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ESTIMATING BETWEEN- AND WITHIN-CLUSTER COVARIATE EFFECTS, WITH AN APPLICATION TO MODELS OF INTERNATIONAL DISPUTES

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Students of international politics often use data in which the covariates vary both within and across units of observation. This is particularly true for dyadic data, which has come to dominate quantitative studies of international conflict, but is also a concern in any work involving a time-series cross-sectional component. Standard regression methods treat both types of covariates as equivalent with respect to their influence on the dependent variable, ignoring possible differences between cross-dyad and within-dyad effects. Here, I discuss the potential pitfalls of this approach, and show how between- and within-dyad effects can be separated and estimated. I then illustrate the approach in the context of a logistic regression, using data on international disputes.

KEY WORDS: time-series cross-sectional data, between-effects, within-effects, international trade, democracy, international conflict.

INTRODUCTION

Political scientists often make use of "clustered" data. Such data generally take the form of repeated measurements on specific units of analysis, either over time, in the form of panel or time-series cross-sectional data, or across space (e.g., multiple observations within a particular geographic area). The use of clustered data offers both opportunities and challenges to empirical researchers. The most commonly addressed challenge in modeling clustered data is how to deal with intracluster (particularly temporal) dependence and its effects on statistical inference, and a host of

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approaches have been proposed for dealing with such dependence.[1]

Here I consider a different but related concern in the use of clustered data. A common characteristic of clustered data is the presence of covariates which vary both within and between clusters. One prominent example is in data on international disputes, where analysts often examine the influence of factors which vary over both time and space (for example, intradyadic trade levels) on the onset of interstate conflict. While it is not often recognized, standard regression models impose the restriction that both types of effects are equivalent in their influence on the response variable; that is, they ignore potential differences between the effects of within-cluster and between-cluster changes on the outcome of interest. Here, I outline the potential pitfalls of these standard approaches, and show how between- and within-cluster effects can be separated and estimated. I then illustrate a method for distinguishing between these effects in the context of a logistic regression, using dyadic data on international disputes, and show how separation of these effects can reveal interesting and important insights about political phenomena.

BETWEEN- AND WITHIN-CLUSTER COVARIATE EFFECTS: A BRIEF DISCUSSION[2]

Consider a model for clustered data, where i indexes the 1,...N distinct units of observation (the "cluster"; for example, the nation or dyad) and t indexes the 1,...T repeated observations on that unit.[3] Suppose we are interested in the effect of some variable X_{it} on the dependent variable Y_{it}, where both Y_{it} and X_{it} vary both between and within clusters. We can write this model in its most general form as:

$$Y_{it} = f(\alpha + \beta X_{it} + u_{it}) \qquad (1)$$

This specification encompasses a range of widely-used models for both discrete and continuous dependent variables (McCullagh and Nelder, 1989; Diggle et al., 1994). Implicit in this specification, however, is the assumption that the effect of the X_{it} on Y_{it} is the same within clusters as it is between them. To see why this is the case, note that we can rewrite (1) in the form:

$$Y_{it} = f[\alpha + \beta_B \overline{X}_i + \beta_W (X_{it} - \overline{X}_i) + u_{it}] \qquad (2)$$

where $\overline{X}_i = T_i^{-1}(\sum_{t=1}^{T_i} X_{it})$ is the within-cluster mean of X.[4] Here, β_B is an estimate of the "between" cluster effects; that is, the average difference in Y which corresponds to a one-unit difference in X across two or more different units of analysis. In contrast, the coefficient β_W measures the "within" cluster effects of X: the average effect of a one-unit change in X on Y *within a particular unit of an analysis* (Judge et al. 1985, Chapter 13). Estimation of β_B results in what is often referred to as the "between" estimator, and is equivalent to estimating the equation:

$$\overline{Y}_{it} = f(\alpha + \beta_B \overline{X}_i + \overline{u}_i) \quad (3)$$

where $\overline{Y}_i = T^{-1}(\sum_{t=1}^{T} Y_{it})$ and $\overline{u}_i$ is similarly defined. Such a specification, as the name suggests, captures only the effects of cross-cluster variation in X on Y. Similarly, estimation of β_W corresponds to the equation:

$$Y_{it} - \overline{Y}_i = f[\beta_W(X_{it} - \overline{X}_i) + (u_{it} - \overline{u}_i)] \quad (4)$$

This is equivalent to the common "fixed effects" estimator, which assumes a separate intercept for each cluster i.[5]

The relationship between the two estimates is illustrated graphically in Figure 1. Note that the estimator in (3) uses only information on the relationship between Y_{it} and X_{it} that varies between different units of observation; it effectively ignores over-time variation. Conversely, the estimator for β_W in (4) uses only information on the temporal covariance of Y_{it} and X_{it} occurring within each observational unit.

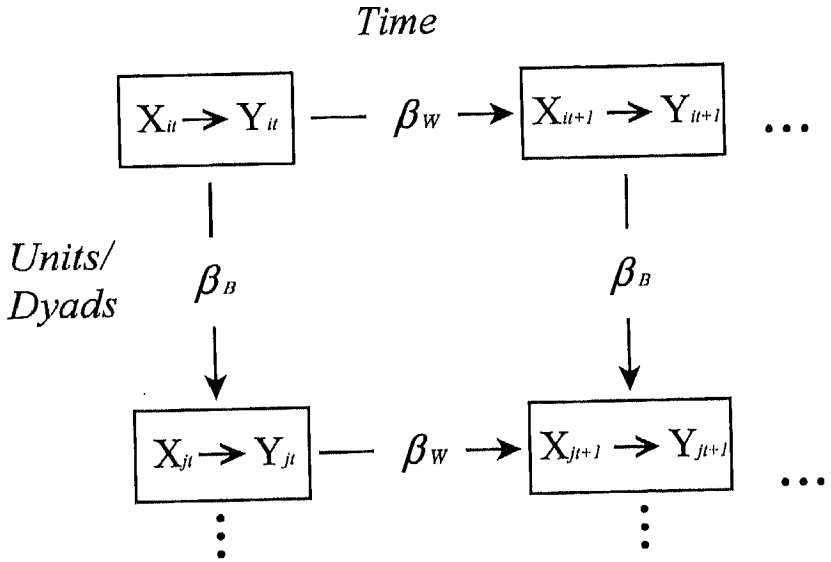

Figure 1. Schematic diagram of within- and between-cluster effects

A key aspect of this general model is that (2) reduces to (1) only when $\beta_B = \beta_W$. Substantively, this corresponds to the situation in which the effect of deviations from the within-cluster average of X have the same effect on Y as do equivalent deviations in the mean level of X observed across different clusters. If, by contrast, $\beta_B \neq \beta_W$, then estimation of (1) will yield estimates for β which are a weighted average of the between- and within-cluster effects for those variables which vary both within and across clusters.[6] The resulting "mixed" estimates will not, as a rule, yield accurate assessments of the effect of X on Y, particularly in instances where the between- and

within-cluster effects have opposing effects on the dependent variable.

The substantive significance of differentiating among between- and within-cluster covariate effects will, of course, depend on the question at hand. In many circumstances, however, one can imagine instances in which separating the two effects would be of some importance. Neuhaus and Kalbfleisch discuss the example of the influence of maternal age on infant birth weight, where the data consisted of a sample of 880 women, each with five children. Considering a model analogous to (2), they note that "the effect of the mother's average age is very different from the effect of the deviation of her age at each birth from her mean" (1998, p. 640). Similarly, an economist, in estimating a panel regression of consumption on income, might hypothesize that long-term differences in baseline income levels (i.e., differences in across individuals or families) may have a greater impact on consumption than equally-sized short-term deviations within a particular unit of observation.

In the context of international relations, we can note several instances in which our theories suggest that there will be differential effects of between-dyad and within-dyad variation in covariates, and where separating between- and within-unit influences may thus prove valuable. One such example involves recent quantitative work on alliance durations. A key explanatory variable in this work has been the domestic regimes of the alliance partners, with numerous scholars (e.g., Gaubatz, 1996; Bennett, 1997; Reed, 1997) suggesting that democratic states will build more durable alliances than their autocratic counterparts. Theoretically, these authors argue that "democratic states are able to make stronger commitments due to normative characteristics and/or domestic structures" (Reed, 1997, p. 1072); as a result, alliances among democratic states are hypothesized (and generally found) to be longer-lasting. Importantly, however, this theory suggests that the important differences vis-a-vis alliances will be *between* different kinds of alliances (here, those involving democratic versus autocratic governments) rather than differences *within* a particular alliance. Put differently, this theory would suggest that, all else equal, there will be a greater impact on alliance duration from a "one-unit" difference in democracy when that difference occurs across space (here, two different alliances) than across time (e.g., due to a change in any one alliance's member states' democracy scores).

A similar issue arises in studies of U.S. foreign aid. Societal theories of foreign policy decision making often suggest that, to the extent that such decisions are driven by domestic political and economic concerns, they are disproportionately influenced by the interests of business and industry (e.g., Rosen, 1974). One implication of such theories is that liberal democratic states with market economies ought to provide greater levels of aid to states which share their commitment to trade openness and free markets (Cigranelli and Pasquarello, 1985; Oye, 1992). Empirically, however, the relationship between trade and market openness and economic aid has been tentative at best (e.g., Meernik et al., 1998). One possible explanation for these countertheoretical findings lies in the potential for variables such as market openness and trade to have differing effects across nations than they do across time. In particular, one possibility is that the United States offers increased levels of aid to some nations as a form of "reward," perhaps in response to their opening up of markets. If this is the case, then the effect on aid of a change (increase) in any given nation's openness may be larger than the effect of the same sized difference across

two different nations in the same year. Put differently, a one-unit increase in nation A's trade openness from time t to time $t+1$ may have a greater (positive) impact on that nation's aid than will the same one-unit difference between nation A and nation B at a single point in time. Here I examine another such example: the effect of democracy and trade on international conflict.

AN EXAMPLE: DEMOCRACY, TRADE, AND INTERNATIONAL CONFLICT

The debate over the relationship among democracy, trade, and international conflict has occupied a preeminent position in recent quantitative work on international relations.[7] Classical liberal and neoliberal theorists generally assert that the potential for gains from trade will lead to a decreased tendency toward conflict among trading partners, and several recent studies appear to support this relationship (Oneal et al., 1996; Oneal and Russett, 1997, 1999a,b, 2001). Others have been critical of the trade-peace relationship, arguing that, for several potential reasons, higher trade may actually increase the probability of militarized conflict (e.g., Barbieri, 1996).

More agreement exists over the finding of a "democratic peace": as a rule, democracies are less conflictual, particularly with one another, than are more autocratic states (e.g., Bremer, 1993; Maoz and Russett, 1993). Beck et al.'s (1998) methodological critique of this literature finds that, after controlling for temporal dependence in the data, the democratic peace result remains intact, but calls into question the liberal connection between trade and peace (but see Oneal and Russett, 1999a). More recently, Green et al.'s (2001) fixed-effects analysis questions both trade and democracy as pacific influences on international behavior.

Throughout all these analyses, no distinction has been made between the effects of differences in trade and democracy levels across dyads and those differences within them (i.e., over time). Such distinctions may be important, particularly given recent work which calls into question the pacific influence of both trade and democratization. As noted above, failure to separate out between- and within-dyad effects can yield (single) coefficient estimates which are inaccurate representations of those effects. From the outset, however, we may have reason to believe that changes in these two variables will not exert the same influences within a given dyad as they do across dyads. This would occur, for example, if more democratic dyads were also generally more pacific, but if increases in the "democraticness" of a particular dyad did not yield the same corresponding decrease in conflict-proneness. This might occur, for example, if newly-democratized states tended to be more conflict prone, as a result of an initial tendency toward nationalism and its correspondingly more militaristic foreign policy (e.g., Mansfield and Snyder 1995; Snyder 2000).

I examine these potentially different effects through a reanalysis of the data used by Oneal and Russett (1997) and Beck et al. (1998). These data are composed of annual observations on 827 "politically relevant" dyads during the period from 1950 to 1985. Each dyad is observed once for each year it is in the data, for a total of 20,990 observations (an average of 25.4 years per dyad). All variables are operationalized as in Beck et al. (1998). Here, I focus on the relationship between trade, democracy, and international conflict, while also controlling for the effects of

economic growth, alliances, contiguity, and relative military capabilities, as well as adopting the Beck et al. approach of using peace-years and cubic splines to account for temporal dependence. After replicating the Beck et al. results, I estimate separate models for the between- and within-dyad effects of democracy and trade, and a fourth model which includes both kinds of effects.

Results of the four analyses are presented in Table 1. Column 1 reports the successful replication of the Beck et al. results. These results show significant pacifying effects of international alliances, military capability imbalances, and democracy, and a correspondingly greater risk of conflict for dyads in which the states are contiguous. Absent is a finding of any significant pacifying influence for the trade variable.

Table 1
Within- and Between-Dyad Effects of Democracy and Trade on International Disputes

Variable	Beck et al. Model	Between-Dyad	Within-Dyad	Full Model
(Constant)	-0.966	-0.957	-0.645	-0.949
	(0.181)	(0.198)	(0.199)	(0.199)
Economic Growth	-1.155	-0.716	-1.696	-0.628
	(1.168)	(1.170)	(1.196)	(1.176)
Alliance	-0.470	-0.438	-0.568	-0.440
	(0.177)	(0.177)	(0.173)	(0.177)
Contiguous	0.694	0.751	0.714	0.750
	(0.183)	(0.189)	(0.174)	(0.188)
Capability Ratio	-0.304	-0.318	-0.305	-0.316
	(0.109)	(0.113)	(0.109)	(0.113)
Democracy (level)	-0.546	...	...	...
	(0.136)			
Trade (level)	-12.884	...	...	...
	(14.152)			
Mean Democracy	...	-0.559	...	-0.556
		(0.185)	...	(0.185)
Mean Trade	...	-59.447	...	-52.858
		(28.772)	...	(28.054)
Democracy-(Mean Democracy)	...	...	-0.176	-0.132
			(0.150)	(0.154)
Trade-(Mean Trade)	...	...	46.620	57.399
			(8.890)	(28.854)
*l*nL	-2582.88	-2568.91	-2606.27	-2563.64

Note. N = 20990. Table entries are logit estimates; robust standard errors are in parentheses. All models also include a variable for the number of peace years, as well as three cubic splines for time, which are not reported here; see Beck et. al. (1998) for details.

Column 2 shows the results for a model which includes only the between-dyad effects of trade and democracy; i.e., in which each variable is replaced with its intra-dyad mean. In general, these results are consistent with those in column 1. The exception is the effect of the trade variable: here, we find that differences in trade levels across dyads exert a significant, negative effect on the probability of conflict. This indicates that, as a rule, dyads which have overall higher levels of trade are less likely to engage in conflict than are those whose trade levels tend to be lower. Excluded from this analysis, however, and of potential interest to scholars of international security, is the effect of changes *within* dyads: specifically, whether increases in trade between two specific nations corresponds to decreases in dispute levels.

This question is answered in the results in column 3. In contrast to the previous findings, results for the model incorporating only the within-dyad variability of democracy and trade lead us to strikingly different substantive conclusions. Deviations from dyadic-mean trade levels exhibit a positive effect on the likelihood of an armed dispute; positive (negative) deviations from average within-dyad trade levels increase (decrease) the probability of conflict between the states in question. The findings for the democracy variable also differ from those of Beck et al.: intradyadic variation in democracy levels exerts a statistically insignificant (and substantively small) effect on the probability of a dispute.

But while the between- and within-dyad models are informative, they are merely illustrations, as each is underspecified without the inclusion of the other.[8] Results for the full model are presented in column 4 of Table 1, and yield a number of interesting findings. Statistically, we note that the full model provides the best fit to the data: a likelihood-ratio test rejects the null of no differences between the full model and the two alternatives (chi-square(2)=10.54 and 85.26 for the between- and within-dyad models, respectively, both $p < .01$). Similarly, Wald tests for the equality of the coefficients lead us to reject the hypothesis that the between- and within-dyad effects of trade are equal (chi-square(1) = 5.31, p = .02); the same test for the two democracy coefficients yields a similar result, albeit one of lesser statistical significance (chi-square(1) = 2.9 1, $p = .09$).

Substantively, the results from columns 2 and 3 hold in the full model as well.[9] The findings generally support the liberal hypothesis that democracies are more pacific, but we find that the locus of that support is in the effects between dyads. That is, the results here support the proposition that "If dyad A is more democratic than dyad B, then dyad A is less likely to engage in conflict." Only very marginally supported, however, is the hypothesis that within-dyad increases in democracy levels lead to more peaceful behavior; dyads which are presently much more (less) democratic than their average are not significantly less (more) likely to engage in disputes. On one hand, these results are consistent with the work of Mansfield and Snyder (1995), in that they suggest that there is little or no pacific effect from democratization itself. The importance of this finding is somewhat limited, however, since the democracy levels in question represent the lower of the two Polity III democracy measures for the countries making up the dyad. Thus, at this time, all that can be said is that within-dyad change in the level of democracy for the less democratic member of the dyad is not associated with any significant shifts in the probability of conflict.

With respect to trade, we see that the between- and within-dyad effects of trade on

conflict run in opposite directions; this fact goes some way toward explaining the null findings of Beck et al. (1998) and others for the effect of this variable. In general, dyads which trade more are less likely to enter into conflicts than those which trade less, a finding again in support of the liberal hypothesis. At the same time, exceptionally high (low) levels of within-dyad trade are associated with an increased (decreased) probability of conflict. One useful way of conceptualizing this difference is to consider the between-dyad term as setting the "baseline" probability of conflict for the dyad; high-trade dyads, generally, will have lower probabilities of conflict than their low-trade counterparts. Fluctuations around that baseline, however, operate in the opposite direction: higher-than-average trade corresponds to a greater likelihood of conflict breaking out between the nations in question.[10]

A substantive explanation for the differential between- and within-dyad effects of trade on international conflict merits further inquiry. One theory is that, while the liberal theorists are correct at a systemic, long-term level, their critics are closer to the truth in more individualized, short-term relations among nations. That is, higher average trade levels, and their associated greater levels of interdependence, lower the incentives to engage in conflict in general. In the short term, however, trade is also an indicator of political salience among nations: lower-than-average levels indicate little interaction between the two, while higher levels increase the potential for conflict. This latter effect may be due to more numerous points of contact (Barbieri, 1996), concern over relative gains from such atypically high trade levels (Grieco, 1990), or other factors. More important, in this context, is that separating the intra- and interdyadic effects of such factors as democracy and trade offers the potential for new insights into the study of international conflict.

CONCLUSION

The larger point of this paper is to make a case for separating and examining between- and within-unit effects when using dyadic (or any form of clustered) data. In addition to their impact on more conventional estimates of variable effects, differences in the magnitudes of such effects can have real and important substantive implications for the phenomena we study. Moreover, allowing the influence of between- and within-dyad influences to differ from one another, and estimating the relative sizes of such differences, is an easy step to take, and one which lends itself readily to formal tests for the significance of such differences. At a minimum, such tests ought to become part of a standard set of diagnostics undertaken whenever clustered or repeated-measures data are used. Moreover, in some cases, distinguishing between these kinds of influences can shed new light on the questions we seek to answer.

With respect to studies of international conflict, and international relations more generally, these findings illustrate the importance of maintaining a close correspondence between theoretical and empirical models of international phenomena. For a number of reasons, analysts have had reason to believe that variation over time within the context of bilateral international relationships may not have the same significance as those same differences writ large across the international system. Changes over time in regime types, alliance patterns, trade flows, and other key factors of international relations result in learning and adaptation by states (Reiter 1996), and

themselves require time to be fully accounted for by affected nations. To forcibly equate the influence of such changes to those disparities observed in a given cross-sectional "snapshot" of the world system is to ignore a fundamental difference between static differences between states and dynamic changes occurring within those states.

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NOTES

1. The literature is vast; see, generally, Diggle et al. (1994), Fahrmeir and Tutz (1995), Hsiao (1986), Liang and Zeger (1992), and Mátyás and Sevestre (1996). In political science, references include Stimson (1985), Beck and Katz (1995), and Zorn (2001).
2. This discussion follows that of Neuhaus and Kalbfleisch (1998), as applied to conditional (i.e., random-effects) models. Interestingly, their discussion makes no reference to similar issues addressed in the econometrics literature, e.g., Maddala (1971); Mundlak (1978); Hsaio (1986).
3. For notational convenience, I assume throughout that ; i.e., that the clusters are "balanced." This is not a critical assumption, since a similar logic applies when clusters are unbalanced as well.
4. Note that Equation (2) is a special case of a more general "multilevel" model; see, e.g., Western (1998) or, more generally, Goldstein (1995). Note as well that a similar decomposition could be undertaken for period-specific effects, if those were of greater substantive interest.
5. See, e.g., Green et al. (2001). By comparison, it can be shown that the widely-used random-effects approach is a variance-weighted average of the between and within estimators (e.g., Maddala, 1971; Judge et al., 1985, 523-524; Neuhaus and Kalbfleisch, 1998). This fact forms the basis for the commonly-used specification test of Hausman (1978).
6. By contrast, for covariates which vary only within clusters (e.g., systemic or time effects), (1) will yield consistent estimates of those effects. Note, however, that interpretation of these estimates can be "difficult" (Neuhaus and Kalbfleisch, 1998, pp. 641), particularly in the case of models in which the link function f is something other than the identity function (e.g., a logit link) (Neuhaus et al., 1991). More thorough discussions of differences between "cluster-specific" and "population-averaged" models can be found in Pendergast et al. (1996) and Hu et al. (1998).
7. Important recent studies include Beck et al. (1998), Beck and Katz (2001); Bennett and Stam (2000), Gleditsch and Ward (2000), Green et al. (2001), Gartzke (2000), Reed (2000) and Signorino (1999).
8. Note, however, that either model might be acceptable on its own if our substantive theory suggested that only between- or within-cluster effects ought to be present.
9. This ought not be too surprising since the "within" variables are, by construction, uncorrelated with both "between" variables.
10. Note that neither the democracy nor the trade findings are a result of the spurious effect of time; inclusion of a counter variable for year in the model leaves the substantive findings unaffected.

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APPENDIX: STATA™ COMMANDS FOR GENERATING BETWEEN- AND WITHIN-DYAD COVARIATES

The analyses presented in Table 1 can be estimated using any standard software for estimating logit regression models. The key component is the creation of variables which separate the between- and within-dyad variation for each covariate of interest. As noted above, between-dyad variation is captured in a variable which equals the within-dyad mean of that covariate, while within-dyad variation equals the difference between the value of the variable and this mean.

Here, I illustrate the creation of the variables used in the analysis in Table 1 using the widely-used Stata™ statistical software package. The intuition is simple: first, create a variable equal to the within-dyad mean of the covariate in question (here, MEANTRAD and MEANDEM). Second, generate a second variable equal to the difference between that covariate and its (dyad-specific) mean value (here, TRADEDIF and DEMDIFF). The Stata™ software allows for relatively easy creation of subject-specific means; procedures for other software will necessarily be somewhat different. Note that multicollinearity is not an issue; by construction, the within- and between-dyad variables are uncorrelated with one another.

```
. d
Contains data from D:\Research\IIpaper.dta
  obs:        20,990
 vars:            13
 size:     1,385,340   (95.7% of memory free)
```

1. dyadid	float	%9.0g	Dyad ID
2. year	int	%9.0g	Year
3. dispute	byte	%9.0g	O&R Militarized Dispute
4. allies	byte	%9.0g	allied dummy
5. contig	byte	%9.0g	contiguity dummy
6. grobkt	float	%9.0g	BKT GROWTH variable / 100
7. capbkt	float	%9.0g	BKT CAPRATIO variable / 100
8. dembkt	float	%9.0g	BKT DEM variable / 10
9. trade	float	%9.0g	dyadic trade
10. py	byte	%8.0g	# of years of peace (O&R)

(Table continued)

11. pys1	float	%9.0g	(py-k1) cubed
12. pys2	float	%9.0g	(py-k2) cubed
13. pys3	float	%9.0g	(py-k3) cubed

```
. * Generating between-dyad trade variable...
. egen meantrad = mean(trade), by(dyadid)
. * Generating within-dyad trade variable...
. gen tradedif = trade - meantrad
. * Generating between-dyad democracy variable...
. egen meandem = mean(dembkt), by(dyadid)
. * Generating within-dyad democracy variable...
. gen demdiff = dembkt - meandem
```

CONTRIBUTOR

Christopher Zorn is an Assistant Professor of Political Science at EmoryUniversity. His work focuses on political methodology, including duration models and methods for time-series cross-sectional data, and on national and international courts and judicial institutions. His articles have appeared in the *American Political Science Review, The American Journal of Political Science, Political Analysis,* and numerous other journals, and he is the author of two forthcoming books on the University of Michigan Press.