WEB APPENDIX

Back to the Future: Modeling Time Dependence in Binary Data

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Abstract

This online web appendix contains supplementary material associated with our article "Back to the Future: Modeling Time Dependence in Binary Data." We provide additional Monte Carlo results comparing logit regressions to cloglog, analyzing the performance of the cubic polynomial and splines in the presence of a time-trended covariate, and we provide the confidence intervals for the Monte Carlo results presented in the article. We also provide additional replication results based on Oneal & Russett (1997); Palmer, London, & Regan (2004); and Crowley & Skocpol (2001). Finally, we provide R and Stata code demonstrating how to implement the cubic polynomial and splines techniques for modeling temporal dependence.

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1 Introduction

Table 1 lists all published articles we found that follow BKT's advice on using time dummies or splines. The list was compiled by locating all published articles that cited BKT in the Social Sciences Citation Index (SSCI) as of July, 2006.

2 Additional Monte Carlo Results

We conduct several additional analyses that are not included in the main text of the paper. First, we conduct Monte Carlo analysis to assess the differences between the cloglog and logit models. Second, we report additional results on how serious separation issues are for time dummies. Third, we report Monte Carlo results that compare how efficient the different methods are in estimating the hazard. Fourth, we conduct Monte Carlo analysis in the presence of a time-trended covariate to assess how well the methods perform in this context.

2.1 Logit versus Cloglog

In the article, we note that there can be differences between cloglog and logit, especially when the probability of a "failure" or "event" is quite high. Here, we provide a more substantial treatment of the difference (or lack of difference) between cloglog and logit. We run a set of Monte Carlo experiments in which we assume that the data-generating process is cloglog. We assume a constant hazard (i.e., exponential) in order to focus more clearly on how different probabilities of failure relate to differences in cloglog and logit estimates and, therefore, predicted probabilities. In the Monte Carlo analysis, we employ a constant and single regressor: $\beta_0 + \beta_1 x$, where the regressor $x \sim U(-2, 2)$. By varying the value of β_0, we are able to vary the average percent of 1's in the data. By varying β_1, we are able to vary the slope of the change in probability from 0 to 1 over the range of x. We conduct the Monte Carlo analysis for slope parameters β_1 of 1, 2, 3, and 8. In each Monte Carlo iteration, the data is generated based on the cloglog model; the cloglog regression model is first estimated; a logit regression model is then estimated; and the

[1] The authors do not show the hazard in the text of the article but do offer an appendix with a plot of the hazard upon request.

[2] They do not actually plot the full hazard but do report the hazard for specific years in a table.

[3] The authors include a table that shows the effect of two covariates on the hazard, but do not show the hazard as a function of time.

Table 1: Use of Splines and Time Dummies

	No Hazard	Interpret Hazard
Splines	**88 (96.7%)** Goodliffe and Hawkins (2006)[1] Hafner-Burton and Montgomery (2006) Dorussen (2006) Caprioli and Trumbore (2006) Rasler and Thompson (2006) Mansfield and Pevehouse (2006) Braithwaite (2005) Buhaug (2005) Benson (2005) Oneal and Russett (2005) Meinke, Staton and Wuhs (2006) Bearce and Omori (2005) Edwards (2005) Melander (2005) Enterline and Greig (2005) Barbieri and Reuveny (2005) Chamberlain and Haider-Markel (2005) Kim and Rousseau (2005) Caprioli and Trumbore (2005) Senese (2005) Besancon (2005) Humphries (2005) Lujala, Gleditsch and Gilmore (2005) Marinov (2005) Caprioli (2005) Sobek (2005) Milner and Kubota (2005) Boehmer and Sobek (2005) Sørli, Gleditsch and Strand (2005) Fritz and Sweeney (2004) Krause (2004) Powers (2004) Mitchell and Prins (2004) Gowa and Mansfield (2005) Sechser (2004) Rasler and Thompson (2004) Goenner (2004) McDonald (2004) Volden and Carruba (2004) Walter (2004) Schamis and Way (2003) Sweeney and Fritz (2003) Cauthen and Peters (2003) Lai (2003*a*) Leblang and Chan (2003) Ray (2003) Reed (2003*b*) Oneal (2003) Gartzke and Li (2003*c*) Gartzke and Li (2003*a*) Sweeney (2003) Choi and James (2003) Mansfield and Reinhardt (2003) Gartzke and Li (2003*b*) Ravlo, Gleditsch and Dorussen (2003) Senese and Vasquez (2003) Bennett and Rupert (2003) Montinola (2003) Lai (2003*b*) Reed (2003*a*) Clark and Regan (2003) Chiozza (2002) Pickering (2002) Kinsella and Russett (2002) Jungblut and Stoll (2002) Davies (2002) Dixon and Senese (2002) Mousseau (2002) Colaresi and Thompson (2002) Peceny, Beer and Sanchez-Terry (2002) Li and Sacko (2002) Zorn (2001) Rasler and Thompson (2001) Drury (2001) Mousseau (2001) Crescenzi and Enterline (2001) Sherman (2001) Henderson and Tucker (2001) Gartzke, Li and Boehmer (2001) Bennett and Stam (2000*a*) Lektzian and Souva (2001) Lemke and Reed (2001) Peet and Simon (2000) Mansfield and Pevehouse (2000) Bennett and Stam (2000*b*) Mousseau (2000) Oneal and Russett (1999*b*) Oneal and Russett (1999*a*)	**3 (3.3%)** Gelpi and Grieco (2001) Simmons (2000) Beck, King and Zeng (2000)
Time Dummies	**24 (85.7%)** Brinks and Coppedge (2006) Volden (2006) Stein (2005) Chang (2005) Krutz (2005) Heath (2005) Lebovic (2004) Stalley (2003) Arceneaux (2003) Lebovic (2003) Gelpi and Feaver (2002) Howard and Roch (2001) Henisz (2002) Dickinson and Tenpas (2002) Ka and Teske (2002) Volden (2002) Ka and Teske (2002) Crowley and Skocpol (2001)[3] Balla (2001) Mooney (2001) Mooney and Lee (2000) Palmer and Whitten (2000) Reed (2000) Thacker (1999) Leblang (1999)	**4 (14.3%)** James (2006) Carpenter and Lewis (2004) Bernard, Reenock and Nordstrom (2003)[2] Clark and Hart (1998)

Table 2: Estimates of $\hat{\beta}_1$

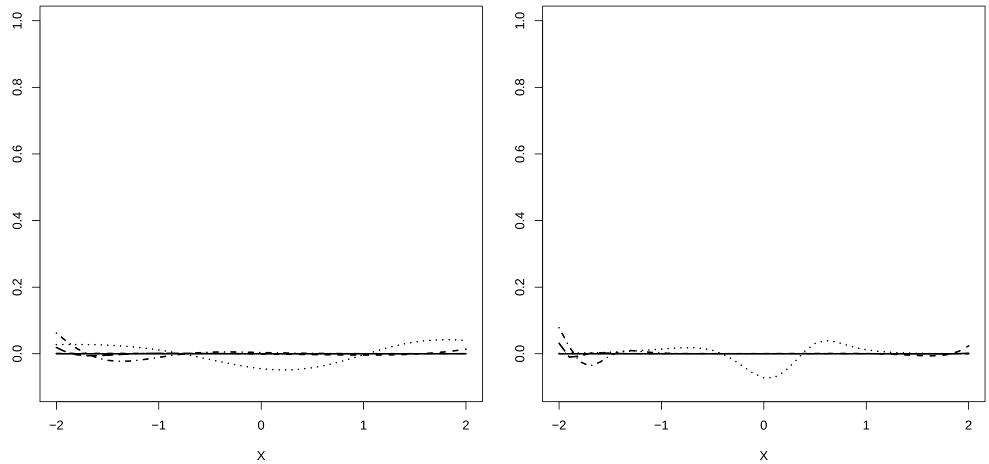
$\%y = 1$	clogog	logit
1%	1.03	1.04
5%	1.02	1.05
10%	1.01	1.08
28%	1.00	1.23
50%	1.00	1.46
76%	1.01	1.84
95%	1.01	2.59
99%	1.05	3.78

estimates from both of these are saved. For each (β_0, β_1) pair, the Monte Carlo analysis is run for 200 iterations. All estimates and plots reported in the following use the average estimates from those 200 iterations.

Table 2 displays the average $\hat{\beta}_1$ estimates for the Monte Carlos where the true $\beta_1 = 1$. Each row represents a different β_0. However, rather than displaying the associated β_0, we display the associated average percent of 1's present in the data, given that β_0. Thus, the table shows the cloglog and logit $\hat{\beta}_1$ when the percentage of 1's in the data were 1%, 5%, 10%,..., 95%, and 99%. As can be seen, the cloglog model recovers the true parameters on average. For very small percentages of 1's, the logit estimates are numerically very close. However, as the percentage of 1's in the data increases, the numerical values increase relative to the cloglog estimates. So, is there a difference in the cloglog vs logit estimates? The answer is clearly "yes." Moreover, the results (not shown here) for the other slope parameters (β_1 =2,3,8) show the same behavior. However, that is unsurprising – the estimates are from regressions based on different probability models. We are usually not interested in comparing the exact numerical estimates from different probability models. Of more interest is how the predicted probabilities differ based on these estimates.

Figure 1 plots the difference between cloglog and logit predicted (or fitted) probabilities as a function of the regressor x. Figure 1(a) is based on the estimates when the slope parameter $\beta_1 = 1$. Figure 1(b) shows the results for the $\beta_1 = 3$ case. In each graph, the differences are plotted using the estimates from the 1%, 5%, 50%, 95%, and 99% cases

Figure 1: Difference in Predicted Probabilities between cloglog and logit

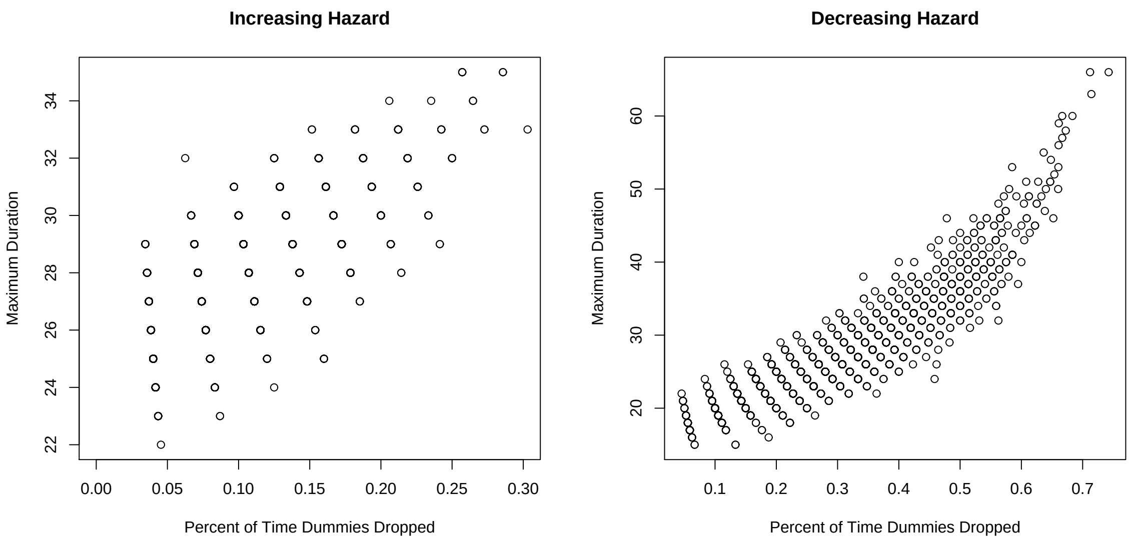


(a) $\beta_1 = 1$ (b) $\beta_1 = 3$

(each represented by a different line). As both plots demonstrate, the magnitude of the difference is never more than about .1 – and is often quite less. The largest differences occur around the inflection points of the S-curves. Thus, we confirm BKT's finding that the differences between cloglog and logit are slight.

2.2 Time Dummies and Separation Issues: Additional Results

Figure 2 shows additional Monte Carlo results on the problem of quasi-complete separation with time dummies. Specifically, we report results that demonstrate how the percentage of time dummies dropped in each Monte Carlo iteration increase as a function of the maximum value of duration in that iteration. In the article, we report results for a non-monotonic hazard but do not report results for the increasing and decreasing hazards in the interest of space. We report both of these results here. Note that the shape of the plots is the same as in the non-monotonic case reported in the article. The main difference between the two shown here is that the problem of separation is more severe in the decreasing hazard case, which was also noted in the article.



(a) Increasing Hazard

(b) Decreasing Hazard

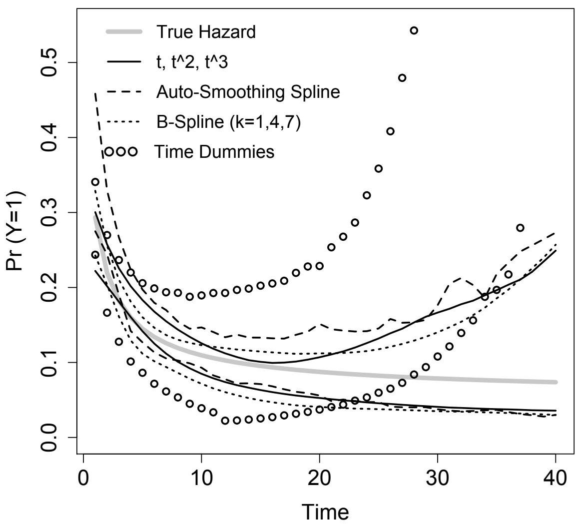
Figure 2: Percent of Time Dummies Dropped as a Function of Maximum Duration

2.3 Confidence Intervals

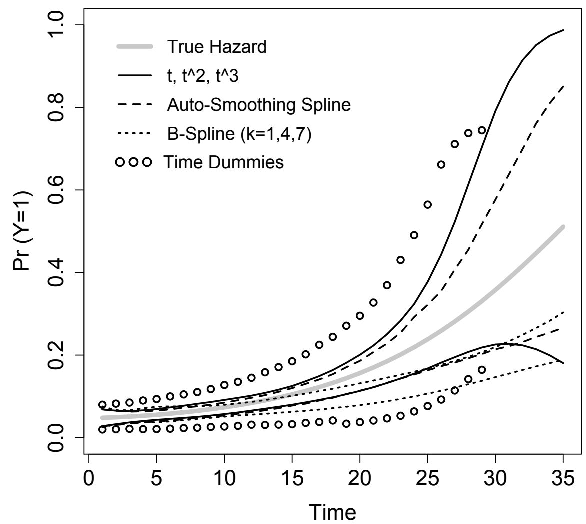
Figure 3 shows estimated 95% confidence intervals for the predicted hazard rates in the paper. In all graphs, the thick grey line is the true hazard. In the decreasing hazard case depicted in figure 3(a), the cubic polynomial and both variants of spline perform quite similarly. The 95% confidence intervals for all three generally contain the true hazard across the entire x-axis and are of similar magnitude. Unsurprisingly, the confidence intervals are wider around the time dummies plot relative to the splines and cubic polynomial, which demonstrates that we have increased uncertainty around these probability estimates. Of even greater concern is the fact that the 95% confidence intervals for time dummies do not even contain the true hazard after about $t = 28$ on. Interestingly, the auto-smoothing spline produces somewhat bumpy lines for longer durations where there are relatively few observations. This indicates that the auto-smoothing spline can suffer from sensitivity to a few observations in a manner similar to time dummies. Of course, this presumes that the researcher simply uses the "default" settings provided by the statistical package.[4]

Figure 3(b) shows that while B-splines suffer from poor knot placement in the increasing hazard case, the other three methods perform reasonably well. As noted in the main

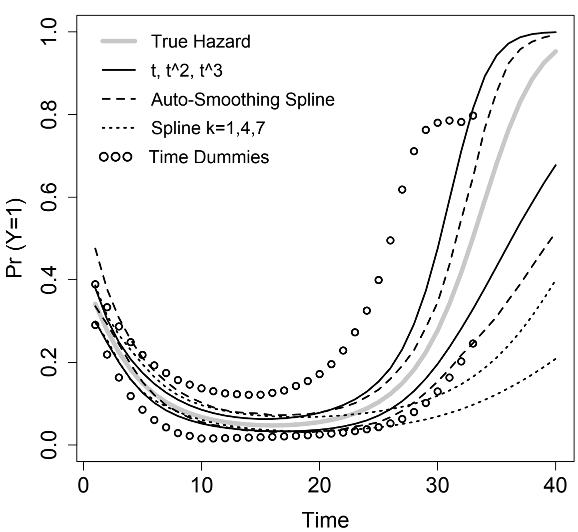
[4] In this case, the `mgcv` package in R is utilized.



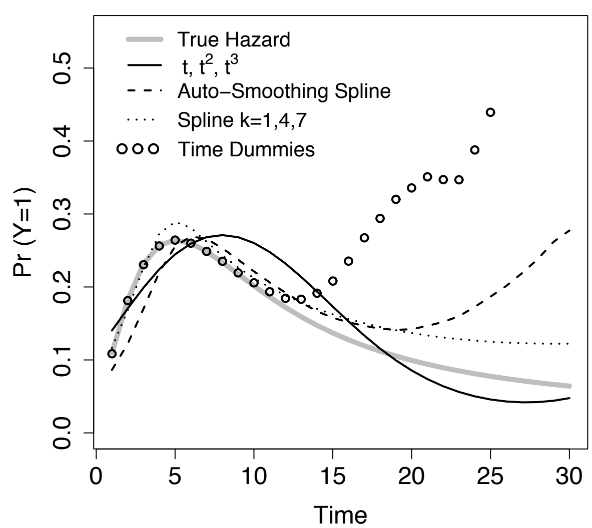
(a) Decreasing Hazard



(b) Increasing Hazard



(c) Non-Monotonic Hazard 1



(d) Non-Monotonic Hazard 2

Figure 3: Monte Carlo Comparison: Confidence Intervals

text of the paper, the estimated hazard produced by B-splines is biased and diverges considerably from the true hazard after about $t = 12$. While the 95% confidence intervals around the time dummies estimates always contain the true hazard, they are wider than both the auto-smoothing spline and the cubic polynomial. Additionally, separation issues cause the plot to not have estimates past $t = 28$.

Figure 3(c) compares confidence intervals for a non-monotonic hazard that takes the form of an asymmetric parabola. t, t^2, and t^3 outperforms both B-splines and time dummies in this case, as the B-splines produce a biased estimated hazard and perfect separation plagues time dummies. The 95% confidence bands for the B-spline hazard are not even close to including the true hazard for about 40% of the plot. The 95% confidence intervals for the automatic-smoothing spline are comparable to those of the cubic polynomial, although the the cubic polynomial performs better in the range $t \in [0, 8]$.

Both the cubic polynomial and B-splines perform reasonably well in the second non-monotonic hazard scenario. The B-spline outperforms the other three models as the knot placement ($k = 1, 4, 7$) is very appropriate for the curvature of the hazard. On the other hand, neither time dummies nor the auto-smoothing spline perform as well. The cubic polynomial suffers somewhat until $t = 12$ due to the global nature of its fit. The time dummies intervals become quite wide after $t = 12$ and do not contain the true hazard after $t = 20$. Surprisingly, the confidence intervals around the automatic smoothing spline estimates also become wide after $t = 16$, although they never fail to contain the true hazard.

2.4 No Temporal Dependence

How do the methods perform when there is no temporal dependence? To investigate this we ran a Monte Carlo of 1000 iterations in which we assume a constant hazard (i.e., exponential) and estimated logit with B-splines, time dummies, and a cubic polynomial. Given that there is no temporal dependence present, none of the methods should indicate that there is a significant temporal trend. The results are presented in table 3. Notice that neither the cubic polynomial nor the cubic B-spline indicates that a significant temporal trend is present. In contrast, many of the time dummies are significant. In fact, 12 of the 21 estimated dummies are significant at the 0.05 level. This is because the time dummies are trying to pick up the constant hazard rate. Finally, note that the coefficient on X_1, or the substantive coefficient of interest, is unaffected by the inclusion of any of the temporal

Table 3: Constant Hazard

Variable	True Value	t, t^2, and t^3	B-splines	Time Dummies
Constant	-1.65	-1.70	-1.63	-1.66
		(0.17)	(0.19)	(0.13)
X_1	1.00	1.00	1.00	1.02
		(0.06)	(0.06)	(0.06)
t		0.31		
		(0.83)		
t^2		-0.52		
		(1.02)		
t^3		0.21		
		(0.35)		
Spline2			-0.10	
			(0.41)	
Spline3			0.02	
			(0.57)	
Spline4			0.23	
			(0.73)	

variables.

2.5 Time-Trended Covariate

None of the Monte Carlo experiments in the paper include time-trended covariates. Given the potential importance of this issue, we provide results from additional Monte Carlos to demonstrate that the current results are not sensitive to time-trending covariates.

We focus our analysis on the increasing hazard case, since this is a scenario in which all methods in our manuscript perform well (including time dummies). This is a scenario in which poor performance by any of the methods can be more safely attributed to the inclusion of a time-trended variable.

In the Monte Carlos, we generate the data according to a logit model with a constant (-2.65) and one covariate X with a coefficient of one. We time-trend our covariate, X,

Table 4: Time Trended Covariate

(a) Covariate X with Decreasing Time Trend.

Variable	True Value	t, t^2, & t^3	Splines	Time Dummies
Constant	-2.65	-2.77	-2.36	-2.69
		(0.30)	(0.30)	(0.34)
X	1.00	1.01	1.01	1.03
		(0.16)	(0.16)	(0.16)

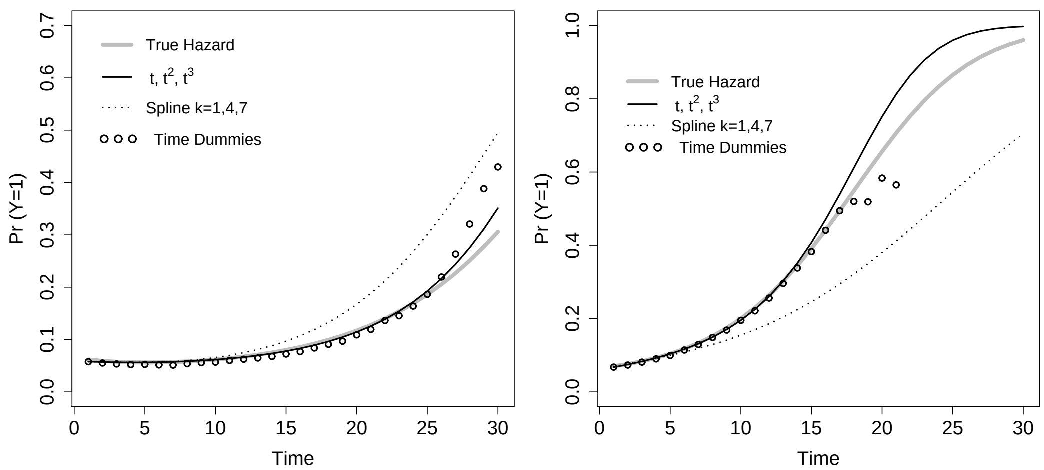
(b) Covariate X with Increasing Time Trend.

Variable	True Value	t, t^2, & t^3	Splines	Time Dummies
Constant	-2.65	-2.74	-2.38	-2.66
		(0.30)	(0.27)	(0.24)
X	1.00	1.01	1.01	1.02
		(0.13)	(0.13)	(0.13)

by adding or subtracting a function of time from the uniform random variable. In the case of a decreasing time-trended covariate, our covariate is $X_t = U(-1, 1) - t/10$ – i.e., we generate a uniformly distributed random variable for that observation and subtract the time trend $t/10$. This variable trends negative as the duration increases, slightly counteracting the increasing hazard. In the case of an increasing time trended covariate, we generate a variable distributed $U(-1, 1)$ and added a time trend, $t/30$. A time-trend of slightly smaller magnitude was required in this case because of the positive impact it had on the $\Pr(Y = 1)$ along with the increasing failure rate of the hazard. In each iteration of the Monte Carlo analysis, 2000 observations were generated; logit with t, t^2, and t^3 was estimated; logit with splines was estimated (using the k=1,4,7 knots); and logit with time dummies was estimated (keeping the constant and dropping the first time dummy). A total of 1000 Monte Carlo iterations were run.

Table 4 shows the mean and standard deviation of the Monte Carlo estimates for the constant and covariate for (a) X with a decreasing time trend and (b) X with an increasing

Figure 4: Hazard with Time Trended Covariate



(a) Decreasing Trend in X (b) Increasing Trend in X

trend. Each subtable displays these results for the three models. As the tables show, neither the constant nor the covariate coefficient are seriously affected by the inclusion of a time-trended covariate.

Figure 4 displays the hazard plots for these two cases (decreasing and increasing trending). Again, we see that all three models track the true hazard fairly well. The exception is the model with splines. However, this is only because this is the version with knots at k=1,4,7. The auto-smoothing spline performs as well as the cubic polynomial, so we did not add it to the plot. Consistent with our findings throughout the paper, the performance of time dummies is worse relative to t, t^2, and t^3.

In sum, then, although this is by no means a comprehensive analysis of the effect of trending covariates, it does provide some confidence that our results are not completely fragile in this situation. Figure 4 demonstrates that both cubic B-splines and a cubic polynomial perform quite well in the presence of a time-trended covariate.

3 Additional Empirical Replications

In this section we provide results from two additional empirical replications not included in the main text of the paper: a study of trade and conflict by Oneal and Russett (1997) and a study of democratic heterogeneity and conflict by Palmer, London and Regan (2004).[5] Additionally, we report predicted probabilities and estimates for the non-proportional hazards results from the Crowley and Skocpol (2001) replication.

3.1 Trade and International Conflict

In an influential article, Oneal and Russett (1997) find that the probability of war is significantly lowered both when two states are democracies and when two states have high levels of trade. Beck, Katz and Tucker (1998) show that the latter relationship no longer significantly lowers the probability of conflict when time dependence is taken into account. Thus, "political liberalism" seems to find support even when the effects of time are taken into account, while "economic liberalism" is not robust. We replicate the results found in both Oneal and Russett (1997) and Beck, Katz and Tucker (1998) and demonstrate that logit with t, t^2, and t^3 obtains the same results.

Table 5 contains the results of using logit with time dummies, spline, and a cubic polynomial. Columns 1 and 3 are replications of the results found in Beck, Katz and Tucker (1998), while columns 2 and 4 show logit with B-spline and t, t^2, and t^3 respectively. Notice that the results across the four different specifications are remarkably similar. The main finding, that trade does not significantly affect the probability of conflict in the period under study, holds up when using logit with t, t^2, and t^3.

In order to more fully assess whether the results of logit with time dummies or spline are substantively no different than of logit with t, t^2, and t^3, we also plot the hazard in Figure **??**. The curves are quite similar, although the logit with t, t^2, and t^3 probability estimate for the year immediately following a conflict (or in some cases the first year included in the data) is slightly lower, ≈ 0.17, than either of the other two estimates, which are ≈ 0.22. The t, t^2, and t^3 curve also decreases less drastically after the first year, but the overall differences are slight in terms of substantive interpretation.

3.2 Parliamentary Democracies and the Initiation of Militarized Disputes

Palmer, London and Regan (2004) examine how heterogeneity among parliamentary democ-

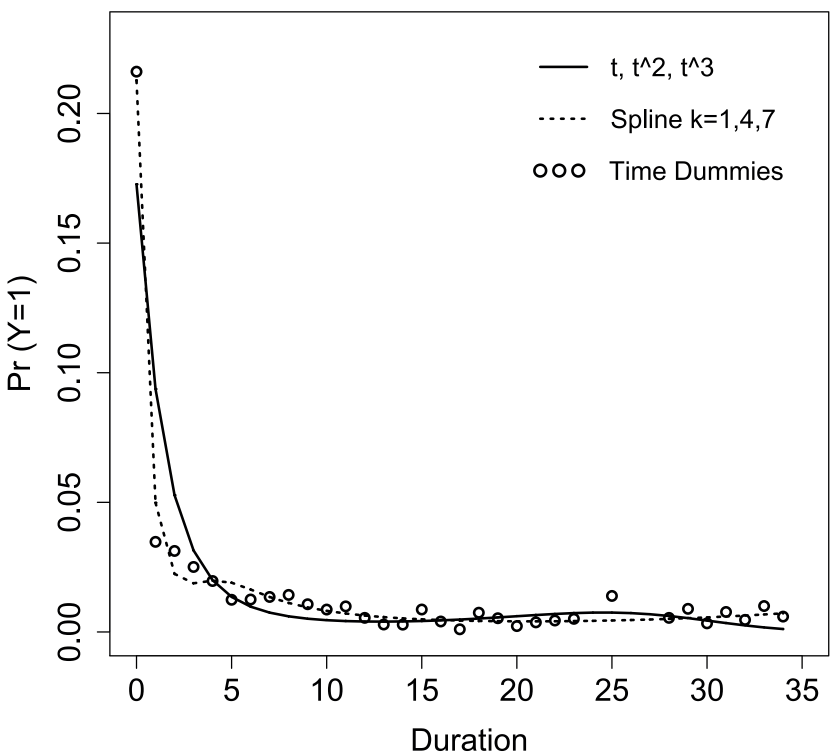
[5] We do not report results for logit with automatic-smoothing splines for these two replications. However, we did run logit with automatic smoothing spline for both replications and found no meaningful differences relative to the other two methods.

Table 5: Oneal and Russett Logit Replication

	Time Dummies	B-Spline	Natural Cubic Spline	t, t^2, t^3
Constant	**-0.943**	**-0.966**	**-0.965**	**-1.209**
	(0.093)	(0.093)	(0.093)	(0.090)
Democracy	**-0.547**	**-0.546**	**-0.546**	**-0.537**
	(0.080)	(0.080)	(0.080)	(0.078)
Economic Growth	-0.115	-0.115	-0.115	-0.155
	(0.092)	(0.092)	(0.092)	(0.090)
Alliance	**-0.471**	**-0.470**	**-0.470**	**-0.489**
	(0.090)	(0.090)	(0.090)	(0.087)
Contiguous	**0.699**	**0.694**	**0.694**	**0.667**
	(0.089)	(0.089)	(0.089)	(0.087)
Capability Ratio	**-0.303**	**-0.304**	**-0.304**	**-0.308**
	(0.042)	(0.042)	(0.042)	(0.042)
Trade	-12.675	-12.884	-12.889	-14.078
	(10.499)	(10.505)	(10.505)	(10.650)
t			**-1.820**	**-7.457**
			(0.111)	(0.340)
t^2				**4.422**
				(0.345)
t^3				**-0.788**
				(0.088)
Spline1		**-2.331**	**-245.712**	
		(0.156)	(26.123)	
Spline2		**-3.637**	**79.705**	
		(0.277)	(10.951)	
Spline3		**-6.711**	**-11.028**	
		(0.246)	(2.759)	
Spline4		**-2.294**		
		(0.361)		
Log-Likelihood	-2554.723	-2582.876	-2582.877	-2658.931
N =	20074	20990	20990	20990

Standard errors in parentheses. Bold estimates: $p < .05$

Figure 5: Hazards for Oneal and Russett Replication



racies affects conflict initiation and escalation decisions. The authors push beyond the standard approach in the democratic peace literature and challenge the idea that all democracies are a homogenous set. In particular, they examine how the following factors affect the initiation and escalation of militarized inter-state disputes: whether or not there is a single ruling party or multiple parties in a coalition, the "left-right" orientation of the ruling party or coalition, the size of the ruling coalition, and whether the government is a minority or majority government. Analysis is conducted on eighteen parliamentary democracies during the period 1949–1992 with separate logit models for initiation and escalation.[6] While the investigation of how the behavior of parliamentary democracies is affected by their past involvement in conflicts would also be of interest, Palmer, London and Regan (2004) do not pursue it for one of the same reasons we criticize time dummies in our paper. As mentioned above, time dummies bring about severe separation issues in their data that result in the loss of 672 out of 2975 observations ($\approx 22.6\%$) as well as 19 of 39 time dummies ($\approx 48.7\%$). Given that almost half of the time dummies had to be dropped, the authors quite reasonably concluded that it was "too high a price to pay (21)", especially given that almost half of the information about time is lost anyhow.

We replicate their results regarding parliamentary democracies' decisions to initiate militarized interstate disputes (MIDs) and reanalyze their data accounting for time with a cubic polynomial, time dummies, and cubic B-spline. The results of the four regressions are shown in table 6.[7] Note that when the effects of time are estimated, none of the variables that pertain to the type of government are statistically significant. The only statistically significant variable is the state's relative military power, which is not a particularly striking finding. Thus, once the effects of time are accounted for, heterogeneity among parliamentary democracies is no longer a strong predictor of conflict initiation.

We also estimate the hazard for logit with a cubic polynomial, spline, and time dummies. The resulting hazard plots are shown in figure 6. Notice that the estimated hazard plots for the cubic polynomial and spline are essentially identical, while the time dummies plot is jagged and missing almost half of the plot due to quasi-complete separation. The plot shows that conflict is most likely in years immediately following conflict, becoming quite unlikely after approximately five years have passed without a militarized conflict. The probability of a parliamentary democracy initiating a MID starts to increase after around two decades of peace, increasing through the maximum duration of 38 years.

[6] They test for selection effects and find none.

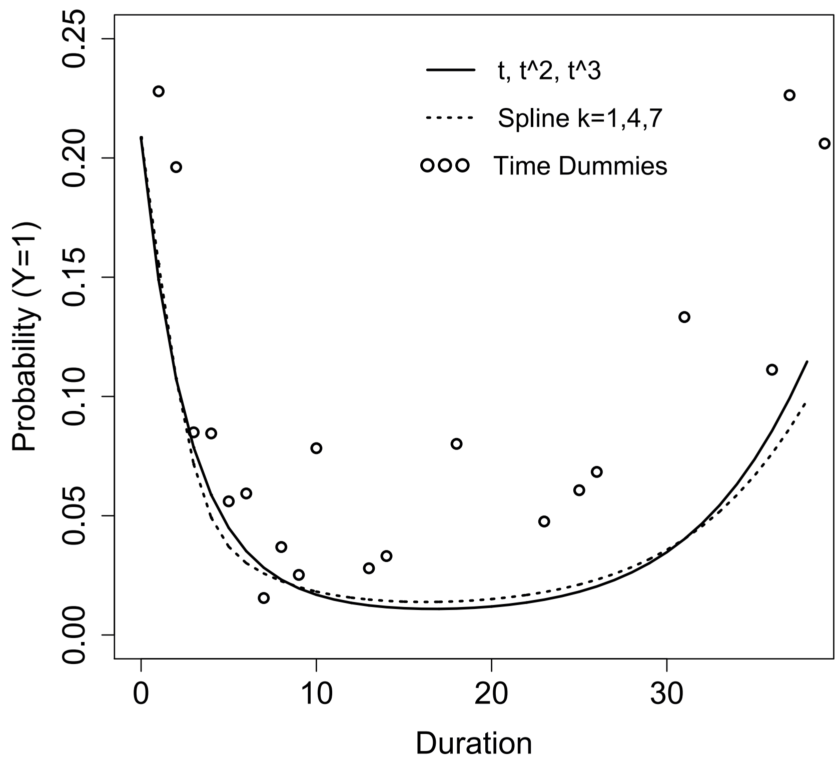
[7] Likelihood ratio tests show that any of the methods for estimating the effects of time are warranted.

Table 6: Palmer, London and Regan (2004) Logit Reanalysis

	Original	Time Dummies	B-Spline	t, t^2, t^3
Constant	**-4.474**	**-2.313**	**-2.328**	**-2.350**
	(0.748)	(0.860)	(0.853)	(0.852)
Coalition Score	**0.142**	0.072	0.070	0.072
	(0.067)	(0.067)	(0.066)	(0.066)
One Pivotal Party	-0.015	-0.111	0.009	0.025
	(0.489)	(0.528)	(0.591)	(0.595)
Multiple Pivotal Parties	-0.636	-0.357	-0.267	-0.267
	(0.390)	(0.528)	(0.522)	(0.527)
% of Seats held by Govt.	**0.018**	0.006	0.005	0.005
	(0.007)	(0.007)	(0.007)	(0.007)
Minority Govt.	-0.627	-0.638	-0.555	-0.560
	(0.421)	(0.587)	(0.582)	(0.587)
Single-Party Govt.	-0.691	-0.444	-0.352	-0.354
	(0.383)	(0.530)	(0.525)	(0.530)
Military Power	**0.450**	**0.244**	**0.245**	**0.248**
	(0.039)	(0.042)	(0.042)	(0.042)
t				**-4.231**
				(0.686)
t^2				**1.658**
				(0.576)
t^3				-0.156
				(0.119)
Spline1			**-1.806**	
			(0.377)	
Spline2			**-3.721**	
			(0.762)	
Spline3			**-2.820**	
			(0.496)	
Spline4			-0.633	
			(0.600)	
Log-Likelihood	-737.075	-659.093	-677.723	-678.276
N =	2975	2303	2975	2975

Standard errors in parentheses. Bold estimates: $p < .05$

Figure 6: Quasi-Complete Separation in Palmer, London and Regan (2004)



While full analysis of this hazard via a thorough examination of cases is beyond the scope of this paper, this counterintuitive upward trend in conflict initiation among democracies is a trend worthy of further investigation.[8]

3.3 Additional Crowley and Skocpol Replication Materials

In the text of the article we demonstrate that Crowley and Skocpol's most substantively important regressor, the average pension received by Union Civil War pensioners in a given state, exhibits non-proportionality in time. Furthermore, we note that the non-proportional effects are actually expected given Crowley and Skocpol's theory. To demonstrate this we report how the shape of the hazard changes as a function of the average pension recieved by Union Civil War pensioners in a state. In table 7, we report the ac-

[8] 442 observations reach a duration of greater than 20, so this is not a negligible portion of the sample.

tual regression results along with the results for the original (i.e., restricted) model. Note that the main findings remain unchanged. Additionally, note that the likelihood ratio test statistic is 20.68 with 3 degrees of freedom, which is significant at any conventional level.

We also replicate the predicted hazard values presented by Crowley and Skocpol (2001) to assess whether the same substantive predictions are obtained from logit with t, t^2, t^3 as were obtained from logit with time dummies. Table 3.3 contains our replication of the predicted hazard rates from Crowley and Skocpol (2001) and the hazard rate predictions from logit with t, t^2, t^3. Examination of the two sets of probabilities demonstrates that there are no large substantive differences between the two models, although the predicted hazards from the model with the cubic polynomial are slightly higher.

Table 7: Crowley and Skocpol Logit Replication

	Restricted Model	Unrestricted Model
Constant	**-2.19**	**-2.46**
	(.43)	(.44)
Urban Growth	.10	**.12**
	(.06)	(.06)
Manufacturing Per Capita	-.15	-.14
	(.29)	(.29)
Railroad Mi. Per Capita	-18.48	-20.70
	(10.52)	(10.60)
Teachers Per Capita	-7.13	-7.13
	(8.68)	(9.01)
Percent Literate	.040	.045
	(.053)	(.053)
Percent in Union Armies	**.031**	**.033**
	(.010)	(.010)
Pension $ Per Pensioner	**.38**	**.63**
	(.08)	(.10)
Pension $ Per Pensioner $*t$		**-.71**
		(.37)
Pension $ Per Pensioner$*t^2$		.19
		(.34)
Pension $ Per Pensioner$*t^3$		-.018
		(.071)
Electoral Competitiveness	**.043**	**.042**
	(.016)	(.016)
Foreign Born Growth	.004	.024
	(.08)	(.091)
Population Growth	-.001	-.002
	(.001)	(.001)
Odd Fellows Per Capita	.35	3.36
	(6.56)	(6.65)
Percent Protestant	**.072**	**.062**
	(.028)	(.029)
Neighbor Effects	**.28**	**.296**
	(.04)	(.044)
t	**.55**	**1.43**
	(.18)	(.54)
t^2	**-.23**	-0.41
	(.09)	(.50)
t^3	.014	0.028
	(.014)	(.11)
Log-Likelihood	-1544.44	-1534.10
N =	2529	2529

Standard errors in parentheses . Bold estimates: $p < .05$

Table 8: Hazard Rate Predictions from Crowley and Skocpol Reanalysis

Pension Dollar Expended Per Pensioner	0% in Union Armies	5% in Union Armies	10% in Union Armies	15% in Union Armies
$0	.20 (.27)	.23 (.30)	.25 (.34)	.28 (.37)
$50	.24 (.31)	.27 (.35)	.30 (.38)	.33 (.42)
$100	.29 (.35)	.32 (.39)	.35 (.43)	.39 (.47)
$150	.34 (.40)	.38 (.44)	.41 (.47)	.44 (.51)
$200	.40 (.44)	.43 (.48)	.47 (.52)	.51 (.56)
$250	.45 (.49)	.49 (.53)	.53 (.57)	.57 (.61)

Logit with Time Dummies produced the probabilities outside of parentheses.
Logit with t, t^2, and t^3 produced probabilities in parentheses

A Example R and Stata Programs

The following four sections provide R and Stata code demonstrating how to estimate logit or cloglog models that smooth time using (1) a cubic polynomial approximation (i.e., t, t^2, and t^3) and (2) cubic splines. Note that the cloglog code is currently commented out in the example programs. The code assumes the dataset has already been loaded into either R or Stata. y is the dependent variable; $x1$ and $x2$ are the independent variables; and tim is the variable denoting the time since the last event.

A.1 Logit with t, t^2, t^3: R Program

```
# Create t^2 and t^3 variables
tim2 <- tim^2
tim3 <- tim^3

# Estimate logit with cubic polynomial
fit <- glm(y~x1+x2+tim+tim2+tim3,family=binomial(link="logit"))
# Alternatively, one can estimate a cloglog model
# fit <- glm(y~x1+x2+tim+tim2+tim3,family=binomial(link="cloglog"))

# To calculate fitted values, first create sequence of time values
# over entire range.
timseq <- 0:max(tim)

# Create X matrix by appending 1 for constant, means of x1 & x2,
# and then time sequence, squared, and cubed.
# Note: These need to be in the same order as estimated betas.
newX <- cbind(1,mean(x1),mean(x2),timseq,timseq^2,timseq^3)

# Use newX and estimated betas for XB
Bhat <- fit$coefficients
XBhat <- newX%*%Bhat

# Calculate logit fitted values
prob <- 1/(1+exp(-XBhat))
# Alternatively, calculate cloglog fitted values
# prob<- 1-exp(-exp(XBhat))

# Plot estimated Pr(Y=1|t)
plot(timseq,prob,type="n",xlab="t",ylab="Pr(Y=1|t)",lty=1,lwd=2)
```

A.2 Logit with t, t^2, t^3: Stata Program

```
# Generate t^2 and t^3 variables
gen tim2=tim*tim
gen tim3=tim2*tim

# Estimate logit model with cubic polynomial
logit y x1 x2 tim tim2 tim3
# Alternatively, one can estimate a cloglog model.
# cloglog y x1 x2 tim tim2 tim3

# Generate means of x1 and x2
egen meanx1=mean(x1)
egen meanx2=mean(x2)

# Drop rows not needed for prediction
duplicates drop tim, force

# Only keep variables needed for prediction
keep tim tim2 tim3 x1mean x2mean

# Rename x1 and x2
rename x1mean x1
rename x2mean x2

# Predict Pr(Y=1)
predict p1

# Relabel X and Y axis for more readable graph.
label var p1 "Probability Y=1"
label var tim "Time"

# Plot estimated Pr(Y=1|t)
twoway line p1 tim
```

A.3 Logit with Cubic Splined Time: R Program

```
# Load package with spline procedures
library(splines)

# Generate spline basis vectors using knots=1,4,7.
# Note: these are simply examples used in BKT and may not be
# appropriate for your application.
k <- c(1,4,7)
basis <- ns(tim,knots=k)

# Estimate logit model with cubic splined time.
# Must omit either constant or one of spline base vectors.
# Here: omitting constant.
fit <- glm(y~x1+x2+basis-1,family=binomial(link="logit"))

# Alternatively, one can estimate a cloglog model
# fit <- glm(y~x1+x2+basis-1,family=binomial(link="cloglog"))

# To calculate fitted values, first create sequence of time values
# over entire range.  Assumes time takes only integer values.
timseq <- 0:max(tim)

# Generate basis for new time sequence and then append means of x1 & x2.
# Must use same knots as those in original data analysis.
# Note: Variables need to be in the same order as estimated betas.
newbasis <- ns(timseq,knots=k)
newX <- cbind(mean(x1),mean(x2),newbasis[,])

# Use newX and estimated betas for XB
Bhat <- fit$coefficients
XBhat <- newX%*%Bhat

# Calculate logit fitted values
prob <- 1/(1+exp(-XBhat))

# Alternatively, calculate cloglog fitted values
# prob<- 1-exp(-exp(XBhat))

# Plot estimated Pr(Y=1|t)
plot(timseq,prob,type="n",xlab="t",ylab="Pr(Y=1|t)",lty=1,lwd=2)
```

A.4 Logit with Cubic Splined Time: Stata Program

```
# Observe minimum and maximum tim values and allow Stata to store as scalars.
sum tim

# Generate scalars for minimum and maximum of tim
local min = r(min)
local max = r(max)

# Generate spline basis vectors using knots=1,4,7. Note: these are simply
# examples used in BKT and may not be appropriate for your application.
mkspline basis=tim, cubic knots(‘min’,1,4,7,‘max’)

# Estimate logit model with cubic splined time.
logit y x1 x2 basis1 basis2 basis3 basis4
# Alternatively, one can estimate a cloglog model.
# cloglog y x1 x2 basis1 basis2 basis3 basis4

# Generate variables for means of x1 and x2.
egen x1mean=mean(x1)
egen x2mean=mean(x2)

#drop duplicates of tim variable duplicates
drop tim, force

# Only keep variables needed for prediction
keep tim x1mean x2mean

# Must use same knots as those in original data analysis.
# Names of variables must match those when original model was estimated.
mkspline basis=tim, cubic knots(‘min’,1,4,7,‘max’)

# Rename x1mean and m2mean
rename x1mean x1
rename x2mean x2

# Predict Pr(Y=1)
predict p1

# Relabel X and Y axis for more readable graph.
label var p1 "Probability Y=1"
label var tim "Time"

# Plot estimated Pr(Y=1|t)
twoway line p1 tim
```

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