Nonproportional Hazards and Event History Analysis in International Relations

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Event history models have become a dominant method of analysis in the study of international relations. Conventional event history models, however, retain the assumption that the effects of the covariates remain proportional to each other throughout the duration of the subject's phase. Nonproportional hazard (NPH) models are used, which allow for the effects of covariates to vary over time. These models are then applied to three previously established data sets on the duration of postwar peace, civil wars, and alliances. Results show that NPH analysis is a useful method for testing new hypotheses, as well as removing possible sources of bias from existing analyses.

Keywords: *proportional hazards; Cox model; peace; civil wars; alliances*

The empirical study of international relations has benefited in recent years from the application of event history analysis, a technique that focuses on the effect of factors that determine the length of time until the occurrence of some event. Event history methods are ideally suited to studying timing and political change (Box-Steffensmeier and Jones 1997, 2003) and have been used to explore a wide range of topics in international relations, including the length of interstate and civil wars (Bennett and Stam 1996; Meek 2001; Balch-Lindsay and Enterline 2000; Goemans 2000; Regan 2002), the causes of conflict and wars (Raknerud and Hegre 1997; Werner 2000; Ireland and Gartner 2001), the duration of alliances (Gaubatz 1996; Bennett 1997; Reed 1997; Lai and Reiter 2000), the duration of enduring rivalries (Bennett 1996, 1998), the durability of peace after war's end (Werner 1999; Grieco 2001; Hartzell, Hoddie, and

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Rothchild 2001; Fortna 1998), whether peace promotes democracy (Reiter 2001), the effect of military defeat on leadership tenure (Bueno de Mesquita and Siverson 1995), the effectiveness of international peacekeeping and mediation (Diehl, Riefschneider, and Hensel 1996; Regan and Stam 2000), and the duration and effects of economic sanctions (Bolks and Al-Sowayel 2000; Allen 2000; Lektzian and Souva 2001).

Our goal is to outline and demonstrate a critical methodological refinement that improves the application of event history analysis to the study of international relations. Briefly, event history analysis conventionally retains what is called the proportional hazards (PH) assumption, that is, that the magnitudes of the effects of covariates on the duration of a state remain proportional across the life of the process. For theoretical reasons, however, we may expect the relative magnitude of an independent variable's influence to vary over the life of a process; that is, the covariate's effect may be weaker or stronger at the beginning of the state than it is later. Conventional event history techniques do not allow the effect of an independent variable to vary in this fashion.

Retaining the PH assumption presents the analyst with two problems. First, it precludes testing more subtle hypotheses about the effects of variables changing across time. Second, it may lead to false inferences about a variable's substantive and statistical significance. For example, the effect of a variable that has a statistically significant but changing influence across time may—using conventional techniques—be found to be statistically insignificant.

Here, we illustrate how to relax the PH assumption. Doing so is straightforward; any scholar skilled enough to employ event history analysis can also use the techniques we describe. In the next section, we provide a detailed description of the PH assumption in event history and the use of what we refer to here as "nonproportional hazards" (NPH) analysis. We then demonstrate how NPH can be applied to international relations research. Specifically, we reanalyze data from previously published scholarship on postwar peace, civil wars, and alliances to show how using NPH permits improved estimation and the testing of more refined hypotheses. We conclude by highlighting why NPH make sense substantively and emphasizing the methodological point that the assumption should be tested for all PH event history models.

EVENT HISTORY ANALYSIS AND (NON-) PROPORTIONALITY

Unlike cross-sectional models, in which the restriction of a single effect parameter to each covariate is (usually) relatively uncontroversial, the introduction of time into the event history context complicates matters both theoretically and empirically. The intuition behind the PH assumption lies in the idea of parameter stability over time: if the effect of a change in a particular covariate remains constant, regardless of when in the process that change occurs, then the proportionality requirement is met. More specifically, as the name implies, PH requires that the effect of a change in the independent variable is to shift the hazard of the event of interest by a factor of proportionality and that the size of the shift remains constant over time.

Through the use of tests for PH and by interacting the covariates with time, we can test whether the covariate effect changes over time; this, in turn, allows a more nuanced understanding of the process under study. In political science, one might

> expect that the effect of one or more predictor variables on the hazard rate increases or decreases over time. There may be a number of different explanations for such changes to occur, including learning effects, shifts in life-course position, maturational changes, and so on. (Teachman and Hayward 1993, 359)

In such circumstances, covariate effects on the hazard of failure are nonproportional: the influence of an independent variable may be great or smaller, or even change signs, depending on the amount of time that has elapsed for that observation.

The classic example of a nonconstant covariate effect is the phenomenon of accumulated resistance to drug therapies. Clinical trials often begin with randomization into treatment and placebo groups; clinicians then use duration models to assess whether the treatment in question influences the time until the onset or reoccurrence of a disease. If study participants develop a resistance to the treatment over time, as is occasionally the case, this will reduce the drug's effectiveness. Thus, although the therapy may have a large effect early in the treatment regime, that effect will decline over time, such that after months or years, there is little or no beneficial effect of the drug. Under these circumstances, it is clear that a researcher who estimates a single value for the influence of the treatment will likely be misled by those findings. In particular, the estimate obtained will be an average of the range of possible effects up until the time at which the analysis is conducted.

Figure 1 illustrates the pernicious effects of assuming proportionality in the face of changing covariate effects. The solid lines show that the effect of a dichotomous covariate X is to increase the hazard of the event. However, the influence of X also declines over time, as the large initial differences between $h(t)|X = 0$ and $h(t)|X = 1$ decrease to zero with the passage of time. The broken line shows that estimating a single coefficient for X will yield a predicted hazard that will be too low early in the process and too high later. In the statistics literature, a number of studies have documented the deleterious consequences of assuming constant effects in the face of nonproportionality (e.g., Kalbfleisch and Prentice 1980; Schemper 1992).

Because of the potential ill effects of assuming proportionality when covariate effects are, in fact, changing, we argue elsewhere (Box-Steffensmeier and Zorn 2001) that testing for nonproportionality should be a standard procedure for event history analysts.[1] Happily, both tests and remedies for nonproportionality are relatively easy to understand and implement using standard software packages. In particular, we recommend residual-based tests to determine whether nonproportional variable effects are present in the data. These tests are generally based on a particular class of covariate-specific residuals. The intuition behind such tests is that, if nonproportionality is pres-

1. The Cox model assumes proportional hazards, as do many parametric models, including the Weibull model and most others commonly used in political science applications.

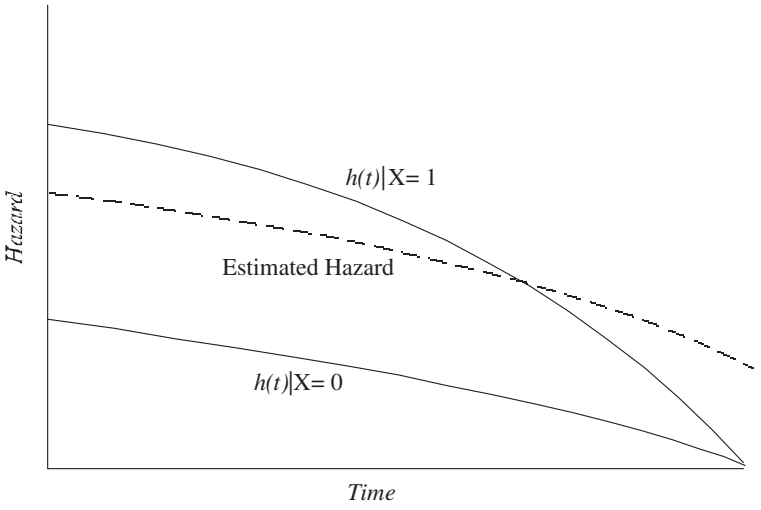

Figure 1: Proportional Hazards Estimation When Hazards are Nonproportional
NOTE: Smooth lines are actual (converging) hazards; dotted line indicates the estimated hazard for $X = 1$. See text for details.

ent, these residuals will vary significantly with time. Figure 1 demonstrates this. If we think of the distance between the actual $h(t)|X = 1$ and its estimated counterpart, we see that this quantity will be positive earlier in the process and grow more negative over time. This suggests that a test for nonproportionality is finding a residual that varies significantly with some function of time (e.g., Grambsch and Therneau 1994).[2] For example, one can look at the correlation (ρ) between the residuals from an event history model, specifically the scaled Schoenfeld residuals, and some function of time. Under proportionality, this correlation should not be statistically significantly different from zero; a finding of a statistically significant positive or negative ρ indicates that the residuals are trending over time and suggests nonproportional influence of that covariate. We illustrate the use of these tests in the section that follows.

In general, one should examine the global test for proportionality of the model; a violation is indicated by a statistically significant p value. In addition, however, one should also examine the covariate-specific tests to isolate the potentially offending covariates.[3] These covariates can then be specified to have nonproportional effects by including their interactions with time and examining the statistical significance of these interactions.

In many important respects, nonproportionality is little different from other instances in which covariate effects change depending on the value of some other variable. In such circumstances, researchers typically adopt multiplicative interaction terms to allow the effect of one independent variable to change according to the value

2. We omit the mathematical details of these residuals here; for a full discussion, see Box-Steffensmeier and Zorn (2001).

3. There is no consensus yet in the literature about the dominance of the global versus local tests or about whether one should take precedence over the other.

of another (e.g., Friedrich 1982). Seen in this light, time (i.e., process time—the duration that has elapsed in the state of interest) is no different from any other covariate and, in fact, may be treated as such. This suggests that we may simply interact the variable with (some function of) time and include that interaction term along with the other covariates in the model. Doing so allows the influence of a variable on the hazard to vary monotonically over time; that is, the variable's effect may increase or decrease over the duration under study. The covariate estimates can be interpreted in standard fashion for multiplicative interaction terms and often provide additional leverage on important theoretical and substantive questions.[4]

NPH AND THE STUDY OF INTERNATIONAL RELATIONS

As we discussed at the outset, event history analysis has already been fruitfully applied to a variety of areas within international relations, including studies of war, alliances, economic sanctions, and others.[5] Some have applied event history models as an approach to handling binary time-series cross-sectional data, thinking of event history as one appropriate means of reducing the bias of temporal autocorrelation with a binary dependent variable (Raknerud and Hegre 1997; Werner 2000; Lai and Reiter 2000). However, event history analysis is also sometimes the functional form that is most directly appropriate for testing the theory and phenomena at hand. Event history models were designed to exploring the duration of biological phenomena (e.g., Kalbfleisch and Prentice 1980; Collett 1994; Klein and Moeschberger 1997). Frequently in international relations, we are interested in analyzing the duration of political phenomena: how long wars last, how long political institutions survive, how international events affect the duration of a leader's tenure in office, and so forth. Using regression to analyze these kinds of questions and data is inferior, for example, in how it handles the problem of right censoring (a subject exiting the data set before the event of interest is observed) (Box-Steffensmeier and Jones 1997, 1415-17).

Most of this scholarship is principally interested in the question of which covariates affect the duration of some phenomenon and usually analyzes the influence of several covariates in a multivariate context, each of which may emerge from a different set of theoretical assumptions. Our general point is that in many of these studies, scholars may have theoretical justification for hypothesizing that the effects of covariates are nonproportional. Significantly, there may be methodological pitfalls from incorrectly

4. Time-varying covariates change values across the span of the observation period. The incorporation of time-varying covariates is one of the strengths of an event history model over the traditional regression model. Variable effects depend on whether the hazard ratio for two individuals with given covariate values alters over time. That is, whether "each individual's hazard function follows exactly the same pattern over time" (Box-Steffensmeier, Arnold, and Zorn 1997, 331). Golub (2002) and Golub and Collett (2002) distinguish time-varying covariates and time-dependent covariates and argue that greater reliance on Cox models that contain time-sensitive covariates will reduce bias, improve precision, and broaden the range of explanatory factors amenable to direct testing.

5. Unlike most other international relations event history scholarship, Grieco (2001) uses NPH analysis. See also Regan (2002) and Regan and Stam (2000).

assuming PH when they are not. As indicated above, these pitfalls include biased estimates, incorrect standard errors, and faulty inferences about the substantive impact of independent variables (e.g., Schemper 1992).

Under what conditions in the analysis of international relations phenomena might we expect nonproportional effects? At the most general level, nonproportionality obtains if the relative effects of the covariates change across time, usually meaning if we expect the effects of one or more variables to wax (perhaps experiencing positive feedback) or wane (perhaps experiencing negative feedback) as time passes. To take one prominent example, constructivism, which stresses the importance of intersubjective, social factors such as norms and identity, often postulates that norms and institutions may strengthen across time. Specifically, international institutions strengthen norms by serving as social environments within which actors are socialized and by actively promoting norms through policy advocacy and epistemic communities (Johnston 2001; Finnemore 1993). In this way, a recursive dynamic develops, with norms and institutions strengthening each other reflexively (Jepperson, Wendt, and Katzenstein 1996, esp. 53, 63). Functionalist approaches also argue that institutions are likely to strengthen across time, as successful cooperation expands from one field to another (Haas 1958). Hence, constructivism (and perhaps functionalism) might predict that the effects of an institution as an independent variable might grow across time, in relation to the relatively unchanging effects of other variables.

Similarly, many psychological theories postulate that certain kinds of conflictual or cooperative relationships might become more robust across time. A state with initially fragile cooperative relationships may, in the process of taking cooperative measures, bolster its own image as a cooperator in the eyes of the other state, in turn making it more willing to cooperate. This notion coincides with the older idea of security communities (Deutsch 1957). Conversely, nations with an initially conflictual relationship may, through hostile or defensive acts, convince the other side that it is a real enemy, thereby solidifying the state of conflict between the two (Jervis 1976). These theories suggest that ongoing conflict or cooperation will make the occurrence of conflict more or less likely as time passes.

A third category of theoretical expectations addresses the notion of memory. A variety of perspectives suggest that the memory of an event affects the likelihood of future occurrences of that event. Such effects will be likely to diminish across time for the simple reason that memory fades. As time passes, the percentage of the politically active population that has been affected by some particular event gets smaller because individuals too young to have been affected by this event reach political age, and some who were affected by the event age and die off. In American foreign policy, for example, the 1920s were dominated by World War I, the 1950s were dominated by World War II, and the 1970s were dominated by the Vietnam War. A number of studies have documented generational effects on foreign policy making (e.g., Jervis 1976; Reiter 1996; Khong 1992). At the same time, there may be other, nonmemory factors hypothesized to affect duration; the influences of these factors are unlikely to diminish across time.

POSTWAR PEACE DURATION

How robust is peace when war ends? What factors cause peace to break down, leading to the re-eruption of war? In a recent study, Werner (1999) (see also Fortna 1998) explored these questions using a parametric PH model. Examining what factors hasten the reoccurrence of interstate wars between dyads, she found that changes in the postwar military balance in a dyad, higher casualties during the war, and the imposition of a regime change on the defeated power were all statistically associated with the faster breakdown of postwar peace in a dyad.

The Werner (1999) study lends itself well to exploring the possibility that memory effects introduce nonproportionality. For example, Werner proposed that the intensity of the war should affect the length of postwar peace. Specifically, she argued for the possibility of a war-weariness effect because belligerents would be less willing to take up arms soon after a more bloody conflict than after a less bloody one. She used two proxies for conflict intensity: logged casualties and a dummy variable for whether the war was multilateral. However, Werner's theory suggests that the passage of time after the end of war might diminish this memory effect: as members of society come to forget the costs of the last war, they may become more willing to fight the next. For example, Linderman (1974) proposed that by the late 1890s, the horrors of the Civil War had receded from national memory, setting the stage for the Spanish-American War. Hence,

> *Peace hypothesis 1 (nonproportional).* The effect of war intensity on the failure of postwar peace should diminish across time.

A second memory-related covariate is whether the war ended in an imposed settlement. Werner (1999) argues that ending the war in an imposed settlement increases the chances of war re-erupting because it may sow the seeds for a war of revenge; perhaps the most famous example is that of Versailles leading to the outbreak of World War II in Europe. Using a PH model, Werner found that the presence of an imposed settlement did not have a statistically significant effect on peace duration. It is possible, however, that the real effect is nonproportional: an imposed settlement makes the reoccurrence of war more likely immediately after the war; but as time passes and memory fades, its impact may wane as the defeated power comes to accept the status quo. Relatedly, constructivist theories suggest that imposed settlement institutions become more accepted as time passes because the settlement comes to be seen as the recognized status quo rather than as a hated imposition. Thus.

> *Peace hypothesis 2 (nonproportional).* An imposed settlement will make the failure of peace more likely, but this effect will diminish across time.

Table 1 provides residual-based diagnostics for the possibility of nonproportionality among the covariates in Werner's (1999) data. The global test provides strong evidence that there is nonproportionality in the model. Covariate-specific tests show that five variables demonstrate potential violations of the assumption of PH. Specifically,

TABLE 1
Nonproportional Hazard Diagnostics
for Duration of Postwar Peace, 1816 to 1992

Variable	ρ	*Chi-Square*	p *Value*
Imposed settlement	–0.153	2.5	.11
Mediator	0.190	3.5	.06
Territorial issue	–0.282	5.84	.02
Stalemate	–0.266	8.79	.003
Victor-imposed regime change	0.009	0.01	.92
Guarantor	–0.019	0.03	.86
Peace treaty	0.002	< 0.01	.99
Change in relative power	0.245	1.90	.17
Constitutional leadership change	0.005	< 0.01	.97
Nonconstitutional leadership change	0.068	0.53	.47
Multilateral war	0.250	7.04	.008
Casualties (logged)	0.005	< 0.01	.97
Global test	—	23.46	.02

NOTE: Data from Werner (1999). Chi-square statistics have one degree of freedom, except for global test (12 *df*). The robust (White 1980) variance-covariance matrix was used.

mediator, territorial issue, stalemate, and multilateral war all appear to be nonproportional at approximately the .05 level and imposed settlement at close to the .10 level. These findings offer mixed support for the peace hypothesis 1, relating to war intensity. The proportionality of the casualties variable, one proxy variable for war intensity, provides evidence against this hypothesis—specifically, that the effect of war casualties on the likelihood of peace breaking down does not change across time after wars end. However, the effect of "multilateral," another proxy for war intensity, does appear to be nonproportional, which can be taken as evidence in favor of this hypothesis. The moderate statistical significance of "imposed settlement" suggests closer examination of this variable as well.

Table 2 contains our NPH analysis of these variables. Column 1 reports the Weibull PH analysis adopted by Werner (1999). In column 2, we add one new variable, "duration of war" (measured in months using Correlates of War data), as a third measure of the general proposition that more intense wars are followed by longer periods of peace. Like "logged casualties," it is statistically significant and in the predicted direction; longer wars are followed by longer periods of peace. We then reestimate the basic model of column 1, using the Cox PH model, in column 3.[6] Columns 4 and 5 include

6. We prefer the Cox model to parametric models due to its less restrictive assumptions. Using a parametric model requires testing for the appropriateness of that chosen distribution. In this example, the results of the Weibull and Cox model are very similar. Parametric models are not as widely used outside the social sciences as is the Cox model; as a result, tests and remedies for nonproportionality in the parametric context are largely nonexistent. Thus, we estimate the Cox model to relax the parametric assumption of the Weibull model and to move toward employing our arsenal of tests for the PH assumption. See Box-Steffensmeier and Zorn (2001) for elaboration. In addition, because most political scientists are interested in the connection between the dependent variable and the covariates, we argue that duration dependency should generally be

TABLE 2
Event History Analysis of the Determinants of Postwar Peace Duration, 1816 to 1992

Variable	*Weibull Model*	*Alternate Weibull Model*	*Cox Model*	*Cox Model,* $\ln\sqrt{T}$ *Interactions*	*Cox Model,* $\sqrt{T}$ *Interactions*
Imposed settlement	–0.560	–0.512	–0.466	4.85*	1.31
	(0.448)	(0.412)	(0.451)	(2.39)	(0.922)
Mediator	0.215	–0.038	0.237	–1.47	–0.417
	(0.336)	(0.370)	(0.341)	(1.13)	(0.713)
Territorial issue	0.220	0.226	0.240	7.79*	3.78**
	(0.307)	(0.306)	(0.303)	(3.26)	(1.27)
Stalemate	–0.980	–0.885	–0.939	7.76**	2.67**
	(0.619)	(0.608)	(0.608)	(2.65)	(1.03)
Victor-imposed regime change	–2.46**	–2.43*	–2.50**	–2.28*	–2.37*
	(1.06)	(1.07)	(1.07)	(1.05)	(1.06)
Guarantor	0.764*	0.763*	0.828*	0.537	0.630
	(0.423)	(0.385)	(0.422)	(0.461)	(0.476)
Peace treaty	0.375	0.436	0.396	0.478	0.400
	(0.336)	(0.334)	(0.331)	(0.351)	(0.346)
Change in relative power	1.56***	1.51***	1.40***	1.43**	1.43***
	(0.353)	(0.350)	(0.410)	(0.484)	(0.470)
Constitutional leadership change	–0.241	–0.211	–0.237	–0.264	–0.264
	(0.282)	(0.282)	(0.281)	(0.280)	(0.286)
Nonconstitutional leadership change	0.127	0.164	0.181	0.430	0.384
	(0.482)	(0.478)	(0.491)	(0.501)	(0.493)
Multilateral war	–0.275	–0.229	–0.357	–1.11	–0.870
	(0.346)	(0.323)	(0.338)	(1.16)	(0.748)
Casualties (logged)	–0.109***	–0.063*	–0.0996***	–0.0892***	–0.0859***
	(0.027)	(0.031)	(0.027)	(0.0268)	(0.027)
War duration	—	0.021*	—	—	—
		(0.012)			
p	0.711***	0.711***	—	—	—
	(0.081)	(0.079)			
Imposed Settlement × Time	—	—	—	–1.02**	–0.114*
				(0.418)	(0.0471)
Mediator × Time	—	—	—	0.408	0.0725
				(0.237)	(0.0489)
Stalemate × Time	—	—	—	–1.84***	–0.312***
				(0.519)	(0.0869)
Multilateral × Time	—	—	—	0.137	0.0307
				(0.221)	(0.0471)
Territory × Time	—	—	—	–1.54**	-0.278**
				(0.621)	(0.0890)
Log likelihood	–170.183	–168.195	–243.638	–221.811	–226.418

NOTE: $N = 10{,}381$. Data are from Werner (1999). Standard errors are in parentheses.
*$p < .05$. **$p < .01$. ***$p < .001$. All significance tests are one-tailed except for imposed settlement, stalemate, and the interaction terms. Results from model 1 differ slightly from those reported in Werner (1999, 925), probably due to rounding in data transfers. Also, guarantor is reported as not statistically significant in Werner (1999, 925), which appears to be a typographical error.

the interaction terms with five variables, thus allowing for nonproportionality in those covariates' effects.[7]

Both "multilateral" and its interaction term remain statistically insignificant, which increases our confidence in rejecting peace hypothesis 2. However, higher "logged casualties" still makes the breakdown of peace less likely; yet, the magnitude of the effect remains proportional across time, thus not offering support for peace hypothesis 2. The consistency of this effect across time may indicate that intense wars reveal more information about capabilities to the combatants (thus making the postwar peace more stable in a more consistent fashion) rather than making societies weary of war, the latter being an effect likely to diminish with time. This pattern is consistent with some bargaining models of war (Smith and Stam 2001). We also note that the variable for "guarantor" is no longer statistically significant.

Interestingly, both "stalemate" and its interaction term are statistically significant, providing support to peace hypothesis 2. This is notable because its estimate is statistically insignificant in the PH models (columns 1 and 2). The positive sign of this coefficient indicates that peace is more likely to break down following stalemated rather than nonstalemated outcomes, but the interaction term indicates that this effect diminishes across time. We illustrate this effect in Figure 2, which plots the change in the estimated hazard[8] associated with a conflict being stalemated. For the model that assumes PH, the negative coefficient yields a net decrease in the hazard of war re-eruption; conflicts that end in stalemates are only 39% as likely to lead to war as others are. In the nonproportional model, however, we see that this effect, in fact, varies significantly over time. Shortly after the end of a stalemate, the hazards for re-eruption of war are substantially higher than for other conflicts; 1 year after the beginning of the peace, settlements following stalemates are more than 20 times as likely to break down as others are. This offers support for past speculation that a military stalemate will leave both belligerents unsatisfied and especially likely to renew hostilities (Blainey 1988; Hensel 1994). Over time, however, this difference decreases, eventually even becoming negative. Thus, a peace that follows a stalemate and has managed to last a full 30 years thereafter is only 5% as likely to re-erupt into war as phases of peace following wars ending in outcomes other than stalemates. This suggests that, as a nation's collective memory of the unsatisfactory outcome fades, such settlements become increasingly like other conflicts in their propensity to re-erupt.

Both the territorial issue variable and its associated interaction are also statistically significant, a deviation from the conclusions using a proportional model. This sup-

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treated as a nuisance and that methods such as the Cox model or its variants with a flexible baseline hazard should be used. These models do not parameterize time dependency. Findings about duration dependency are sensitive to model specification. That is, if one changes the specification, often just slightly, different conclusions about positive, negative, or no duration dependency are drawn.

7. Time is not included as a covariate when it is interacted with other covariates in the Cox model. The purpose of interacting the covariate with time is to relax the assumption that the hazard ratios (i.e., the conditional relative risks across substrata) are proportional to each other across time. Because the dependent variable is time until an event occurs, if one included time as a covariate, one would be explaining time until an event occurs with a time counter.

8. This change is defined as $[exp(\beta) - 1] \times 100$. We use the results of the nonproportional model with $ln(T)$ interactions; the results are substantively identical if the results in column 5 are used instead.

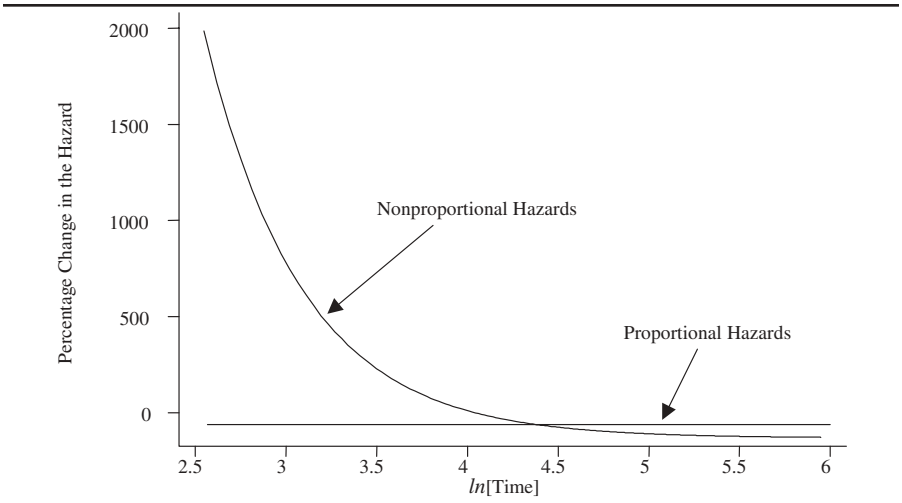

Figure 2: Percentage Change in the Estimated Hazard for the Stalemate Variable, Proportional and Nonproportional Models

NOTE: The figure plots the change in the estimated hazard for the stalemate variable in the proportional and nonproportional models. See text for details.

ports the general claim that territorial disputes are especially likely to encourage conflict, and peace following wars over territory is less stable then peace following wars over other issues (e.g., Huth 1996). This result also parallels the finding elsewhere that mediation is especially unlikely to be successful in preventing war in enduring rivalries over territory (Diehl and Goertz 2000, 212). However, the negative coefficient on the interaction term indicates that, although wars over territory are more likely to reerupt into war, this effect diminishes across time. One constructivist explanation might be that as time passes, an international border (even one created through war) gains more acceptance and becomes less likely to be challenged because the practice of recognizing the de facto physical existence of a border slowly provides it with accepted meaning and legitimacy.

"Imposed settlement" and its interaction are also statistically significant, again in contrast to findings of the PH models. This indicates that peace following a war concluded by a victor-imposed peace settlement will break down faster than peace following other kinds of wars. This offers support for a "revenge" effect, by which a humiliating settlement imposed on a loser (such as Germany in 1918) will sow the seeds of renewed war. Interestingly, the negative sign on the interaction term indicates that this effect diminishes across time. This may indicate a degree of memory decay; generations that experienced the war may be likely to seek revenge, but as they are replaced by individuals with less direct experience or knowledge of the defeat, a war of revenge becomes less likely. It may also offer support to constructivist speculation that the passage of time offers legitimacy to the status quo.

The mediator result is a bit more complex to interpret. The estimate itself is negative but statistically insignificant at the .05 level using a one-tailed test (although statisti-

cally significant at the .10 level), as it was in the proportional models. However, the interaction term is positive and statistically significant using a one-tailed test. This provides weak evidence that the presence of a mediator can reduce the chances of peace breaking out into war but that this effect diminishes across time. Again, initial conditions, although influential at the outset of a peace, are seen to decay in influence over time.

Our analysis in column 4 of Table 2 used interactions of the variables identified by the PH testing in Table 1 multiplied by the natural logarithm of the duration of peace (measured in months). Although using the log of time is convention (e.g., Collett 1994), there is no mathematical or theoretical reason for this particular function of time to be preferred. One might, for example, take the square root or some other function of time for the interaction terms. In this example, using the square root allows more variability among higher values of the time variable than the log transformation does.

In column 5, we estimate the model with time interactions that employ square root transformations rather than the log transformation. Although the results are generally quite similar to those in column 3, there are a few differences. For example, *imposed settlement* is no longer statistically significant, although the interaction term remains so. The sensitivity of these results to specification of the temporal transformation leads to two conclusions. First, the choice of a temporal transformation may make a difference. Optimally, the analyst should choose the one most closely fitting his or her theory; however, without grounds for such a theoretical preference, the analyst may wish to try differing transformations as a test of robustness. Second, these findings demonstrate the potential importance of choosing the temporal unit. In this study, Werner (1999) chose months, but she could just as easily have chosen days, weeks, or years. Had she chosen years, differences between the temporal transformations would have been reduced because the differences between logarithms and square root transformations grow as the numbers get bigger. The opposite is true for smaller units: the differences between the transformations would have been bigger had she instead chosen days or weeks.

In sum, NPH has sharpened our understanding of the factors that determine the duration of peace following interstate war. We are more confident in some of Werner's (1999) core results, namely, that changes in relative power balances make it more likely that peace will break down and that signing treaties to end wars does not make peace more durable. However, NPH did provide some important differences in results, specifically that an imposed settlement may hasten the breakdown of peace to war, although with diminishing effects as time after war elapses; that peace following wars over territory or stalemated wars is likely to break down more quickly, although also with diminishing effects; and that the presence of a guarantor may not, in fact, hasten the breakdown of peace.

CIVIL WARS

Dylan Balch-Lindsay and Andrew Enterline (2000) explored the determinants of the duration of civil wars. They used a Cox model to examine all civil wars since 1820,

finding that costly civil wars are shorter, separatist civil wars last longer, intervention of all kinds (including intervention favoring the government, intervention favoring the opposition, and balanced intervention) prolongs rather than shortens civil wars, and geographic size, government strength, and political system age do not have a statistically significantly relationship to duration.[9] Their study uses time-varying covariates, meaning that it allows for the values of the independent variables to change across time within the span of a single subject.

In this context, NPH analysis can help us explore the intervention result. Other research has found that intervention can help end civil wars (Walter 2002; Regan 1999). One possibility is that timing crucially affects the likely success of intervention. Some might argue that earlier intervention, before violence has reinforced the enmity on both sides, might be more likely to succeed (on violence hardening identities, for example, see Kaufman 1996). Conversely, others might argue that intervention is more likely to work after a civil war has raged for several years, putting the combatants closer to a "hurting stalemate" (Zartman 1989) and hence more willing to accept outside peacekeepers. In either case, we might expect the following:

> *Civil war hypothesis 1 (nonproportional).* The effects of balanced, government, and opposition intervention on civil war duration will not be proportional over time.

We again begin with a diagnostic analysis, based on the Schoenfeld residuals; these results are provided in Table 3. The global diagnostic indicates that we cannot reject the null hypothesis that there is proportionality in the model. However, we find no evidence of nonproportionality for the intervention variables, encouraging the rejection of civil war hypothesis 1. On the other hand, we do find that nonproportionality is indicated for some other variables and that we can reject the hypothesis of proportional effects for the geographic size variable at the .05 level and that for the costs and local civil wars variables at the .10 level. Unfortunately, there are no clear guidelines about the use of global versus local residual tests for NPH. Accordingly, results suggesting variable-specific nonproportionality should not be ignored in the face of a residual indicating global proportionality. Given the conflicting evidence about potential NPH, we proceed with the NPH analysis. Table 4 presents the Cox model with time interactions for the three variables in question.

Column 1 of Table 4 lists the results reported in Balch-Lindsay and Enterline (2000, 630). In column 2, we provide the results of the NPH analysis, in which we include log-time interactions for the three potentially nonproportional variables. The results are quite striking. Aside from the three nonproportional variables themselves, the government strength variable is now negative and statistically significant, meaning that civil wars are shorter in nations with stronger governments. Whereas its effects are both small and statistically insignificant in the PH model, both the geographic size variable and its interaction are statistically significant in the NPH model. The combination of the positive coefficient for the direct effect with the negative coefficient for the interaction indicates that increases in geographic size initially make civil war termination

9. Balch-Lindsay and Enterline (2000) also report results when outliers are removed. We restrict our analysis to the full data set.

TABLE 3
Nonproportional Hazard Diagnostics
for Duration of Civil Wars, 1820 to 1992

Variable	ρ	*Chi-Square*	p *Value*
Prior political grievance	0.055	0.55	.46
Geographic size	0.173	4.24	.039
Political system age	–0.115	2.54	.11
Frequency of neighboring states	–0.102	1.75	.19
Proximity to major power	0.106	1.57	.21
Separatist	–0.011	0.02	.88
Government strength	0.069	0.67	.42
Civil war costs	0.149	2.94	.09
Intervention (opposition)	–0.001	< 0.01	.99
Intervention (governmental)	–0.116	1.71	.19
Balanced intervention	0.065	0.67	.41
Target of militarized dispute	–0.021	0.07	.79
Local civil war	0.137	3.37	.07
Local militarized interstate conflict	0.020	0.07	.79
Global test	—	13.98	.45

NOTE: Data are from Balch-Lindsay and Enterline (2000). All chi-square statistics have 1 degree of freedom, except for Global Test (14 *df*). The robust (White 1980) variance-covariance matrix was used.

more likely, but the effect diminishes as the civil war endures. Similarly, the estimate for the costs variable is positive and statistically significant, as it was in the proportional analysis, with its log-time interaction also positive and statistically significant. This shows that not only do higher costs make termination more likely at the outset but also that the effect increases as time passes. This finding thus confirms much speculation about civil wars: war weariness is a particular trait of such conflicts, and a population's tolerance for costs under such circumstances declines over time.[10]

Finally, the estimate for the direct effect of the local civil war variable is positive and statistically significant, in contrast to the proportional analysis in which it was negative and statistically significant. This illustrates how PH models can mislead when hazards are actually nonproportional. The interaction term is statistically significantly negative and quite large, indicating that the positive effect diminishes rapidly over time; the effective coefficient for this variable is zero after approximately 160 days and negative thereafter. This marks a period far shorter than most of the civil wars in the data, with the result that, absent an accounting for temporal variation, the analyst runs the risk of making incorrect inferences about the variable's influence.[11]

10. Another possible explanation as to why higher costs hasten civil war duration is that higher costs reflect more intense fighting, which, in turn, means the faster revelation of more information to the two sides about each other's true capabilities, thereby more rapidly creating bargaining space and permitting termination (Smith and Stam 2001).

11. In column 3, we explore the robustness of these findings by altering the time transformation, again using square root of time (measured in days) instead of the natural log of time. As with our analysis of the duration of peace, some of the results do change. Specifically, the geographic size variable returns to being statistically insignificant, although the interaction term remains statistically significant and negative. The costs interaction variable becomes statistically insignificant, whereas the local civil war variable and its interaction remain statistically significant and with the same signs.

TABLE 4
Event History Analysis of the Determinants of Civil War Duration, 1820 to 1992

Variable	*Cox Model*	*Cox Model,* lnT *Interactions*	*Cox Model,* T *Interactions*
Prior political grievance	1.53	–1.01	1.56
	(2.44)	(2.40)	(2.45)
Geographic size/1,000,000	–0.0042	0.730*	0.224
	(0.058)	(0.398)	(0.148)
Political system age	–0.0000046	0.000919	0.000788
	(.00292)	(0.00304)	(0.00303)
Frequency of neighboring states	0.0561	0.0222	0.0193
	(0.0408)	(0.0403)	(0.0418)
Proximity to major power/1,000	0.0445	0.0457	0.0466
	(0.0413)	(0.0436)	(0.0426)
Separatist	0.497*	–0.449*	–0.495*
	(0.237)	(0.229)	(0.231)
Government strength	–19.3	–25.0*	–22.5*
	(11.8)	(12.8)	(12.6)
Civil war costs	2.63***	1.58**	2.89***
	(0.501)	(0.668)	(0.779)
Intervention (opposition)	–0.185	–0.145	–0.121
	(0.246)	(0.247)	(0.251)
Intervention (government)	–0.779•	–0.823•	–0.838•
	(0.340)	(0.357)	(0.362)
Balanced intervention	–1.94	–1.79	–1.78
	(1.15)	(1.18)	(1.19)
Target of militarized dispute	0.736***	0.784***	0.752***
	(0.160)	(0.168)	(0.165)
Local civil war	–0.493*	1.74*	0.375
	(0.221)	(0.670)	(0.394)
Local militarized interstate conflict	0.165*	0.145*	0.146*
	(0.0828)	(0.0723)	(0.0756)
Costs × Time	—	1.03**	–0.100
		(0.437)	(0.375)
Geographic Size × Time	—	–0.122	–0.001
		(0.066)	(0.0006)
Local Civil War × Time	—	–0.343***	0.0276*
		(0.107)	(0.0124)
Log likelihood	–519.727	–512.748	–515.148

NOTE: $N = 449$. Data are from Balch-Lindsay and Enterline (2000). Cell entries are coefficient estimates; robust standard errors are in parentheses. See text for details.

In sum, our NPH analysis provides striking differences in results from previous studies of civil war durations, although with the caveat that some of these differences were not robust across different operationalizations of the time interaction. Two variables (geographic size and local civil war) changed in sign and statistical significance. Two variables (costs and local civil war) had statistically significant interaction terms,

meaning that the substantive effects changed across time in relation to other variables. Finally, a fourth variable (government strength), which did not exhibit proportionality, became statistically significant when nonproportionality in other variables was accounted for.

ALLIANCE DURATION

What factors cause alliances to endure? This question has received the attention of a number of published empirical studies (Gaubatz 1996; Reed 1997; Bennett 1997; Zorn 2000). In this section, we apply NPH analysis to Bennett's (1997) data to test a new twist on the conventional proposition that democratic alliances endure longer.

Bennett (1997) examined the Correlates of War data on all interstate alliances from 1816 to 1984. Using a PH Weibull model, he found alliance duration to be statistically significantly associated with an array of factors, including the end of war, number of alliance members, and changes in the security environment and capabilities of the alliance members. He also found that alliances made up of democracies endure longer than other kinds of alliances, confirming an earlier study (Gaubatz 1996; see also Reed 1997).

This last finding deserves closer examination. Should the effects of democracy on alliance vary over time? Different theories offer different answers to this question. Gaubatz (1996) develops an explanation as to why democratic alliances should last longer, based on democratic institutional form. Specifically, he argues that democratic foreign policy (and hence democratic alliance choices) should generally be stable across time because of stability in both leadership and public preferences. Furthermore, the rule of law and economic interdependence ought to make democracies less inclined to break alliances. Finally, the separation of powers and political transparency of democracies make democracies less likely to break their commitments in general. Critically, note that these arguments together present a proportionality hypothesis: that the effects of democracy do not change across time because they emerge from essential aspects of democratic systems.

> *Alliance hypothesis 1 (proportionality).* The effects of democracy on alliance duration should not vary across time.

There is an alternative basis of theoretical support for this claim, albeit one that Gaubatz (1996), Bennett (1997), and Reed (1997) left unconsidered. Constructivist theories argue that states may generate collective identities so that within such groups conflict is reduced, cooperation is increased, and states begin to identify with each other's interests (Wendt 1999). As far back as Karl Deutsch's (1957) discussion of security communities, liberal democracies have long been identified by constructivists as especially likely to form such groupings.

An important prediction of such theories is that action can help create and form identities. Specifically, the formation of international institutions can help create mutual identity through the continual identification with other alliance members, creation of institutional rules and forms that reinforce identity, and so forth. Democratic

TABLE 5
Nonproportional Hazard Diagnostics
for the Duration of Alliances, 1816 to 1984

Variable	ρ	*Chi-Square*	p *Value*
Change in security	–0.025	0.05	0.83
Alliance security improvement	0.115	0.83	0.36
Mutual threat	0.093	2.39	0.12
Capability change	–0.077	0.85	0.36
Symmetry	–0.144	2.21	0.14
Capability concentration	–0.105	1.26	0.26
Democracy (liberal)	0.063	0.44	0.51
Polity change	0.062	0.48	0.49
Number of states	–0.064	0.42	0.52
Wartime	–0.067	1.03	0.31
War termination	0.076	0.91	0.34
Global test	—	7.97	0.72

NOTE: Data from Bennett (1997). Chi-square statistics have 1 degree of freedom for all variables, except for the global test (11 *df*). Robust (White 1980) variance-covariance matrix used.

allies are especially likely to experience this strengthening of corporate identity because democracies are more likely to recognize each others' common liberal values (Owen 1997). Kahl (1999) makes this point explicitly:

> Positive identification between liberal democracies will be fostered by the extent to which structural capacities (spatial relations, physical and technological capacities, and institutional practices) enable or privilege patterns of interaction with other liberal democracies, and/or the extent to which structural constraints "commit" states to take on such identities. (P. 116)

For example, NATO strengthened across time as processes of social interaction within the institution strengthened the sense of community (Risse-Kappen 1996, 371).

Constructivism, then, posits that alliances with democracies ought to strengthen across time. This implies the following:

> *Alliance hypothesis 2 (nonproportionality).* The effect of democracy on alliance duration ought to increase with the age of the alliance.

We begin by assessing whether there is nonproportionality in Bennett's (1997) data. Table 5 presents the results of the residual-based tests outlined in the previous section.[12] Table 5 indicates that we cannot reject the null hypothesis that there is proportionality among all the covariates across time, including that for democracy.

12. The statistical tests are easy to run in popular statistical packages, such as Stata and S-Plus. Specifically, the -stphtest- command will generate the global and Grambsch/Therneau covariate-specific tests in Stata.

Specifically, the *p* value of the global test is .72, indicating that overall the model does not violate the PH assumption. The covariate-specific values echo this conclusion. This provides support for alliance hypothesis 1 and against alliance hypothesis 2.

This null result has important theoretical consequences. It indicates that alliances among democracies do not strengthen across time in relation to other kinds of alliances, but rather the failure-resistance of democratic alliances across time is consistent across the life of the alliance. This is evidence against the constructivist speculation, favoring instead a more institutionalist explanation of democratic alliance and cooperation behavior (e.g., Leeds 1999) and democratic foreign policy in general (e.g., Reiter and Stam 2002).

CONCLUSION

Testing the assumption of PH when conducting event history analysis in the study of international relations is important for both substantive and methodological reasons. We have demonstrated that there are a number of theories that make nonproportional predictions, especially theories of institutions and norms, memory, and conflict and cooperation. We addressed several theories regarding the duration of alliances, peace following interstate war, and civil wars. Moreover, in addition to offering more nuanced theory testing, examining model assumptions is simply good statistical practice.

Our statistical analysis demonstrated the benefits of exploring the possibility of nonproportionality. In our examination of alliance duration, the absence of NPH for the democracy variable provided key evidence against a constructivist explanation for why democratic alliances endure longer and in favor of the institutionalist explanation. In our analysis of peace duration, we found that several variables that appear to be statistically insignificant in the proportional analysis become statistically significant in NPH analysis. In addition, we showed that that the magnitude of the effects of many important covariates in these models diminishes across time. Finally, in the analysis of civil war duration, we uncovered similar results; a variable that was statistically significant in the proportional analysis reversed its sign in the NPH analysis. Our work also highlights the importance of the time transformations used to address the NPH problem.

Event history analysis has proven to be a boon to analysis in international relations because it is ideally suited for analyzing questions of timing and political change. Scholars have been quick to employ increasingly advanced applications of event history analysis, adopting event history models with different parametric assumptions, employing time-varying covariates, using competing risk models, and so forth. Incorporating NPH analysis is a logical next step to be taken in the continuing growth and sophistication of such analyses.

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