Multilevel, Stratified, Frailty Models and the Onset of Civil War

Janet M. Box-Steffensmeier *
The Ohio State University
Department of Political Science
2140 Derby Hall, 154 N. Oval Mall
Columbus, OH 43210-1373

Suzanna De Boef
The Pennsylvania State University
Department of Political Science
219 Pond Laboratory
University Park, PA 16802

Kevin Sweeney
The Ohio State University
Department of Political Science
2140 Derby Hall, 154 N. Oval Mall
Columbus, OH 43210-1373

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*We thank Amber Boydstun, Kyle Joyce, and Justin Ronca for advice and suggestions. The authors can be reached at steffensmeier.2@osu.edu, sdeboef@psu.edu, and sweeney.101@osu.edu respectively. Authors are listed alphabetically.

1 Introduction

The past decade has seen an increase in the number of studies of civil conflict in the comparative politics and international relations literature. There are several reasons for this growth. First, according to standard data sets such as the Correlates of War Project's Civil War Data Set, civil wars are breaking out at an all-time record rate (David 1997, Sarkees & Singer 2003, 60). Such an increase, particularly when set against a relative decrease in the frequency of interstate war onsets, is bound to draw the attention of empirical scholars. Second, many of these recent conflicts have occurred in high profile areas, such as the former Yugoslavia and Soviet Union. Other conflicts have drawn the attention of international agencies, such as the World Bank (Collier & Sambanis 2002), because they are persistent and cause tremendous amounts of human suffering. Third, in the post-September 11th era, the foreign policy focus of the Western World, and in particular of the United States, has shifted from the Great Powers to failed states because they are among the last vestiges of authoritarian rule on the planet and are a main breeding ground for corruption, child prostitution, narco-trafficking, international terrorism and, potentially, weapons of mass destruction proliferation. This implies that the scholarly study of civil conflict, particularly in relation to political institutions, has significant policy relevance.

Because of our desire to generalize the causes of such conflict, it is unsurprising that many of these recent studies of civil conflict are quantitatively oriented (e.g. Auvinen 1997, Collier & Hoeffler 1998, Collier & Hoeffler 2002, Elbadawi & Sambanis 2002, Fearon & Laitin 2003, Fortna 2004, Henderson & Singer 2000, Hegre & Gleditsch 2001, Krain & Edson-Myers 1997, Reynal-Querol 2002). While we laud the progression of this literature, in this paper we caution against the robustness of current empirical results. We do so for two reasons. As we detail below, civil conflict is an extremely heterogeneous event with several causes that are measured inconsistently or unmeasured in the extant literature, and may well be immeasurable for quantitative studies. These covariates may exist both at the country and regional levels. Additionally, the occurrence of civil conflict in a state may affect the likelihood of additional, future conflict, creating event (or occurrence) dependence. Current analyses, we argue, do not adequately capture these theoretically and empirically important features of the process leading to civil conflict. Far from suggesting that scholars abandon the quantitative approach to civil conflict, in this paper we highlight statistical techniques that cope with possible heterogeneity and event dependence, apply them to the study of civil conflict, and offer a strategy for the analysis of repeated events processes that promises to produce more robust results in this important literature and more generally for phenomenon that may be affected by heterogeneity and/or event dependence. Specifically, we recommend a conditional frailty estimator which captures and tests for important features of the civil conflict process as we understand it. More generally, the estimator has desirable properties when heterogeneity and/or event dependence may underlie the processes we care about, allowing analysts to draw valid inferences about the timing and (re)occurrence of events.

In general, the price of omitting important features of political processes from the models we estimate is paid in biased and inefficient estimates, the nature and extent of which varies across contexts. In the study of civil conflict that price may be too high, both empirically and substantively. As civil conflict becomes a focus of policy concerns and as its consequences impinge on domestic politics and economics, the urgency with which we press our understanding of civil conflict and the factors that lead to or from conflict grows.

2 A dizzying array: the case for a new modeling strategy

The recent literature on civil conflict is incredibly diverse, with a dizzying array of covariates and modeling strategies that chip away at this complex problem. The diversity is both a strength and a weakness. The strength is that almost every article that enters the literature adds significantly to the existing body of work on this important topic. In some cases the contribution is to bring another set of valuable independent variables into focus, in others the contribution is to model civil wars in new ways to get at essential questions such as whether international peacekeepers successfully keep the peace after a civil war. The weakness is that the diversity highlights two important conceptual hurdles, unobserved heterogeneity and event dependence. The failure to clear these hurdles can have heavy implications for the extant statistical results.

2.1 Unobserved Heterogeneity in the Civil Conflict Literature

The case for unobserved heterogeneity in the quantitative civil conflict literature can be made in two distinct ways. First, one need not look far into the literature to see that the set of independent variables included in models with the same, or virtually the same, dependent variable is large and contains surprisingly little overlap. Four recent papers, selected because of their centrality to the literature, are an example of this phenomenon.[1]

In what is considered a foundational paper for the new quantitative civil conflict literature Collier and Hoeffler (1998) propose an economic theory of civil war in which, "the probability of civil war and its duration are a function of the gains from rebellion, made up of the probability of rebel victory and the gains from victory (state capture of secession), and the costs of rebellion, made up of the opportunity costs of conflict and the cost of coordination" (567). Proxies for these variables are drawn from four main categories: per capita income, natural resource endowment, population size, and ethno-linguistic fractionalization. The statistical results from the model are robust, with almost all of the covariates exceeding standard levels of statistical significance. A second effort to model the likelihood of civil war was put forth by Henderson and Singer (2000), who include economic, political, and cultural concepts in their theoretical formulation. They too achieve impressive statistical results. Henderson and Singer (2000) account for political elements (semi-democracy) and civil-military elements (military spending), which are excluded from the Collier and Hoeffler (1998) model. However, the Henderson and Singer (2000) treatment of the economic causes of civil war, measured only with energy consumption as a proxy for development, is substantially less well developed than Collier and Hoeffler (1998).

Hegre et al. (2001), which we cover in greater detail below, take the study of political institutions and their relationship to civil war onset to a new level accounting for not only regime type by also changes in regime type (small and large) toward and away from democracy. They also add a measure, a dummy variable for the presence of a civil war in a neighboring country, which points to a plausible regional dimension of civil conflict, diffusion, that went unmodeled in previous studies. They model the same cursory treatment of economic variables as Henderson and Singer (2000), but exclude the measure of military spending that Henderson and Singer argue is critical.

[1]We refer interested readers to the original papers for more detailed discussions of model specification, and note here that the literature on the onset of civil conflict offers an even greater diversity of conceptual and empirical focus than is captured in these four papers on the civil conflict literature.

Finally, Fearon and Laitin (2003) model the economic causes of civil war much like Collier and Hoeffler (1998), but do not account for changes in political institutions like Hegre et al. (2001), or military spending like Henderson and Singer (2000). Moreover, Fearon and Laitin (2003) add variables to the model that are missing from the other three studies to account for the geographic dimensions of insurgency (% Mountainous, and the presence of a territorial base separated from the states center by water or distance), and present a strong argument that the most important natural resource endowment for questions of civil conflict is fossil fuel.

The statistical results from each of these four papers, combined with their notable differences in theoretical focus, and hence model specification, is an indicator that all of them exclude covariates that are potentially important causes of civil war. Thus, when taken as a whole, all appear to suffer from the problem of unobserved heterogeneity. This heterogeneity occurs most often at the country level, for example changes in political institutions, but also at the regional level, for example neighboring civil wars and fossil fuel exportation. Moreover, the potential problem of unobserved heterogeneity looms for these, and other, studies of civil conflict.

There is a second argument for consideration of unobserved heterogeneity in the civil conflict literature too. Several theoretical arguments thought to be extremely important to the conflict generation process, both at the country and regional levels, cannot be adequately captured by currently available data and may well be immeasurable for quantitative studies that seek to investigate even small to medium sized temporal and spatial domains.[2]

One such country level immeasurable stems from the well known theory of relative deprivation (Gurr 1970). Relative deprivation is defined as the gap between what people think they should be getting from society and what they are actually getting, and the plausible hypothesis that flows from this theoretical concept with respect to civil conflict is that when that gap is large enough for a sufficient percentage of the population, the people will rebel. The problem with testing this argument is that data to measure relative deprivation is difficult to find. The most common proxy variable is income inequality measured with a gini coefficient.[3] Sometimes using that proxy and sometimes using some other variable because of scare income data, Russett (1964), Sigelman and Simpson (1977), Muller (1985), Muller and Seligson (1987), and Boswell and Dixon (1990, 1993) have all found evidence in support of the theory. However, almost all these studies examine small temporal and spatial domains, and have little overlap between them. In addition, Hardy (1979), Weede (1981, 1987), and Fearon and Laitin (2003) have failed to find support for the relative deprivation hypothesis. There is little doubt that poor data quality is the main culprit for these inconsistent results (Fearon & Laitin 2003, 85), and the nature of the variable indicates that sufficiently reliable data over an extended period of time and spatial domain will be near impossible to collect.[4] This is one important potential cause of civil conflict that is often left out,

[2]Most studies in the literature tend to focus on the temporal domain from 1960 to 1992, and while some examine all countries, others like Henderson and Singer (2000) and Collier and Hoeffler (2002) pick post colonial or just African states.

[3]For a review of the literature on the relationship between relative deprivation and conflict see Lichbach (1989).

[4]Even if data measuring income inequality for a large number of states over a long period of time could be collected, there would still be some doubt as to whether it would adequately tap the intended theoretical concept. As Weede (1987, 641) points out, "Only if there is a discrepancy between what people get and what they feel rightly entitled to is there relative deprivation. As long as an untouchable street sweeper in Calcutta accepts his low status and extremely meager income as deserved (that is, earned by bad deeds in a previous life), he will not feel deprived relative to his standards of justice and expectations, however absolutely deprived he may seem by Western standards."

indeed cannot help but be left out, of quantitative studies.

A second likely immeasurable source of country level heterogeneity is the major finding of one of the most impressive large scale qualitative efforts to determine the causes of civil conflict. After surveying the 16 contributions to his edited volume on the subject Brown (1996, 23) states, "My main argument with respect to the causes of internal conflict is that most major conflicts are triggered by internal, elite-level activities—to put it simply, bad leaders—contrary to what one would gather from reviewing the scholarly literature on the subject. Elite decisions and actions are usually the catalysts that turn potentially volatile situations into violent confrontations." The impressive case study work in the book lends substantial support to this argument. The reason why this variable was missing from much of the literature to that date, and continues to be neglected in the literature since, is that much of the literature is quantitatively oriented and there is no reliable way to measure the catalytic decisions made by 'bad leaders' over any substantial temporal or spatial domain. This is another important causal mechanism for civil conflict that is unlikely to be tested nomothetically any time soon.

There are also several potentially important causes of civil conflict that operate at a regional level that are unlikely to be measured sufficiently to be included in quantitative studies of the subject. Hegre et al. (2001) come closer to capturing the regional issue than other studies with their inclusion of a dummy variable recording whether a neighboring state is experiencing a civil war. This models the plausible hypothesis that conflict spreads outward, however, it neglects the very real possibility that conflict spreads inward. For instance, "swarms of refugees or fighters crashing across boarders, bringing turmoil and violence with them, or radicalized politics sweeping throughout regions" could cause conflict in a previously peaceful state, or malevolent leaders in a state may provoke conflict in a neighboring state for domestic political purposes (Brown 1996, 569). Moreover, there are several reasons to believe that some regions of the world are simply less likely to experience civil strife than others. For instance, some regions have ingrained norms and established international institutions of peaceful conflict resolution, whereas others lack them; and some regions have hegemonic powers that act to stabilize the environment, whereas other regions have powerful states that are forces for destabilization. This jumble of regional factors, which are clearly important because few would disagree with, for instance, the statement that civil conflict is more likely in Africa than in Western Europe, defies straightforward measurement in way that would make it amenable to quantitative testing. The usual approach for quantitative scholars who are concerned with regional dynamics is to pick a particular region such as Africa (Collier & Hoeffler 2002) or the post-colonial world (Henderson & Singer 2000) on which to focus. However, this solution is less than ideal because it negates our ability to generalize cross-regionally—something that a significant portion of the literature seeks to do.

The causes of civil conflict are heterogeneous. We do not suggest that scholars should attempt to include every possible covariate in their models. This would be unwise and inefficient. However, we do suggest that quantitatively oriented scholars take the issue of unobserved heterogeneity seriously. Fortunately, there are established statistical techniques which make dealing with unobserved heterogeneity easier. Unfortunately, the fact that they have not been applied to date in this literature places many of the established statistical causes of civil conflict in doubt.

2.2 Event Dependence in the Civil Conflict Literature

Unobserved heterogeneity is not the only conceptual hurdle with which the civil conflict literature must contend. It is a very common finding in the literature that states which experience one civil war are more likely to experience further conflict. This implies that the process of civil conflict is dynamic, and should be modeled as such. The failure to do so could lead to biased and inconsistent estimates.

The very fact that a literature on the recurrence of civil conflict exists implies that the process of civil conflict is event dependent. One need not look too far into the literature for evidence to support the claim that states often experience multiple failures. Licklider (1995, 688-9), Doyle and Sambanis (2000, 784-5), and Fortna (2004, 288-290) all provide tabular evidence on civil conflict onset that demonstrates, even with three different operationalizations of the concept, that many (if not most) of the episodes occur in states that have already experienced internal conflict at least once. While ranking as a non-trivial normative concern, this event dependence is also a crucial methodological and substantive concern with major policy implications. Since the international community often seeks solutions to civil conflict and oftentimes fails in its quest, factors that effect subsequent failure are extremely important ones to model accurately.

There are several reasons why a state, having experienced one episode of civil conflict, is at an increased risk to fail again. Some of this literature focuses on the way in which the previous conflict ended (Licklider 1995, Doyle & Sambanis 2000, Hartzell & Rothchild 2001). Walter (2004, 372) provides a concise summary of these arguments, "In this view, earlier wars set the stage for conflict that occur in later years because the original grievances were not resolved, because violence exacerbated ethnic divisions making coexistence difficult, because war ended in unstable compromise settlements, or because the human costs of war created psychological barriers to building peace." Strong statistical evidence from these studies suggests that many of these causal mechanisms are, indeed, operable. Walter (2004) adds to the literature by noting that unless underlying political and economic questions are addressed, the tenor of the previous settlement is of little concern.

While all of these arguments are certainly plausible, and are backed by the reporting of statistically significant coefficients, there is good reason to doubt the veracity of the evidence. The main bulk of the quantitative evidence is drawn from logit or probit analyses that do not account for event dynamics. While Walter's (2004) explicit focus is on the dynamics of the process, she models subsequent civil wars without accounting for the first war, and then further partitions her data to run separate analyses on subsequent wars fought over the same issues as a previous conflict or subsequent wars fought over new issues. Partitioning the data in this way ignores the very dynamics that were of interest in the first place. Even scholars use an event history approach (e.g. Fortna 2004) fail to properly account for the dynamics. A more appropriate way to model the question would be to use an event history approach and stratify by event number. This allows the baseline hazard to vary by event number.

Taking the literature on civil war recurrence as a whole, we conclude that event dependence is a second major hurdle that the civil conflict literature has yet to clear. It is critical to use a modeling strategy that can account and test for for both unobserved heterogeneity and event dependence, and can accurately partition the effects of each.

3 Modeling Dynamics and Heterogeneity in Repeated Events

Almost all of the civil war onset literature fails to incorporate the role of time, ignoring the fact that civil war is the end stage of a process—which can repeat—predicted both by time constant and time varying characteristics of the state and the system it is a part of. Hegre et al.'s work is an important exception to this norm. Most of the previous literature analyzes whether or not a civil war occurred in any given point in time, using logit, for example, rather than the the timing and occurrence (the *onset*) of civil war or put differently, the duration of peace. The distinction is subtle but important and it is the basis for the analysis in Hegre et al.

Event history or duration models are particularly well-suited to test the effects of covariates on the risk for event (re)occurrence Cox (1972). Indeed since their introduction to political science (1997, 2004), there has been an explosion of the use of these models. An event history framework incorporates time dependence as an important feature of the data generating process. Incorporating the time dependency of the peace process into the statistical model is imperative both theoretically and empirically. This can be done in a discrete time logit event history set up by adding piecewise functions, transformations on t, or smoothing functions, like splines to the models (2004). Unfortunately, many analysts still ignore duration dependence issues in discrete time models, as is the case with the bulk of the civil war onset literature, re: a traditional logit model is used. The disadvantage of using discrete time event history approaches to account for time dependence is that covariate parameters are often sensitive to the function of t you choose. Here, time dependence is incorporated directly into the model and the functional form of time dependence is estimated rather than assumed.[5]

Recent advances in event history promise an estimation strategy that incorporates important features of the theoretical and empirical properties of the process of civil war onset that current applications do not use. The study of civil war violates the independence of events assumption of the Cox model. Dependence is induced in two ways: (a)the occurrence of a civil war may increase the risk of future civil wars within a country and (b)heterogeneity across countries may make some countries more likely to experience civil wars (to be at higher risk) than others. Only recently has there been a focus on modeling and distinguishing these distinct sources of correlation (Therneau & Grambsch 2000, Box-Steffensmeier & Boef 2004). The adoption of more sophisticated event history estimators allows us to model the correlation and in so doing, to avoid biased and inconsistent estimates, and to more faithfully model civil war and other processes as we understand them. Taking this step makes event history models ideally suited to test hypotheses about the factors that increase/decrease the risk of civil conflict and is applicable to the quantitative study of other political events.

3.1 Sources of Dependence: Event dependence and heterogeneity

Repeated events processes occur when the subject experiences the same type of event more than once. Most applications of event history in political science will be subject to repetition. Such diverse phenomena as international conflicts (Box-Steffensmeier & Zorn 2002), cabinet transitions

[5] The Cox model does assume proportional hazards, re: that changing values of covariates affect risk by raising or lowering the baseline hazard function rather than changing its shape. This assumption should be tested.

(King, Alt, Burns & Laver 1990), presidential nominations for executive branch appointments (McCarty & Razaghian 1999), senate confirmation of judicial nominations (Binder & Maltzman 2002), government survival (Warwick 1995), and European Union decision making (Schulz & K”nig 2000) are all examples of processes that may occur repeatedly over time.

Observations in repeated events processes are correlated; observations on a case in one period are informative for that case in another period. Or put alternatively, there is potential correlation among the observations on an individual subject so that independence should not be assumed to hold when there are repeated events. Observations may be dependent across *events*, and they may be dependent across *cases*, i.e., there may be a clustering of events versus a clustering of cases. We refer to (and therefore distinguish) the problem of dependence across events as *event dependence* and refer to the problem of dependence across cases as *heterogeneity*.

It is well known that any correlation among events—produced individually or jointly by heterogeneity and event dependence—violates the Cox model's assumption that the timing of events is independent. Whatever their source, correlated observations violate the assumption of independence so that standard errors are understated. Further, in non-linear event history models, such as the Cox model, the parameter estimates are both biased and inconsistent (Sastry 1997, Aalen 1988, Trussell 1992, Therneau & Grambsch 2000, Kelly & Lim 2000, Mahe & Chevret 2001, Box-Steffensmeier & Boef 2004).

These consequences have led scholars to begin to take seriously the problems created by correlations in repeated events data and to understand the differences between dependence created by heterogeneity and that created by event dependence. These distinctions are important methodologically *and* substantively. Distinguishing these two types of dependence has important policy implications too. In the case of civil wars, event dependence implies a cycle of violence and has vastly different policy prescriptions than if heterogeneity across countries or regions is a primary component of civil war onset.

Theory tells us that civil violence begets civil violence. In other contexts we might argue that instability breeds instability or that behavior, once established as the norm, leads to more and more frequent events of a variety of sorts. Alternatively, the occurrence of an event may make future events less likely. To the extent that second and subsequent events are likely to be influenced by, and therefore different from, first events the correlation produced by event dependence may be quite high (Box-Steffensmeier & Boef 2004). Box-Steffensmeier and Zorn (2002) point out that when analysts treat repeated events as independent, when in fact they are not, they run the risk of yielding misleading results for two reasons. First, the presence of correlated events presents a problem similar to autocorrelation in conventional regression analysis: by treating such observations as independent, we overstate the amount of information each observation provides, leading to incorrect estimates of standard errors. Second, such models implicitly restrict, most importantly, the baseline hazard, and also the influence of covariates, to be the same across events when, in fact, there may be varying baseline hazards and effects from one event occurrence to the next. The methodological solution, which is important and elegantly simple, is to stratify by event number to allow the baseline hazards to vary (Box-Steffensmeier & Boef 2004, Mahe & Chevret 2001).

Heterogeneity in repeated events processes will also induce correlations in event times. The mechanism here is different, but the result the same. Where the causes of events are unmeasured (and thus omitted) they will be correlated with the event times. Some cases may have a higher or lower event rate than other cases due to unmeasured, unmeasurable, or unimagined covariates. Some cases may experience their first, second, third, etc., event recurrence more quickly than other cases. This introduces heterogeneity across individuals and produces within-subject correlation in the occurrence and timing of recurrent events within a given subject. At the same time, event rates can be homogeneous within cases producing within-subject correlation in event times.

Frailty models present a promising estimation strategy for dealing with the effects of heterogeneity in the event history context, e.g., (Oakes 1992) and (Therneau & Grambsch 2000). They are typically considered as:

$$\lambda_i(t) = \lambda_0(t) exp(X_i\beta + Z_i\omega) \tag{1}$$

where X and Z are covariate matrices, β corresponds to the fixed effects in the model (from the measured covariates), ω corresponds to the unknown frailties or random effects, and Z_i is an indicator for whether the observation is a member of group j that shares that common frailty.

The underlying logic of frailty models is that some observations (or groups or clusters) are intrinsically more or less prone to experiencing the event of interest than are others. It starts as a theoretical question. In the realm of civil wars, some of the literature emphasizes heterogeneity. For example, the literature tells us that relative deprivation is important (Gurr 1970). While some have attempted to measure relative deprivation, these measures are admittedly imperfect. Relative deprivation is, arguably, unmeasurable. "Frailty" in a model of civil wars represents an individual country's susceptibility to the risk of a civil war. It captures the total effect of *all* factors that influence the individual country's risk of civil war that are not included in the baseline hazard (Sastry 1997). "Since the model can account for observed covariates, the frailty effects represent unmeasured or unmeasurable effects" (Sastry 1997)[246]. That is, we can begin to account for the frailty through statistical adjustments.

A major advantage of frailty, or random effects, models is their ability to analyze data that are also correlated at several different hierarchical levels (Goldstein 1995, Bandeen-Roche & Liang 1996, Sastry 1997). We think that the applicability of multilevel data in political science is epidemic, even though there is currently a shortage of these models in practice (for an excellent introduction to these models see Steenbergen & Jones 2002, Rohrschneider 2002, Jones, Johnston & Pattie 1992, Mondak & McCurley 1994). For example, if we are studying survey respondents attitudes toward governmental policies, we may want to cluster by congressional district, state, and region. Allowing for this heterogeneity, re: essentially testing for it, relaxes the assumptions imposed by the model. One can simply use a likelihood ratio test for the statistical significance of the frailty to see if it is an essential component of the model or whether the more restricted model is acceptable (Therneau & Grambsch 2000).

Frailty models are subject to two primary criticisms, The first concerns the choice of the distribution for the random effect. Neither theory nor data typically provides much guidance for imposing a specific distribution on the frailties, and "parameter estimates *can* be highly sensitive to the assumed parametric form of the error term" (Blossfeld & Rohwer 1995, 255).[6] Because

[6] There is continuing research on how to best choose a distribution (Schumacher, Olschewski & Schmoor 1987, Lancaster 1990, Hougaard 1991, Larsen & Vaupel 1993, Sastry 1997). Among the most promising is that of Commenge (1995), who develop a test for random effects that does not require specification of the unknown error term distribution (see also Andersen, Klein & Zhang 1999, Guo & Rodriquez 1992).

the hazards are necessarily positive, the distribution is usually chosen from the class of positive distributions; in applied work, the most widely used are the gamma, Gaussian, and t distributions, with the gamma being by far the most frequent. Once chosen, the distribution of the random effects is assumed independent of the model covariates. Scholars, such as Sastry (2004), are working on relaxing this assumption.

Fixed effects represent an alternative to random effects. Fixed effects suffer from four problems. First, effects for time invariant covariates cannot be estimated in a fixed effects model; the two are perfectly correlated. In the context of the civil war data, if we include region as a fixed effect, we cannot assess the effect of any other time invariant variables, such as contiguity. Second, estimates of the effects of slowly changing variables will be imprecise (because they are highly collinear with the fixed effects). Third, fixed effects models use a lot of degrees of freedom. Finally, fixed effects in event history can also result in inconsistent estimates, deflated standard errors, and thus generally are not used (). One can think of random effects such that rather than treating heterogeneity as fixed (and estimating the effects) we treat each case as a random draw from some single distribution. We can then estimate the parameters of that distribution, which (relative to fixed effects) reduces the number of parameters estimated.

3.2 The conditional frailty model

Event dependence implies that the occurrence of an event itself may raise (or lower) the subsequent event rate. In contrast, heterogeneity across cases implies that some cases will have a higher or lower event rate: countries that are more prone to conflict than the population will experience their first, second, third, etc., civil war more quickly than others. We allow for both features of civil war onset by estimating a conditional frailty model. The estimator controls for event dependence by stratifying and for heterogeneity by including a frailty term (see Box-Steffensmeier & Boef 2002).

We present the conditional frailty model to illustrate these two types of dependence below:

$$\lambda_{ik}(t) = \lambda_{0k}(t) \exp(X_i(t)\beta + \mu_i). \tag{2}$$

where λ_{ik} denotes a subject's risk for event k. This risk is a function of λ_{0k}, an event specific baseline hazard and μ_i, a subject specific random effect. The former introduces event dependence, which itself may follow a variety of forms. The latter produces heterogeneity by contributing differently to each subject's risk. As in the case of λ_{0k}, the random effect may follow a variety of forms producing unique types of heterogeneity.

The major innovation of this model is that the sources of dependence, whether due to repeated events or heterogeneity can be separated. The condition of joint event dependence and heterogeneity is important to consider for two reasons (Box-Steffensmeier & Boef 2004). First, it seems likely that both sources of correlation may simultaneously describe many of the processes that we care about. Second, even if only one source of correlation exists, we typically cannot know which source drives the correlation a priori and therefore do not know whether to stratify or adopt a random effects approach to estimation (Cook & Lawless 2002, Fong, Lam, Lawless & Lee 2001, Lawless 2003, Hougaard 2000).

4 Civil War Onset

We apply these modeling strategies to the recent paper published by Hegre et al. (hereafter referred to as HEGG) (2001) in the *American Political Science Review*. We chose this paper for replication both because it is the closest approximation of our proposed methodology currently in print, and because it is a generally well done study with a number of covariates that are especially interesting from an event history perspective. While we refer interested readers to the original manuscript for an in depth discussion of model specification, a brief review of the model is appropriate here.

HEGG set out to determine if there is evidence of Democratic Civil Peace with a model that takes the relationship between domestic political institutions and such conflict much further than any previous, or later, effort. They do so over the entire spatial domain of states (according to the Correlates of War Project's System Membership Data) for the time period from 1816 to 1992. The variables in the model for the entire time period are: Proximity of Regime Change, Democracy, Democracy^2, Proximity of Civil War, Proximity of Independence, International War in Country, and Neighboring Civil War. Data for the political variables are drawn from the Polity IIId dataset (McLaughlin et al. 1998), and the war and system membership data are taken from the various data sets of the Correlates of War Project. Separate models are estimated for the post-World War Two era (1946-1992), and include Development, Develoment^2, and a measure of Ethnic Heterogeneity. The Development data is taken from the Correlates of War Project, and is measured as energy consumption per capita, and the measure of ethnic heterogeneity is taken from Ellingsen (2000). HEGG find that the proximity of regime change, the proximity of independence, the proximity of civil war, and ethnic heterogeneity all increase the hazard of civil war onset; and find inverse U shaped relationships between both the level of democracy and the level of development an the hazard of civil war onset. International war in country and neighboring civil war are weakly related to an increasing hazard of civil war onset.

One of the interesting aspects of this paper is the way in which the data is set up. Arguing against the typical country-year formulation (HEGG, 35), the authors choose instead to have the temporal unit of analysis be days. This argument is convincing because, as HEGG point out, regime changes (the covariate in which they are most interested) and civil wars occur within years, and a coarse unit of analysis, such as the country-year, may miscode events that happened at different times as happening simultaneously. Thus, all of the 'proximity' variables mentioned above, are counts of the number of days since the event each variable is measuring took place. Interestingly, however, rather than observe every country-day, HEGG record observations for all countries only on the days when a civil war broke out somewhere in the world. They refer to this method as taking a 'snapshot' of the international system.

A snapshot approach does not capture all the dynamics of the covariates so we chose to expand the HEGG dataset to include observations for every country day, resulting in slightly over 4.1 million observations for the period from 1816-1992. In the process of this expansion we attempted to remain as faithful to the HEGG coding where possible. In some cases, new data releases allowed us to update the covariates with additional data. In other cases, we corrected coding errors made by HEGG.[7] This implies that our statistical estimates, even for replications of

[7] Many of these coding errors were small and their correction should have a minimal effect on the estimates presented in HEGG. However, one coding error was quite large and will affect the size of the proximity of independence coefficient. HEGG claim to use the Correlates of War Project's System Membership data to code this variable; however

the exact HEGG statistical model, will not match exactly. Our data gathering and manipulation process, and its relationship to the data in the original HEGG paper, is covered, in full, in the appendix to this paper.

Using this expanded data we estimate event history models with both country and regional frailties to assess the effects of country and regional-level unobserved heterogeneity. These terms provide an assessment of the effects of the spatial structure of the data. The existence of country-level unobserved heterogeneity will always be a concern in comparative political or social analyses and should be allowed for and tested. Our use of both frailty terms (at either the country- or regional-level) and event dependence sets up opposing substantive hypotheses. Event dependence emphasizes the importance of breaking the cycle once it begins. Country-level heterogeneity emphasizes the uniqueness of the dynamics by country, whereas regional level clustering provides more evidence of regional contagion. All three of these may be found in the data and are allowed for and tested by our model.

5 Event Dependence, Heterogeneity: Making the case with a study of Civil War Onset

We have argued that we need: (a)to expand the dataset in order to include all the information relevant for testing (i)the hypotheses laid out by Hegre et al. and (ii)additional hypotheses related to the underlying structure of the data and our theoretical understanding of the process leading to outbreaks of civil war; (b)to control for the lack of independence in the observations—the data contain multiple observations on each country; (c)to allow for the possibility that the correlation is due to event dependence; and simultaneously (d)to control for the biasing effects of heterogeneity, which may be nested or multi-level. We now present the case by estimating a series of models. Briefly, we begin with the basic Cox model estimated by Hegre et al., but estimated using the expanded dataset (CIVIL-X). We present our results using robust standard errors clustering on country. This post-estimation correction adjusts for the lack of independence of observations, but does not effect the covariate estimates themselves, just their standard errors.[8] After establishing the baseline models, we quickly turn our attention to models that incorporate event dependence and heterogeneity.

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a glance at their data shows that they either used a different source or committed errors. For instance, a civil war broke out in Algeria on July 28, 1962, which implies that every member of the international system at that time should have an observation. HEGG have an observation on that date for Trinidad and Tobago, but the Correlates of War System Membership Data indicate that Trinidad and Tobago did not enter the international system until August 31 of that year. Not wanting to omit original observations from the dataset, we back code all such cases to the first recorded observation in the HEGG data. However, upon further investigation we discovered that according to HEGG Trinidad and Tobago was already on day 53,533 of its existence (even though this is the first time Trinidad and Tobago appear in their data). This would place Trinidad and Tobago's entry into the international system sometime in 1819 - clearly incorrect. This problem occurred for several other countries as well. We code proximity of independence from the Correlates of War data, and thus have many states much closer to independence when they are observed than HEGG. Because some of these states experience civil wars, the implication is that we will find strong statistical support for this hypothesis in our replication.

[8] When using robust standard errors and clustering on the case identification number, the class of Cox models estimated is referred to as variance-corrected models (for details on this class of models see Kelly & Lim 2000, Andersen & Gill 1982, Prentice, Williams & Peterson 1981).

5.1 The baseline Cox model

We begin by estimating a Cox model with identical righthand side variables as that estimated by Hegre et al. for both 1816-1992 and 1946-1992, but using the expanded version of the data set. We compare this with the published results reported by Hegre et al. The models vary with respect to the data. The results of these two models are presented in columns 1 (Hegre et al) and 2 (Using CVIVIL-X) of Table 1. Column 3 (Conditional Frailty, Gap Time) presents results from the estimation of the conditional frailty model. The model is presented in gap time such that the time to civil war is coded in days since the previous civil war (rather than days since independence).[9]

Insert Table 1 here.

In brief, Hegre et al find that proximate regime change, civil war, and independence each increase the relative risk of civil war. The effects of democracy are symmetric about zero (democracy is not statistically significant) and follow a U-shape (democracy squared term) such that more democratic or autocratic regimes are less likely to experience civil war than countries on the middle of the scale. There is no effect on the relative risk of civil war if a neighboring country is undergoing a civil war, but if a country is in an international war it is statistically significantly more likely (p=.075) in the post World War II period to experience civil war. Also post World War II, development and its square contribute to decreased risk of internal violence while ethnic heterogeneity increases the risk.[10]

5.2 The expanded data

If a snapshot of the system captures all the information contained in the larger dataset, then estimation of a basic Cox model applied to CIVIL-X should replicate the results from the Cox model applied to the snapshot data; results in columns 1 and 2 should produce the same inferences.[11] Do they? We can evaluate the results in a variety of ways. We focus on two questions: Are the same coefficients statistically significant? And if so, are the substantive effects of the same sign and similar magnitude?

In general, the same coefficients are statistically significant. In some cases, the level of significance changes, but our inferences about whether or not democracy or the proximity of regime change, for example, affect the risk of civil war would not change if we adopt $p \leq .10$ as our standard. Assessing the significance of the change in the substantive impact due to the change in data is more subjective. We find, for example, that the effect of proximity of regime change on the relative risk of

[9] In contrast, elapsed times have a carry over effect, as the second interval includes the first interval, third interval includes the first and second intervals, etc. Elapsed time models assess the effect of covariates on the kth event since the time of the start of the study, versus gap time and the effect since the previous event. Box-Steffensmeier and Zorn state that most political science applications will require gap time.

[10] Because not all countries exist in the international system at any given time, while the estimation is based on all cases, there are not 169*129=21801 total observations in their analysis. In addition, even after making this allowance, the true degrees of freedom is less than in a traditional analysis pooling country observations over time because not all countries contribute information to the likelihood for each time period.

[11] We also estimated the Cox model on a snapshot version of our data in an effort to replicate the published results. Given corrections in coding errors, there are some differences.

civil war increases from 3.56 times to 5.75 times the baseline risk in the day after a regime change. After 1 year the difference is still visible. Hegre et al. estimate the relative risk to be 1.89 times greater than the baseline, while using the expanded data set we estimate the relative risk to be 2.40 times greater than the baseline risk. The differences disappear after 6 years. The effect of the proximity of civil war is also estimated to be similarly greater. Proximity of independence has a substantially larger estimated effect, with the risk of civil war estimated to be over 31 times greater in the day after independence (compared to 4.5 times greater than the baseline hazard based on Hegre et al's estimates) and 5.5 times greater after one year.

5.3 Dealing with dependence: the importance of event dependence and heterogeneity

To this point, we have done nothing to account for either event dependence or heterogeneity. Theories of civil war, however, suggest that both of these are important features of the process that may predict civil war onset. If, as we believe, the risk for future civil wars increases having had one or more civil wars, then the Cox model estimated above will produce biased estimates of the effects of the covariates. We need to allow for this change in the baseline hazard and to do so requires us to stratify based on the number of civil wars a country has previously experienced.

In addition, theory tells us that there may be heterogeneity across cases or put alternatively, (1) homogeneity *shared* by (within) a country over time or (2) heterogeneity shared by all countries within a region over time. Civil wars occur within countries – they "belong" to a particular country. Factors unique to a country, but omitted from the model, that influence the occurrence of a civil war are likely to affect the probability of subsequent civil wars, creating correlations among events within countries. Alternatively (or additionally) heterogeneity across countries and within regions may be the dominate source of dependence. Each country is nested within a region. A shared ethos that evades measurement or simply unmeasured factors at the regional level induce the same effects on estimates from standard event history models. We begin to account for unmeasured heterogeneity by singly accounting for the effects of country and regional heterogeneity.

We incorporate the effects of event dependence and heterogeneity into our estimation in results presented in column 3 Table 1 by using the conditional frailty estimator. We present results for the conditional frailty estimator including a random effect for region.[12] Before we present the results of the estimation, we consider additional issues relating to model specification.

Any time we are assessing the risk of event occurrence, we need to ask what is the appropriate start date or reference point from which to measure the duration of time before the event? Closely related to this question, we must ask, given that an event has occurred what is the right reference point from which to measure the second duration and calculate the risk of recurrence? These questions should be answered based on theory. Hegre et al. measure duration of peace in time since a country's independence, implying that countries are at risk for any number of civil wars once they gain independence. In other words, the process leading to not only the first but also *each* subsequent civil war onset is one that begins at independence and builds until the onset of violence that marks a civil war. Alternatively, as we argue, if we think the process of civil war onset begins

[12]We estimated random effects for countries, but none were statistically significant. We return to this discussion later in the text.

with independence and then restarts anew with each civil war occurrence, then the better referent in time is the last civil war. In this case, the duration should be measured relative to the previous civil war (or independence if civil war has not occurred). The first of these two types of codings is referred to as elapsed time, the second as gap time.[13]

Once this decision is made, there are implications for the treatment of other righthand side variables measured in "time since". In particular, any independent variable coded so that the duration time determines its value is by definition endogenous. This endogeneity presents both statistical and theoretical problems. Specifically, as in other cases, endogeneity produces biased estimates. Additionally, for the analyst to include these terms in the duration model makes little sense: Consider that HEGG measure the onset of civil war in time (days) since independence. The time since independence—proximity of independence—is also a righthand side variable, coded as exp(-days since independence/α). In essence, the time since independence until civil war is thus conditional on a function of time since independence. The Cox model would determine the functional form of the time dependence linking the duration of time since independence to civil war occurrence and therefore makes this specification redundant! (If we estimate the model in terms of days since last civil war, then the same is true for proximity of previous civil war.)

While the civil wars literature does not discuss the "start date" for the civil war onset process directly, we argue that it makes the most sense to treat onset as a process that restarts with each civil war. The seeds for violence may be sewn in the conditions in place at independence, but conditions change and thus we model the duration of peace since the previous civil war. That is, we estimate the conditional frailty model in gap time. In order to avoid the endogeneity problem, we omit proximity to civil war from the model. The effects of proximity to civil war are picked up in the duration time and in the stratification.

The conditional frailty model in gap time is presented in column 3. Effects are computed relative to the time since the previous civil war rather than independence. We present the results for the conditional frailty model estimated assuming that the random effect follows a gamma distribution. The gamma distribution is asymmetric, implying that although most of the observations have a frailty near zero, there is a proportion with large negative values, re: clusters of observations with exceptionally low risk (Therneau and Grambsch 2000, 234).

Immediately apparent are the similarities between the coefficients and levels of significance on a subset of parameters for this and the Cox model estimates based on the same data set: proximity of regime change, development, and development squared have nearly identical magnitude effects and levels of significance. Nearly the same can be said for democracy and democracy squared. We also notice some changes in the inferences drawn from this model. In particular, the effects of independence drop dramatically; the coefficient drops in size and is no longer statistically significant. In contrast, in the post World War II period, having a neighbor state in a civil war significantly

[13]The key distinction in the estimation of this model is that the relative risks are computed based on a different risk set. A country 10,000 days from independence and experiencing civil wars at day 200 and 500 and another country 120,000 days from independence that experiences civil war 100,000 and 100,300 days after independence would contribute different information in these two formulations of the conditional frailty model. In gap time both have a 300 day gap between their first and second civil war and thus are both at risk for their third civil war at the same time. In the elapsed time formulation, there is no overlap and the countries do not contribute information to the same risk set. Which formulation is correct is a question best decided by theory and the specific question at hand. See Box-Steffensmeier and Zorn 2002

reduced the relative risk for civil war, although this was not true over the longer time span. Most notably, the effect of ethnic heterogeneity is much stronger and more robust in models that use the conditional frailty estimator. The more ethnically diverse a country, the greater the risk for civil war; as ethnicity increases, the relative risk increases by 4.66, compared to 2.27 in the basic Cox model.

In neither the shorter or longer time period is the variance of the random effect statistically significant (and estimates of the remaining coefficients are unaffected by its removal).[14] At first blush, this seems to suggest that there is no heterogeneity in the data. Such a conclusion is, of course, unwarranted. Theoretically it is implausible. Statistically the explanation is less obvious, but no less implausible. In order for the random effect to be statistically significant, there must be significant within unit variation relative to variation across units. That is there must be significant shared variation within countries compared to the variation across them in order for the country level frailties to be statistically significant.

Similarly there must be significant shared variation within regions distinct from the variation across them for the frailty based on region to be significant. Given the small number of civil wars in combination with the large amount of within and across country and/or region heterogeneity—the dizzying array of causes—the patterns of variation are not distinct. This is, however, comforting for the analyst. The exclusion of additional covariates, whether by choice or because we cannot obtain measures of all the covariates of theoretical importance, is not biasing the results.

Insert Figures 1 and 2 about here.

More compelling than the actual coefficient estimates are the findings regarding event dependence. Figures 1 and 2 plot the cumulative baseline hazards for the conditional frailty models for the two time periods under consideration. If we did not stratify and instead used a basic Cox model, we would get a single cumulative baseline hazard. If dummy variables are included for event rank, the hazard would be shifted by a factor of proportionality, which is also less flexible than stratification.

The overall level of the hazards generally increase with higher-ordered events. [15] That is, the hazards for first conflicts are lower overall than those for second, third, fourth, etc. conflicts. This illustrates the event dependence and escalation of conflict.

6 Significance and Implications

A conditional frailty model for repeated events allows for heterogeneity across cases, dependence across the number of events, and both heterogeneity and event dependence. The most likely scenario is that repeated events data will exhibit both event dependence and heterogeneity and it is unlikely that we can rule out either a priori. The conditional frailty model helps us to diagnosis the source of

[14]Results are unaffected by substitution of the gaussian distribution rather than the gamma distribution or by assuming heterogeneity within countries rather than regions.

[15]We will collapse event ranks where there are few events in future iterations, which will make this clearer. That is, as one reaches the highest event numbers there are few events and thus it makes little sense to plot separate hazards. There are 4, 3, 2, and 1 event(s) for event numbers 6, 7, 8, and 9 respectively. These clearly should be combined.

correlation in the data. Stratification accounts for event dependence and the frailty term accounts for heterogeneity.

We apply the conditional frailty model to civil conflict data to determine whether there is heterogeneity across countries or regions, dependence across the number of events, or both. We find strong support for event dependence. The occurrence of an event itself raises the subsequent event rate. That is, civil violence begets civil violence.

The policy implications of event dependence are very different from that of heterogeneity at the country or regional level. Event dependence implies that the cycle of civil conflict within a country should be the focus of policy intervenors, not the diffusion of civil wars across countries or regions. Event dependence suggests that the international community should focus resources early. Once civil conflict begins, the dependence is harder to break.

Event dependence, in contrast to heterogeneity, has more positive policy prescriptions. Heterogeneity would imply that the task would be to confine civil conflict to a country or region. Policy makers would need to keep a pulse on other surrounding countries and the policy prescriptions would involve specific policies for specific countries. That is, it would vary on a case by case basis and the optimal policy intervention would vary based on a detailed case study. Event dependence suggests that there needs to be early intervention to prevent a conflict outbreak in the first place. This places a premium on diplomacy. If conflict does breakout, heavy intervention is suggested given that event dependence is underlying the process.

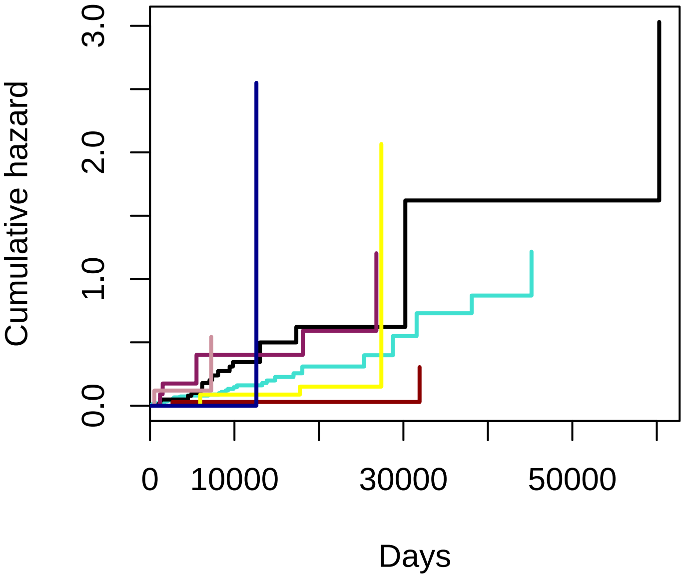

Figure 1: Cumulative hazards by numbers of civil wars, 1946-1992

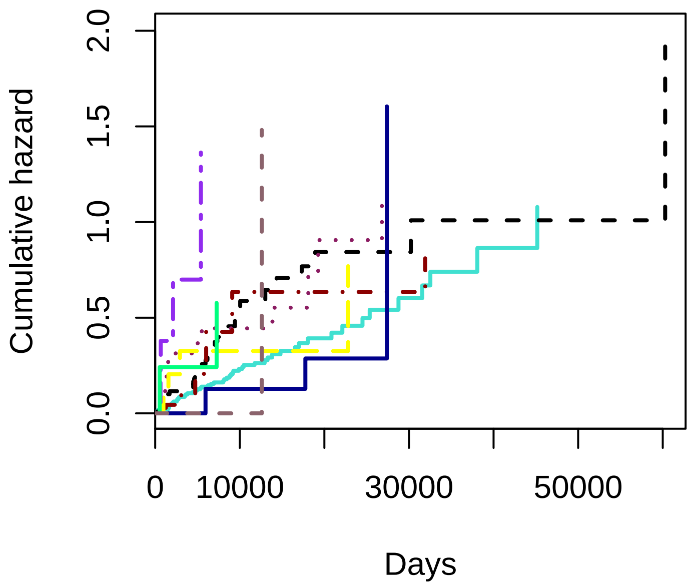

Figure 2: Cumulative hazards by numbers of civil wars, 1816-1992

Table 1: **The Risk of Civil War**

	Hegre et al. Published Results		**Hegre Model Using Civil-X**		**Conditional Frailty Gap Time**	
Explanatory Variables	$\hat{\beta}$	Standard Error	$\hat{\beta}$	Standard Error	$\hat{\beta}$	Standard Error
A. 1946-92						
Proximity of regime change	1.27**	(0.47)	1.75**	(0.43)	1.77**	(0.48)
Democracy	−0.002	(0.02)	−0.02	(0.02)	−0.03	(0.03)
Democracy squared	−0.012**	(0.01)	−0.011*	(0.00)	−0.010†	(0.005)
Proximity of civil war	1.16†	(0.97)	1.61**	(0.48)		
Proximity of independence	1.51†	(0.97)	3.44*	(1.60)	0.47	(2.28)
International war in country	0.86†	(0.59)	0.42	(0.63)	0.55	(0.66)
Neighboring civil war	0.10	(0.33)	−0.1	(0.32)	−0.619†	(0.38)
Development	−0.48**	(0.16)	−0.35*	(0.14)	−0.37*	(0.16)
Development squared	−0.066*	(0.04)	−0.06*	(0.02)	−0.06*	(0.03)
Ethnic heterogeneity	0.80**	(0.39)	0.82†	(0.46)	1.54**	(0.55)
Variance of Random Effect					0.15	
Sig of Random Effect					0.13	
B. 1816-1992						
Proximity of regime change	0.98**	(0.37)	1.28**	(0.36)	1.198**	(0.34)
Democracy	−0.01	(0.02)	−0.02	(0.02)	−0.02	(0.02)
Democracy squared	−0.013**	(0.00)	−0.012**	(0.00)	−0.011**	(0.00)
Proximity of civil war	1.66**	(0.25)	1.56**	(0.32)		
Proximity of independence	1.86**	(0.68)	2.57**	(0.77)	1.07	(1.20)
International war in country	0.24	(0.42)	−0.04	(0.40)	0.23	(0.48)
Neighboring civil war	0.27	(0.27)	0.17	(0.23)	0.04	(0.27)
Variance of Random Effect					0.027	
Sig of Random Effect					0.26	

Column 1 presents coefficients and standard errors published in (Hegre & Gleditsch 2001), Table 2, page 39, produced from a Cox model (no clustering, using naive standard errors). Column 2 gives coefficients and standard errors obtained by replicating this exact same Cox model using our CIVIL-X data set with clustering and robust standard errors. Column 3 is the conditional frailty model with time to civil war coded in time since the previous civil war (or time since independence prior to a civil war). The random effect is assumed to be distributed gamma and is based on region. For region definition see the appendix.

Significance levels : † : 10% * : 5% ** : 1%.

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