Research Statement

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My research interests include econometric theory, applied econometrics, and causal inference. I am broadly interested in the definition, identification, modeling, and estimation of causal effects. In one research theme, I study extensions of instrumental variables (IV) methods. This research demonstrates how various structural relations determine exogeneity and exclusion restrictions that yield moment conditions supporting identification. Further, it studies IV methods in nonparametric structural systems with heterogeneity and mismeasured instruments. In a second research theme, I study tests of conditional exogeneity, a key condition ensuring identification of causal effects, and the consequences of the failure of this assumption on the identification of treatment effects in structural systems. In a third and recent research theme, I employ restrictions on confounding, such as sign and magnitude restrictions, to obtain full or partial identification of various parametric and nonparametric causal effects in structural systems without requiring conditional exogeneity. I apply these new methods to study the financial return to education and the black-white wage gap and to measure Engel curves. A fourth research theme develops settable systems as a formal framework for causal inference which accommodates notions of optimization, equilibrium, and learning that are central to economics. This research develops rigorous notions of causal effects and studies their interconnections to probabilistic notions such as conditional independence relations. This research also applies the settable systems framework to study causal discourse in several environments such as games of incomplete information and to link Granger causality to structural notions of causality in dynamic structural systems. Below are synopses of my published papers and some of my current research organized along these four research themes.

Instrumental Variables Methods: Extensions, Heterogeneity, and Mismeasurement

This research studies extensions of instrumental variables methods. It employs exogeneity and exclusion restrictions to define a class of extended instrumental variables for the identification of causal effects. It also studies instrumental variables methods in nonparametric structural systems with heterogeneity and possibly mismeasured instruments.

[I1] Chalak, K. and H. White (2011), "An Extended Class of Instrumental Variables for the Estimation of Causal Effects," *Canadian Journal of Economics*, 44, 1-51. (PDF)

This paper examines how structural systems can yield observed variables instrumental in identifying and estimating causal effects. We provide an exhaustive characterization of potentially identifying conditional exogeneity relationships and demonstrate how structural relations determine exogeneity and exclusion restrictions that yield moment conditions supporting identification. This provides a comprehensive framework for constructing instruments and covariates. We introduce notions of conditioning and conditional extended instrumental variables (XIVs). These permit identification but need not be traditional instruments, as they may be endogenous. We distinguish between observed XIVs and proxies for unobserved XIVs. A main message is the importance of sufficiently specifying causal relations governing the unobservables.

[I2] Schennach, S. M., H. White, and K. Chalak (2012), "Local Indirect Least Squares and Average Marginal Effects in Nonseparable Structural Systems," *Journal of Econometrics*, 166, 282-302. (PDF)

This paper studies the scope of local indirect least squares (LILS) methods for nonparametrically estimating average marginal effects of an endogenous cause X on a response Y in triangular structural systems that need not exhibit linearity, separability, or monotonicity in scalar unobservables. One main finding is negative: in the fully nonseparable case, LILS methods cannot recover the average marginal effect. LILS methods can nevertheless test the hypothesis of no effect in the general nonseparable case. We provide new nonparametric asymptotic theory, treating both the traditional case of observed exogenous instruments Z and the case where one observes only multiple error-laden proxies for Z.

[I3] Chalak, K. (2013), "Instrumental Variables Methods with Heterogeneity and Mismeasured Instruments," revise and resubmit, *Econometric Theory*. (PDF)

In the linear constant effect case, an instrument or an error-laden proxy for it (e.g. with error at random) can be used to identify the constant causal effect. What are the implications of substituting a proxy for an instrument on the interpretation of the Wald, local instrumental variables (LIV), and instrumental variables (IV) (e.g. two stage least squares) estimands in systems with heterogeneous effects? This paper studies this question in the context of an ordered discrete choice structural system with heterogeneity and shows that Wald and LIV estimands using an error-laden proxy W for instruments Z identify weighted averages of local average treatment effects (LATEs) or marginal treatment effects (MTEs). Unlike Z, W need not satisfy monotonicity and exogeneity. The paper studies necessary and sufficient conditions for nonnegative weights. These conditions can be useful e.g. for determining the sign of the treatment effect or for testing the hypothesis of no effect. Further, it gives conditions (e.g. these are trivially true for binary Z) under which the Wald or LIV estimand using W identifies the same LATEs or MTEs that would have been recovered using Z. One can then also recover the average treatment effects for the population, treated, and untreated using W. This relaxes the conditions in the literature by demonstrating how any suitable proxy for Z can be used to identify these various average treatment effects.

Conditional Exogeneity: Testing and Failure

This research provides new approaches to testing conditional exogeneity and studies the consequences of its failure on the identification of treatment effects in structural systems.

[F1] White, H. and K. Chalak (2010), "Testing a Conditional Form of Exogeneity," *Economics Letters*, 109, 88-90. (PDF)

This paper gives two new approaches to testing conditional exogeneity, a condition ensuring identification of structural effects. These approaches permit the presence of treatment effects under the null thereby complementing methods from the literature. The first approach relies on an auxiliary observable response to the treatment that is conditionally unrelated to the confounders. The second relies on observable covariates driven by the confounders.

[F2] White, H. and K. Chalak (2013), "Identification and Identification Failure for Treatment Effects using Structural Systems," *Econometric Reviews*, 32, 273-317. (PDF)

This paper provides necessary and sufficient conditions for effect identification, thereby characterizing the limits to identification. Our results link the non-structural potential outcome framework for identifying and estimating treatment effects to structural approaches in economics. This permits economic theory to be built into treatment effect methods. We elucidate the sources and consequences of identification failure by examining the biases arising when the necessary conditions fail, and we clarify the relations between unconfoundedness, conditional exogeneity, and the necessary and sufficient identification conditions. A new quantity, the exogeneity score, plays a central role in this analysis, permitting an omitted variable representation for effect biases. This analysis also provides practical guidance for selecting covariates and insight into the price paid for making various identifying assumptions and the benefits gained.

Measuring Causal Effects without Exogeneity under Restrictions on Confounding

This research demonstrates how restrictions on confounding, such as sign and magnitude restrictions, yield full or partial identification of various causal effects without requiring conditional exogeneity of causes, treatment, or instruments. I apply these methods to study the financial return to education and the black-white wage gap and to measure Engel curves.

[E1] Chalak, K. (2013), "Identification without Exogeneity under Equiconfounding in Linear Recursive Structural Systems," in X. Chen and N. Swanson (eds.), *Causality, Prediction, and Specification Analysis: Recent Advances and Future Directions - Essays in Honor of Halbert L. White, Jr.*, Springer, 27-55. (PDF)

This paper obtains identification of structural coefficients in linear recursive systems of structural equations without requiring that observable variables are conditionally exogenous. Instead, the paper demonstrates that the availability of one or two variables that are equally affected by the unobserved confounder as is the response of interest, along with exclusion restrictions, permits identifying all of the system's structural coefficients. We provide conditions under which equiconfounding supports either full identification of structural coefficients or partial identification in a set consisting of two points.

[E2] Chalak, K. (2013), "Identification of Average Effects under Magnitude and Sign Restrictions on Confounding," Boston College Department of Economics Working Paper. (PDF)

This paper obtains full or partial identification of various average effects of X on Y (e.g. covariate-conditioned average random coefficients, average nonparametric discrete and marginal effects, local and marginal treatment effects, and average treatment effects for the population, treated, and untreated) by imposing magnitude and sign restrictions on confounding without requiring (conditional) exogeneity of causes, treatment, or instruments. We characterize the omitted variables bias, due to confounders U, of regression and IV methods for the identification of these average effects. In particular, full or partial identification of average effects of X on Y (e.g. return to education) obtains by employing restrictions on how the average direct effects of unobserved confounders U (e.g. ability) on the outcome Y (e.g. wage) compare in magnitude and sign to those of U on proxies W (e.g. test scores) for U. Exogeneity and proportional confounding are limit cases yielding full identification. Alternatively, the effects of X on Y are partially identified in sharp bounded intervals if W is sufficiently sensitive to U, and sharp upper or lower bounds may obtain otherwise. After studying estimation and inference, we apply this method to study the financial return to education and the black-white wage gap.

[E3] Chalak, K. and D. Kim (2013), "Identification in Systems of Multiple Structural Equations under Restrictions on Confounding," work in progress.

This paper studies measuring causal effects in systems of multiple structural equations by imposing restrictions on confounding without requiring conditional exogeneity. For example, the paper shows that the effects of causes on multiple outcomes are fully or partially identified under magnitude and sign restrictions on confounding. We apply the new method to measure Engel curves when expenditure data may be error-laden.

Settable Systems

This research puts forward the settable systems framework for studying causal relations. Roughly speaking, a settable system is a mathematical framework describing an environment in which multiple agents interact under uncertainty. The settable system framework is explicit about the principles underlying decision making and as such accommodates notions of optimization, equilibrium, and learning. General notions of causal effects are formally defined within settable systems and the interrelation between these notions of causality and conditional independence relations is studied. Settable systems are employed to study causal relations in several decision and game theoretic environments, such as auctions and rational expectations models, and to link Granger causality to structural notions of causality.

[S1] White, H. and K. Chalak (2009), "Settable Systems: An Extension of Pearl's Causal Model with Optimization, Equilibrium, and Learning," *Journal of Machine Learning Research*, 10, 1759-1799. (PDF)

The Pearl Causal Model (PCM) is often used for causal inference in machine learning and artificial intelligence for example. This paper offers the settable systems framework as an extension of the PCM that permits causal discourse in systems that exhibit features of central interest to economists and econometricians: optimization, equilibrium, and learning. Because these are common features of physical, natural, or social systems, the settable systems framework may prove generally useful for economics and machine learning. Important features distinguishing the settable system framework from the PCM are its countable dimensionality and the use of partitioning and partition-specific response functions to accommodate the behavior of optimizing and interacting agents and to eliminate the requirement of a unique fixed point for the system. Refinements of the PCM include the settable systems treatment of attributes, the causal role of exogenous variables, and the dual role of variables as causes and responses. A series of closely related machine learning examples and examples from game theory and machine learning with feedback demonstrates some limitations of the PCM and motivates the distinguishing features of settable systems.

[S2] Chalak, K. and H. White (2012), "Causality, Conditional Independence, and Graphical Separation in Settable Systems," *Neural Computation*, 24, 1611–1668. (PDF)

We study the connections between causal relations and conditional independence within the settable systems framework. The paper's results shed light on two questions fundamental to the understanding of empirical relationships. First, what implications for the joint probability distribution of variables of interest derive from knowledge of functionally defined causal relationships between them? Conversely, what restrictions (if any) on the possible causal relationships holding between variables of interest follow from knowledge of the joint probability distribution governing these variables? To address these questions, we provide definitions in terms of suitable functional dependence for direct causality and for indirect and total causality via and exclusive of a set of variables. Based on these foundations, we provide causal and stochastic conditions formally characterizing conditional dependence among random vectors of interest in structural systems. In particular, we state and prove the conditional Reichenbach principle of common cause, obtaining the classical Reichenbach principle as a corollary. We apply the conditional Reichenbach principle to show that the useful graphical representation tools of d-separation and D-separation can be employed to establish conditional independence within suitably restricted settable systems analogous to Markovian PCMs.

[S3] White, H., K. Chalak, and X. Lu (2011), "Linking Granger Causality and the Pearl Causal Model with Settable Systems," *Journal of Machine Learning Research Workshop and Conference Proceedings*, 12, 1-29. (PDF)

The notions embodied in the concept of Granger causality are probabilistic, relating to the ability of one time series to predict another conditional on a given information set. On the other hand, the causal notions of the Pearl Causal Model involve specific notions of interventions and of functional rather than probabilistic dependence. This paper demonstrates that these concepts are in fact closely linked by showing how each relates to straightforward notions of direct causality embodied in settable systems. In particular, under a conditional exogeneity condition in a dynamic structural system, Granger non-causality is equivalent to a notion of structural direct non-causality. We then provide straightforward practical methods to test for direct causality using tests for Granger causality.

[S4] White, H., H. Xu, and K. Chalak, "Causal Discourse in a Game of Incomplete Information," *Journal of Econometrics*, accepted. (PDF)

Notions of cause and effect are fundamental to economic explanation. Despite the immediate intuitive content of price effects, income effects, and the like, rigorous foundations justifying well-posed discussions of cause and effect in the wide range of settings relevant to economics are still lacking. We illustrate the need for these foundations using the familiar context of an N-bidder private-value auction, posing a variety of relevant causal questions that cannot be formally addressed within existing causal frameworks. We extend the settable systems framework to introduce topological settable systems, a causal framework capable of delivering the missing answers. In particular, our framework can accommodate choices that are elements of general function spaces. Our analysis suggests how topological settable systems can be applied to support causal discourse in more general games and in other areas of economic inquiry.