): "Stochastic choice and preferences for randomization," Journal of Political Economy, 125(1), 40–68.
- AHN, D. S., AND T. SARVER (2013): "Preference for flexibility and random choice," *Econo*metrica, 81(1), 341–361.
- ALLAIS, M. (1953): "Le Comportment de l'Homme Rational devant 1e Risque, Critique des Postulates et Axiomes de l'Eco1e Americaine," *Econometrica*, 21, 803–815.
- ANDERSON, S., A. DE PALMA, AND J. THISSE (1992): Discrete choice theory of product differentiation. MIT Press.
- APESTEGUIA, J., M. BALLESTER, AND J. LU (2017): "Single-Crossing Random Utility Models," *Econometrica*.
- APESTEGUIA, J., AND M. A. BALLESTER (2017): "Monotone Stochastic Choice Models: The Case of Risk and Time Preferences," *Journal of Political Economy*.
- BALLINGER, T. P., AND N. T. WILCOX (1997): "Decisions, error and heterogeneity," The Economic Journal, 107(443), 1090–1105.
- BARBERÁ, S., AND P. PATTANAIK (1986): "Falmagne and the rationalizability of stochastic choices in terms of random orderings," *Econometrica*, pp. 707–715.
- BLOCK, D., AND J. MARSCHAK (1960): "Random Orderings And Stochastic Theories of Responses," in *Contributions To Probability And Statistics*, ed. by I. O. et al. Stanford: Stanford University Press.
- BRADY, R. L., AND J. REHBECK (2016): "Menu-Dependent Stochastic Feasibility," Econometrica, 84(3), 1203–1223.
- BRANCO, F., M. SUN, AND J. M. VILLAS-BOAS (2012): "Optimal search for product information," Management Science, 58(11), 2037–2056.
- BROCAS, I., J. D. CARRILLO, S. W. WANG, AND C. F. CAMERER (2014): "Imperfect choice

or imperfect attention? Understanding strategic thinking in private information games," *The Review of Economic Studies*, p. rdu001.

- CAPLIN, A., AND M. DEAN (2013): "Behavioral implications of rational inattention with shannon entropy," Discussion paper, National Bureau of Economic Research.
- (2015): "Revealed preference, rational inattention, and costly information acquisition," *The American Economic Review*, 105(7), 2183–2203.
- CAPLIN, A., AND D. MARTIN (2016): "The Dual-Process Drift Diffusion Model: Evidence from Response Times," *Economic Inquiry*, 54(2), 1274–1282.
- CATTANEO, M., AND Y. MASATLIOGLU (2017): "A Random Attention Model: Identification, Estimation and Testing," *mimeo*.
- CERREIA-VIOGLIO, S., D. DILLENBERGER, P. ORTOLEVA, AND G. RIELLA (2017): "Deliberately Stochastic," *mimeo*.
- CERREIA-VIOGLIO, S., F. MACCHERONI, M. MARINACCI, AND A. RUSTICHINI (2017): "Multinomial logit processes and preference discovery," .
- CHAMBERS, C. P., AND F. ECHENIQUE (2016): *Revealed preference theory*, vol. 56. Cambridge University Press.
- CHE, Y.-K., AND K. MIERENDORFF (2016): "Optimal Sequential Decision with Limited Attention," *in prepraration*.
- CHIONG, K. X., A. GALICHON, AND M. SHUM (2016): "Duality in dynamic discrete-choice models," *Quantitative Economics*, 7(1), 83–115.
- CLARK, S. (1996): "The random utility model with an infinite choice space," *Economic Theory*, 7(1), 179–189.
- CLARK, S. A. (1990): "A concept of stochastic transitivity for the random utility model," Journal of Mathematical Psychology, 34(1), 95–108.
- COSTA-GOMES, M., V. P. CRAWFORD, AND B. BROSETA (2001): "Cognition and behavior

in normal-form games: An experimental study," *Econometrica*, 69(5), 1193–1235.

- CRAWFORD, G. S., AND M. SHUM (2005): "Uncertainty and learning in pharmaceutical demand," *Econometrica*, 73(4), 1137–1173.
- VAN DAMME, E., AND J. WEIBULL (2002): "Evolution in games with endogenous mistake probabilities," *Journal of Economic Theory*, 106(2), 296–315.
- DAVIDSON, D., AND J. MARSCHAK (1959): "Experimental Tests of Stochastic Decision Theory," in *Measurement Definitions and Theories*, ed. by C. W. Churchman. John Wiley and Sons.
- DE OLIVEIRA, H., T. DENTI, M. MIHM, AND M. K. OZBEK (2016): "Rationally inattentive preferences and hidden information costs," *Theoretical Economics*, pp. 2–14.
- DEBREU, G. (1958): "Stochastic Choice and Cardinal Utility," *Econometrica*, 26(3), 440444.
- DEBREU, G. (1960): "Review of RD Luce, Individual choice behavior: A theoretical analysis," American Economic Review, 50(1), 186–88.
- DEKEL, E., B. LIPMAN, AND A. RUSTICHINI (2001): "Representing preferences with a unique subjective state space," *Econometrica*, 69(4), 891–934.
- DEKEL, E., B. L. LIPMAN, A. RUSTICHINI, AND T. SARVER (2007): "Representing Preferences with a Unique Subjective State Space: A Corrigendum1," *Econometrica*, 75(2), 591– 600.
- DWENGER, N., D. KUBLER, AND G. WEIZSACKER (2013): "Flipping a Coin: Theory and Evidence," Discussion paper.
- ECHENIQUE, F., K. SAITO, AND G. TSERENJIGMID (2013): "The Perception Adjusted Luce Model," Discussion paper.
- EDWARDS, W. (1965): "Optimal strategies for seeking information: Models for statistics, choice reaction times, and human information processing," *Journal of Mathematical Psychology*, 2(2), 312–329.

EPSTEIN, L. G., AND S. JI (2017): "Optimal Learning and Ellsberg's Urns,".

- ERDEM, T., AND M. P. KEANE (1996): "Decision-making under uncertainty: Capturing dynamic brand choice processes in turbulent consumer goods markets," *Marketing science*, 15(1), 1–20.
- ERGIN, H. (2003): "Costly contemplation," Unpublished paper, Department of Economics, Duke University.[22] Ergin, Haluk and Todd Sarver (2010), A unique costly contemplation representation. Econometrica, 78, 1285–1339.
- ERGIN, H., AND T. SARVER (2010): "A unique costly contemplation representation," *Econo*metrica, 78(4), 1285–1339.
- FALMAGNE, J. (1978): "A representation theorem for finite random scale systems," Journal of Mathematical Psychology, 18(1), 52–72.
- FISHBURN, P. C. (1998): "Stochastic Utility," Handbook of Utility Theory: Volume 1: Principles, p. 273.
- FRICK, M., AND R. IIJIMA (2015): "A Warring Selves Model of Random Choice and Delay," .
- FRICK, M., R. IIJIMA, AND T. STRZALECKI (2017): "Dynamic Random Utility," mimeo.
- FUDENBERG, D., R. IIJIMA, AND T. STRZALECKI (2014): "Stochastic choice and revealed perturbed utility," *working paper version*.

(2015): "Stochastic choice and revealed perturbed utility," *Econometrica*, 83(6), 2371–2409.

- FUDENBERG, D., AND D. K. LEVINE (1995): "Consistency and Cautious Fictitious Play," Journal of Economic Dynamics and Control, 19, 1065–1089.
- FUDENBERG, D., P. STRACK, AND T. STRZALECKI (2017): "Speed, Accuracy, and the Optimal Timing of Choices," .
- FUDENBERG, D., AND T. STRZALECKI (2015): "Dynamic logit with choice aversion," *Econo*metrica, 83(2), 651–691.

GABAIX, X., AND D. LAIBSON (2005): "Bounded rationality and directed cognition," Harvard University.

---- (2017): "Myopia and Discounting," .

- GOWRISANKARAN, G., AND M. RYSMAN (2012): "Dynamics of Consumer Demand for New Durable Goods," *mimeo*.
- GUL, F., P. NATENZON, AND W. PESENDORFER (2014): "Random Choice as Behavioral Optimization," *Econometrica*, 82(5), 1873–1912.
- GUL, F., AND W. PESENDORFER (2006): "Random expected utility," *Econometrica*, 74(1), 121–146.
- GUL, F., AND W. PESENDORFER (2013): "Random Utility Maximization with Indifference," *mimeo*.
- HARSANYI, J. (1973): "Oddness of the number of equilibrium points: A new proof," International Journal of Game Theory, 2(1), 235–250.
- HAUSMAN, J., AND D. MCFADDEN (1984): "Specification tests for the multinomial logit model," *Econometrica: Journal of the Econometric Society*, pp. 1219–1240.
- HÉBERT, B., AND M. WOODFORD (2017): "Rational Inattention with Sequential Information Sampling," *mimeo*.
- HECKMAN, J. J. (1981): "Heterogeneity and state dependence," in *Studies in labor markets*, pp. 91–140. University of Chicago Press.
- HENDEL, I., AND A. NEVO (2006): "Measuring the implications of sales and consumer inventory behavior," *Econometrica*, 74(6), 1637–1673.
- HEY, J. D. (1995): "Experimental investigations of errors in decision making under risk," *European Economic Review*, 39(3), 633–640.
- (2001): "Does repetition improve consistency?," *Experimental economics*, 4(1), 5–54. HOFBAUER, J., AND W. SANDHOLM (2002): "On the global convergence of stochastic fictitious

play," *Econometrica*, 70(6), 2265–2294.

- HUBER, J., J. W. PAYNE, AND C. PUTO (1982): "Adding Asymmetrically Dominated Alternatives: Violations of Regularity and the Similarity Hypothesis," *Journal of Consumer Research*, 9.
- IYENGAR, S. S., AND M. R. LEPPER (2000): "When choice is demotivating: Can one desire too much of a good thing?," *Journal of Personality and Social Psychology*, 79(6), 995–1006.
- JOHNSON, E. J., C. CAMERER, S. SEN, AND T. RYMON (2002): "Detecting failures of backward induction: Monitoring information search in sequential bargaining," *Journal of Economic Theory*, 104(1), 16–47.
- KAHNEMAN, D., AND A. TVERSKY (1979): "Prospect theory: An analysis of decision under risk," *Econometrica*, pp. 263–291.
- KAMENICA, E. (2008): "Contextual Inference in Markets: On the Informational Content of Product Lines," American Economic Review, 98, 2127–2149.
- KASAHARA, H., AND K. SHIMOTSU (2009): "Nonparametric identification of finite mixture models of dynamic discrete choices," *Econometrica*, 77(1), 135–175.
- KE, S. (2016): "A Dynamic Model of Mistakes," working paper.
- KE, T., AND M. VILLAS-BOAS (2016): "Optimal Learning before Choice," mimeo.
- KE, T. T., Z.-J. M. SHEN, AND J. M. VILLAS-BOAS (2016): "Search for information on multiple products," *Management Science*, 62(12), 3576–3603.
- KITAMURA, Y., AND J. STOYE (2016): "Nonparametric analysis of random utility models: testing,".
- KRAJBICH, I., C. ARMEL, AND A. RANGEL (2010): "Visual fixations and the computation and comparison of value in simple choice," *Nature neuroscience*, 13(10), 1292–1298.
- KRAJBICH, I., B. BARTLING, T. HARE, AND E. FEHR (2015): "Rethinking fast and slow based on a critique of reaction-time reverse inference.," *Nature Communications*, 6(7455),

700.

- KRAJBICH, I., D. LU, C. CAMERER, AND A. RANGEL (2012): "The attentional drift-diffusion model extends to simple purchasing decisions," *Frontiers in psychology*, 3, 193.
- KRAJBICH, I., AND A. RANGEL (2011): "Multialternative drift-diffusion model predicts the relationship between visual fixations and choice in value-based decisions," *Proceedings of the National Academy of Sciences*, 108(33), 13852–13857.
- KREPS, D. (1979): "A representation theorem for" preference for flexibility"," *Econometrica*, pp. 565–577.
- KRISHNA, V., AND P. SADOWSKI (2012): "Dynamic Preference for Flexibility," mimeo.

(2016): "Randomly Evolving Tastes and Delayed Commitment," *mimeo*.

- LIANG, A., X. MU, AND V. SYRGKANIS (2017): "Optimal Learning from Multiple Information Sources," .
- LIN, Y.-H. (2017): "Stochastic Choice and Rational Inattention," mimeo.
- LU, J. (2016): "Random choice and private information," *Econometrica*, 84(6), 1983–2027.
- LU, J., AND K. SAITO (2016): "Random intertemporal choice," Discussion paper, mimeo.
- LUCE, D. (1959): Individual choice behavior. John Wiley.
- LUCE, R. D. (1986): Response times. Oxford University Press.
- LUCE, R. D., AND H. RAIFFA (1957): Games and decisions: Introduction and critical survey. New York: Wiley.
- MACHINA, M. (1985): "Stochastic choice functions generated from deterministic preferences over lotteries," *The Economic Journal*, 95(379), 575–594.
- MAGNAC, T., AND D. THESMAR (2002): "Identifying dynamic discrete decision processes," *Econometrica*, 70(2), 801–816.
- MANSKI, C. F. (1993): "Dynamic choice in social settings: Learning from the experiences of others," *Journal of Econometrics*, 58(1-2), 121–136.

- MANZINI, P., AND M. MARIOTTI (2014): "Stochastic choice and consideration sets," *Econo*metrica, 82(3), 1153–1176.
- MARSCHAK, J. (1959): "Binary Choice Constraints on Random Utility Indicators," Cowles Foundation Discussion Papers 74, Cowles Foundation for Research in Economics, Yale University.
- MASATLIOGLU, Y., D. NAKAJIMA, AND E. Y. OZBAY (2011): "Revealed attention," 102, 2183–2205.
- MATEJKA, F., AND A. MCKAY (2014): "Rational inattention to discrete choices: A new foundation for the multinomial logit model," *The American Economic Review*, 105(1), 272–298.
- MATTSSON, L.-G., AND J. W. WEIBULL (2002): "Probabilistic choice and procedurally bounded rationality," *Games and Economic Behavior*, 41, 61–78.
- MATZKIN, R. L. (1992): "Nonparametric and distribution-free estimation of the binary threshold crossing and the binary choice models," *Econometrica*, pp. 239–270.
- MCFADDEN, D. (1973): "Conditional logit analysis of qualitative choice behavior," in *Fron*tiers in *Econometrics*, ed. by P. Zarembka. Institute of Urban and Regional Development, University of California.
- MCFADDEN, D., AND M. RICHTER (1971): "On the Extension of a Set Function on a Set of Events to a Probability on the Generated Boolean σ -algebra," University of California, Berkeley, working paper.
- MCFADDEN, D., AND M. RICHTER (1990): "Stochastic rationality and revealed stochastic preference," *Preferences, Uncertainty, and Optimality, Essays in Honor of Leo Hurwicz*, pp. 161–186.
- MCFADDEN, D. L. (2005): "Revealed stochastic preference: a synthesis," *Economic Theory*, 26(2), 245–264.
- MCKELVEY, R., AND T. PALFREY (1995): "Quantal Response Equilibria for Normal Form

Games," Games and Economic Behavior, 10, 638.

- MCKELVEY, R. D., AND T. R. PALFREY (1998): "Quantal response equilibria for extensive form games," *Experimental economics*, 1(1), 9–41.
- MILLER, R. (1984): "Job matching and occupational choice," The Journal of Political Economy, 92, 1086–1120.
- MORRIS, S., AND P. STRACK (2017): "The Wald Problem and the Equivalence of Sequential Sampling and Static Information Costs," *mimeo*.
- MORRIS, S., AND M. YANG (2016): "Coordination and Continuous Choice," .
- NATENZON, P. (2016): "Random choice and learning,".
- NORETS, A., AND X. TANG (2013): "Semiparametric Inference in dynamic binary choice models," *The Review of Economic Studies*, p. rdt050.
- OUD, B., I. KRAJBICH, K. MILLER, J. H. CHEONG, M. BOTVINICK, AND E. FEHR (2014): "Irrational Deliberation in Decision Making," *mimeo*.
- PAKES, A. (1986): "Patents as options: Some estimates of the value of holding European patent stocks," *Econometrica*, 54, 755–784.
- RAIFFA, H., AND R. SCHLAIFER (1961): Applied statistical decision theory. Boston: Division of Research, Harvard Business School.
- RAND, D. G., J. D. GREENE, AND M. A. NOWAK (2012): "Spontaneous giving and calculated greed," *Nature*, 489(7416), 427–430.
- RATCLIFF, R. (1978): "A theory of memory retrieval.," Psychological review, 85(2), 59.
- RIESKAMP, J., J. R. BUSEMEYER, AND B. A. MELLERS (2006): "Extending the Bounds of Rationality: Evidence and Theories of Preferential Choice," *Journal of Economic Literature*, 44(3), 631–661.
- ROSENTHAL, A. (1989): "A bounded-rationality approach to the study of noncooperative games," *International Journal of Game Theory*, 18.

- RUBINSTEIN, A. (2007): "Instinctive and cognitive reasoning: A study of response times," The Economic Journal, 117(523), 1243–1259.
- RUST, J. (1987): "Optimal replacement of GMC bus engines: An empirical model of Harold Zurcher," *Econometrica*, pp. 999–1033.
- (1989): "A Dynamic Programming Model of Retirement Behavior," in *The Economics of Aging*, ed. by D. Wise, pp. 359–398. University of Chicago Press: Chicago.
- ——— (1994): "Structural estimation of Markov decision processes," *Handbook of econometrics*, 4, 3081–3143.
- SCOTT, D. (1964): "Measurement structures and linear inequalities," Journal of mathematical psychology, 1(2), 233–247.
- SIMS, C. A. (2003): "Implications of rational inattention," Journal of monetary Economics, 50(3), 665–690.
- STEINER, J., C. STEWART, AND F. MATĚJKA (2017): "Rational Inattention Dynamics: Inertia and Delay in Decision-Making," *Econometrica*, 85(2), 521–553.
- STONE, M. (1960): "Models for choice-reaction time," Psychometrika, 25(3), 251–260.
- TODD, P. E., AND K. I. WOLPIN (2006): "Assessing the Impact of a School Subsidy Program in Mexico: Using a Social Experiment to Validate a Dynamic Behavioral Model of Child Schooling and Fertility," *American economic review*, 96(5), 1384–1417.
- TVERSKY, A. (1969): "Intransitivity of Preferences," *Psychological Review*, 76, 31–48. ——— (1972): "Choice by Elimination," *Journal of Mathematical Psychology*, 9, 341–367.
- WALD, A. (1945): "Sequential tests of statistical hypotheses," The Annals of Mathematical Statistics, 16(2), 117–186.
- WILCOX, N. T. (2008): "Stochastic models for binary discrete choice under risk: A critical primer and econometric comparison," in *Risk aversion in experiments*, pp. 197–292. Emerald Group Publishing Limited.

— (2011): "Stochastically more risk averse: A contextual theory of stochastic discrete choice under risk," *Journal of Econometrics*, 162(1), 89–104.

WOODFORD, M. (2014): "An Optimizing Neuroeconomic Model of Discrete Choice," Columbia University working paper.