

The Political Violence Cycle

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Elections are often violent affairs, casting doubt on the canonical claim that democracy makes societies more peaceful by creating nonviolent means to contest for power. We develop a formal argument to demonstrate that this conclusion is incorrect. Holding elections has a direct effect of increasing levels of violence close to the voting, as this is when electoral violence can influence political outcomes. Precisely for this reason, elections also have an indirect effect of decreasing levels of violence at all other times, as parties can wait for the election when their efforts are more likely to succeed. The direct and indirect effects generate a “political violence cycle” that peaks at the election. However, when the indirect effect is larger, politics would be more violent without elections. When elections also provide an effective nonviolent means to contest for power, they unambiguously make society more peaceful while still generating a political violence cycle.

Sick of elecshun [sic] related violence and terror attacks. Can't wait for elecshuns to be over and get non-elecshun related violence back.

—A tweet from the satirical and pseudonymous @majorlyp during the 2013 Pakistani elections

A prominent argument for democracy centers around the fact that elections allow political groups to compete via ballots rather than bullets. However, elections are often violent affairs. Conflict surrounding the 2007 elections in Kenya led to around a thousand deaths and hundreds of thousands displaced. Similarly, dozens were killed in the May 2013 election-related violence in the Philippines. More generally, electoral violence is not a new phenomenon nor limited to nascent democracies, but a problem “virtually all states have experienced” (Rapoport and Weinberg 2000, 42). As many Western governments and NGOs at least nominally encourage other countries to hold elections, the question of whether doing so incites violence is of great practical as well as theoretical importance.

That elections are a necessary condition for electoral violence is tautological; of greater interest is how elections affect patterns of political violence more generally. Still, recent empirical studies have found that various forms of political violence sometimes *do* spike around elections (e.g., Aksoy 2014; Hafner-Burton, Hyde, and Jablonski 2014; Newman 2013). Figure 1 illustrates this pattern for several African countries in a way that will relate closely to our theoretical model.

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Previous versions of article were presented at the European Political Science Association 2014 Annual Meeting, the International Studies Association 2015 Annual Meeting, the Midwest Political Science Association 2015 Annual Meeting, and the Berkeley Center for Political Economy. Many thanks to audience members at these seminars, Deniz Aksoy, Tiberiu Dragu, Patrick Kuhn, Tom Pepinsky, Mike Miller, Arturas Rozenas, Ignacio Sanchez-Cuenca, Inken von Borzyskowski, four anonymous referees, and the editors of the *APSR* for helpful comments and discussion. All remaining errors are ours.

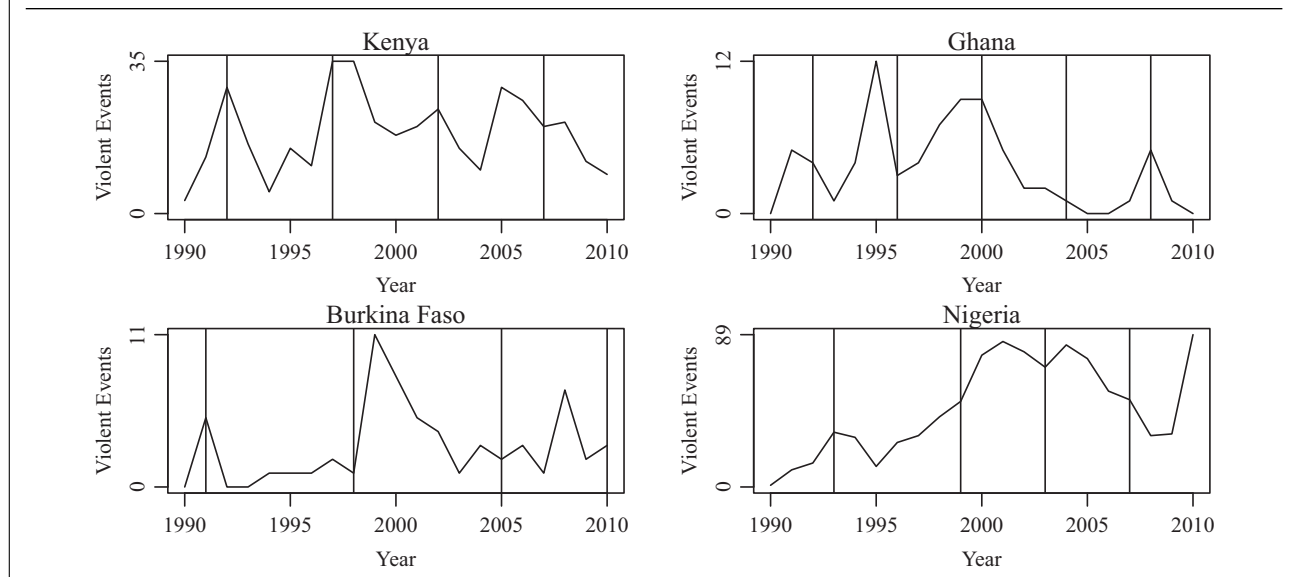
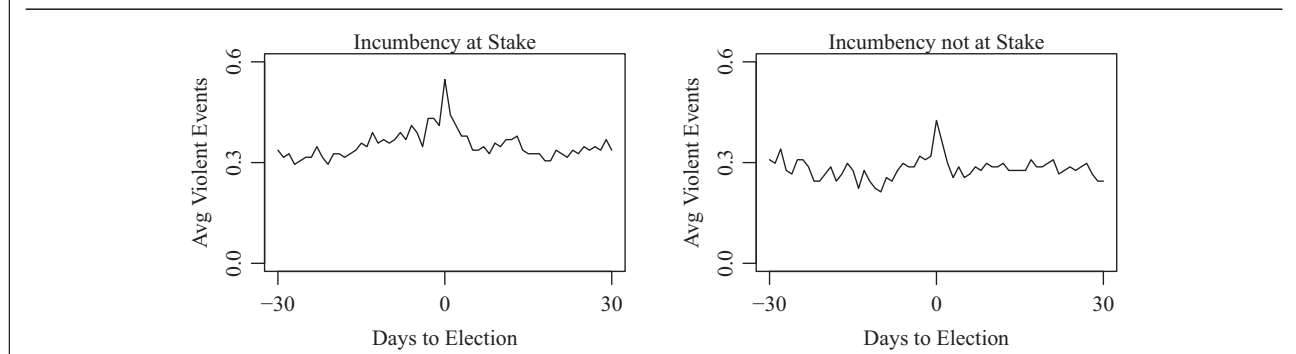
Received: June 5, 2016; revised: August 19, 2016; accepted: September 14, 2016.

Each panel shows yearly counts of violent events in a country from the Social Conflict Analysis Database (SCAD) for 1990–2010 (Saleyhan et al. 2012) with vertical lines illustrating years with elections where the chief executive office was at stake (Hyde and Marinov 2012). Kenya illustrates the pattern we seek to explain starkly: in three out of four years with elections, there were more violent events than the years before and after. Ghana experienced similar spikes in violence around elections in 2000 and 2008, though the most violent year was the one preceding an election (1995). In Burkina Faso, the largest spike of violence occurred in the year following an election, while in Nigeria patterns in violence seems unrelated to election years.

A clearer view of this “political violence cycle” emerges when aggregating across countries and taking a more fine-grained time window. Figure 2 presents the average daily level of violence from a month before to a month after election day, for elections where the office of the incumbent leader was (left panel) and was not (right panel) at stake, using the full sample of SCAD (which includes Latin America in addition to Africa). Two patterns readily stand out: first, there is a cyclical pattern with a clear spike in violence around the day of the election for both types of elections. Second, there is a higher (average) level of violence around elections when the incumbent leader’s office was in contention. (See the Appendix for a complete description of the data and procedures that generate these graphs.)

Motivated by patterns like this and the association between elections and violence more generally, some have suggested that promoting elections could be dangerous in certain contexts (Brancati and Snyder 2012; Collier 2009; Flores and Nooruddin 2012). More frequently, scholars of the relationship between elections and violence do not advocate against holding elections, but do express a clear unease that their results could be used to make such an argument.¹ And these fears are

¹ For example, Chenoweth (2010, 28) succinctly summarizes this notion in the context of terrorism, noting that “Most studies that establish a positive relationship between terrorism and democracy find themselves in awkward positions because of the implications of their results—namely, that undermining democracy may also

FIGURE 1. Counts of Violent Events for Select African Countries by Year, with Vertical Lines at Years with Elections where the Office of the Incumbent was Contested**FIGURE 2. Average Counts of Ongoing Violent Events by the Number of Days to the Closest Election for Full Sample of SCAD**

not unfounded: those writing for more general audiences have used this association to discourage democracy promotion, e.g., calling elections or democracy more broadly a “curse” (Economist 2013) or “among the causes of both the Rwandan and Yugoslavian genocides” (Chua 2004, 12).

We provide a simple and general formal argument which demonstrates that spikes of violence during elections cannot be used as evidence that elections make politics more violent on average.² The crux of our ar-

undermine terrorism.” Hafner-Burton, Hyde, and Jablonski (2014, 175) note that “scholars and pundits may be tempted to interpret the fact that leaders sometimes use political violence to manipulate elections as confirmation that elections are necessarily ‘bad’ for countries without a history of elections and democracy,” though they caution against this conclusion. Even those criticizing a universal push for early elections warn that “our findings justify neither authoritarian leadership in postconflict countries nor the automatic postponement of postconflict elections” (Flores and Nooruddin 2012, 568).

² We always use the average level of violence as our metric of how peaceful society is. This is the natural statistic when thinking about

argument is that elections affect incentives to use violence to further political objectives not only leading up to and directly after the voting, but at all times. In particular, the presence of an election in the future can decrease incentives to commit violence today precisely because violence—as well as nonviolent political action—become more effective during electoral periods. That is, making electoral violence a more effective tool to change political outcomes has a *direct effect* of increasing violence surrounding elections, but this can be partially if not fully offset by an *indirect effect* of decreasing violence in the periods between elections. So, we cannot conclude from this evidence that elections—or more consequential elections—make politics more violent.

Our theoretical argument has important implications for the empirical study of electoral violence. The strategic use of violence around elections and

levels of violence as measuring things like the number of people killed.

associated temporal dynamics makes empirical assessment of how elections affect total violence levels extremely difficult, since it involves constructing the counterfactual of a world with less consequential elections or none at all. For example, when observing a country where violence increases during elections, it is tempting to conclude that politics would have been more peaceful without elections. However, the increase in violence could be driven by the direct effect or indirect effect described above (or both).

To allow for such counterfactual comparisons (albeit theoretically), we develop a series of formal models which generate dynamics similar to the empirical record with elections, and then ask what would happen were elections to become less consequential or nonexistent. In our main model, two parties compete over the spoils from holding office, and the party in opposition commits violence in an attempt to oust the incumbent.³ To set up a “hard case” for elections to have a pacifying effect, we take it as a given that violence is more effective in electoral periods, in the sense that a marginal increase in the opposition’s violent effort has a higher impact on their chance of taking over office. Consistent with Figures 1 and 2, this simple setup generates a political violence cycle, where conflict peaks in electoral periods. However, the presence of elections decreases the amount of violence in nonelectoral periods compared to a baseline where elections never happen. When the indirect effect of reducing violence in nonelectoral periods outweighs the direct effect of increasing violence during electoral periods, the average level of violence is *lower* in a society with elections than in the counterfactual without elections. So, our first main result is that even when assuming that the only thing elections do is periodically make violence more effective, the overall impact of elections can be to make politics more peaceful.

Our second main result is that a similar cyclical pattern of violence can arise if elections also provide a nonviolent means to contest for power and unambiguously make society more peaceful. To demonstrate this, we allow the opposition to also take nonviolent actions to increase their chance of taking office during electoral periods (e.g., campaigning). Providing this alternative means of contesting for power lowers the level of violence in electoral periods as well as the periods leading up to elections for a similar reason described above; there is less incentive to commit violence leading up to an electoral period when parties can wait until they are able to contest for power peacefully. If the relative cost of nonviolent political activity is sufficiently low, there will *always* be less violence in a political system with elections; in fact, there may be less violence in *every* period compared to a baseline without elections. Further, when the nonviolent activity is sufficiently effective, peaks of violence can occur after the election, consistent with the prevalence of postelection protest, par-

ticularly in less-than-democratic countries (Daxecker 2012; Rozenas 2012; Hyde and Marinov 2014).

Finally, we conduct two additional extensions to demonstrate that the central arguments of the article apply to violence committed by different actors and with different goals. First, we allow the incumbent to commit violence, which shows that our model can also capture the (often more empirically relevant) incidence of violence perpetrated by government forces. Similar results hold even if the incumbent commits the vast majority of violence. Second, we consider violence used to attain more incremental political objectives than taking over office, which also leads to a similar cycle of violence around elections that can make society more or less peaceful on average. In sum, the models suggest that political violence committed by any actor for any purpose can follow a cyclical pattern peaking at election time without implying that there would be less violence of this form without elections.

RELATED WORK

Holding regular elections is central to democracy since it provides a mechanism through which societal differences are peacefully resolved and voters can hold their representatives accountable for their actions (Przeworski 2005; Przeworski, Stokes, and Manin 1999; Schumpeter 1942). However, a growing literature on when and why violence is used during elections has challenged this idea by showing the link between the central instrument of democracy and conflict.

The existing theoretical literature on electoral violence primarily analyzes how elites use violence around elections to improve their chances at the polls. For example, Ellman and Wantchekon (2000) present a model on how threats of violence influence policy choices of different parties. Similarly, Chaturvedi (2005) shows how elites use violence to influence both voter turnout and vote choice. In a similar vein, Collier and Vicente (2012) argue that in situations where violence is effective in swaying swing voters, some types of incumbents and challengers will use repression and terrorism, respectively. However, these models do not examine how elections affect incentives to commit violence in nonelectoral periods or what would happen in the absence of elections, so they tell us little about how elections affect patterns of political violence more generally.

Other recent game-theoretic work compares levels of violence in a game with and without elections, but only in a single period (Cox 2009; Little 2012). In many existing formal models, elections always reduce violence as—loosely speaking—voting or elections act as substitutes for fighting (Fearon 2011; Przeworski, Rivero, and Xi 2012), the election fully alleviates the uncertainty that can cause bargaining to break down (Cox 2009), or reducing antigovernment violence is the goal of elections (or democratizing) and hence they are only held when serving this end (Acemoglu and Robinson 2000; Little 2012).

³ As discussed below, we allow only the opposition to commit violence in the first model to illustrate our argument in a simple fashion, but later show the conclusions hold when the incumbent commits violence as well.

A considerable empirical literature supports the more skeptical theoretical models. For instance, Hafner-Burton, Hyde, and Jablonski (2014) show that incumbents will use violence during electoral periods when she fears losing power or when there are institutionalized constraints, but that this may also lead to risky postelection violence (Hafner-Burton, Hyde, and Jablonski 2015).⁴ Similarly, Aksoy (2014) shows that electoral violence is more likely in places with low “electoral permissiveness.” Both Wilkinson (2004) and Brass (2003) describe how Indian elites use violence to increase the turnout of their supporters and decrease that of the challengers. Using data from Africa, Daxecker (2012) argues international monitoring of flawed elections can raise the salience of fraud and consequently the risk of postelection violence, and Kasara (2015) shows how violence may also influence future (and not just upcoming) elections in Kenya. Elections may be particularly dangerous in countries that have recently transitioned from an autocracy to a democracy (Cederman, Hug, and Krebs 2010; Collier 2009), or that have recently recovered from conflict (Brancati and Snyder 2012; Flores and Nooruddin 2012; Reilly 2002).⁵

Most directly related to our model is a burgeoning empirical literature which focuses specifically on spikes in violence, repression, and terrorism during electoral periods (Bekoe 2012; Goldsmith 2014; Newman 2013; Norris, Frank, and Martinez i Coma 2015; Staniland 2015). The types and perpetrators of violence may also change surrounding elections: e.g., Straus and Taylor (2012) show that incumbents tend to inflict violence before the vote and challengers are more likely to be involved in postelection violence.

While this empirical literature has highlighted potential ways in which elections may incite violence, the research designs employed cannot speak directly to the theoretically and policy-relevant counterfactual of what would happen in the absence of elections, or if elections had lower stakes. Studies that compare levels of violence cross-nationally face the well-known problems of identifying causal effects from observational data. More subtly, studies that compare levels of violence closer and farther from elections within countries could more plausibly identify the causal effect of elections if nonelectoral periods can serve as “control” periods for times closer to elections. Our models show this inference is dangerous, since the “treatment” of having (competitive) elections affects incentives to use violence at all times. In fact, we find that in some cases elections lead to less violence overall precisely when

⁴ However, violence may sometimes decrease during elections, especially if they are strategic substitutes (Davenport 1997; Dunning 2011).

⁵ There is a wide literature that examines whether democracy in general is associated with civil conflict and other forms of violence (Collier and Hoeffler 2004; Fearon and Laitin 2003; Hegre et al. 2001; Hegre and Sambanis 2006). Similarly, a large number of studies have focused on the use of political repression in different types of regimes and have generally found that strong democratic institutions are associated with lower levels of repression and human rights violations (Davenport and Armstrong 2004; Poe and Tate 1994).

the difference between violence in electoral and non-electoral periods is large.

Finally, our argument is also related to models developed to answer how electoral rules can be obeyed in the shadow of force, which argue that the results of elections can be followed and substitute for conflict if losers prefer the potential to contest for power again in future elections to fighting today (Przeworski 1991; Przeworski 2005; Przeworski, Rivero, and Xi 2012). On the other hand, Bates (2008) argues that the prospect of losing power via competitive elections makes leaders less patient and more apt to act in a predatory manner towards their citizens (see also Bates, Greif, and Singh 2002). Both of these approaches focus on conditions under which there is an equilibrium with no conflict or predation, while our model has a unique equilibrium that makes precise predictions about patterns of violence over time. That is, rather than describing a society that is in perpetual conflict or peace, the equilibrium to our model has cycles of violence and peace around elections, as in the empirical record.

THE BASELINE MODEL

We first present a simple model of political violence in a repeated setting. There are two parties competing for office. The game proceeds over $T > 1$ time periods.⁶ In each period, one party is the incumbent, the other in opposition. The parties are symmetric, in the sense that the actions and period payoffs assigned to the incumbent and opposition do not depend on which party holds which role. As a result, we refer to decisions made by the incumbent party and opposition party even though the actor in these roles may alternate.⁷

The incumbent takes no actions and earns rents from office $\psi > 0$. The party in opposition in time t chooses violence level $v_t \geq 0$, incurring a cost $c(v_t)$. Assume c is increasing and convex, with $c'(0) = 0$. That is, the first unit of violence is “free,” and the marginal cost of violence is increasing.⁸

The benefit to committing violence is that it increases the chances of taking over as incumbent in the next period. In particular, the probability of taking over

⁶ Picking a finite time horizon allows for a straightforward characterization of a unique equilibrium which holds for any arbitrary large number of periods and set of exogenous parameters, which would not be possible in the analogous infinite horizon model.

⁷ To be more precise, we could define the game as between two parties, A and B , one of which starts the game as the incumbent. In each period, $v_{J,t}$ is the amount of violence party J would choose if in the opposition role in period t , and the probability of taking office when party J in the opposition is $p(v_{J,t}; k_t)$. Since we identify a unique equilibrium and the objective function for the party in opposition does not depend on their label, it must be the case that both sides always choose the same level of violence.

⁸ We do not assume there is a budget constraint as this complicates the analysis by raising the possibility of boundary conditions when the opposition spends their entire budget on violence. If anything, adding budgets would make our results stronger, as it could lead to a “cap” of how much violence can spike during elections. Further, if the budget does not perfectly reset every period there would be intertemporal substitution more directly baked into the model as any unit of violence used during an election would have to come from another period.

office is given by $p(v_t; k_t)$, which is continuous and twice-differentiable in both arguments. We assume that the chance of taking over office is strictly increasing in the violence choice ($\frac{\partial p}{\partial v_t} > 0$) with diminishing marginal returns ($\frac{\partial^2 p}{\partial v_t^2} < 0$). The $k_t \in [0, 1]$ parameter represents the *effectiveness of violence* in period t . To formalize this, we assume that $\frac{\partial p}{\partial k_t} > 0$ and $\frac{\partial^2 p}{\partial v_t \partial k_t} > 0$, meaning the probability of taking office and the marginal effect of committing more violence are always increasing in k_t . To preview, when applying the model to cycles of violence around elections we assume that k_t is higher in general periods, but first provide the solution to the general model.

Formally, the period payoff to a party is given by

$$u_t = \begin{cases} \psi & \text{as incumbent} \\ -c(v_t) & \text{as opposition.} \end{cases}$$

The payoff for the entire game is the discounted sum of the period payoffs and a “continuation value” for ending the game in each role. For consistency with later notation, we write the value of ending the game as the incumbent $\pi_I^*(T+1)$, and as the opposition $\pi_O^*(T+1)$.⁹ We assume it is better to end the game as the incumbent: $\pi_I^*(T+1) > \pi_O^*(T+1)$.

Both parties discount future payoffs at rate $\delta \in (0, 1]$. So, the total payoff for a party that attains period payoffs u_1, \dots, u_T and ends the game as party J is

$$\sum_{t=1}^T \delta^{t-1} u_t + \delta^T \pi_J^*(T+1).$$

This setup is deliberately simple to highlight our core argument in a clear fashion.¹⁰ An inevitable drawback to this simplification is that some aspects of the model are *prima facie* at odds with how much violence unfolds in actual elections. For example, we assume that only the opposition uses violence despite the fact that much if not most electoral violence is committed by or on behalf of the incumbent regime. We choose to have only one actor commit violence in the baseline model as this greatly streamlines the presentation. Further, assuming the actor committing violence is trying to change rather than maintain the status quo leads to cleaner intuitions, and in this context that is the opposition. Importantly for connecting our model to the empirical literature, we later extend the model (in Section 4) to allow violence by both actors, and find that our central results hold.

Two other particularly consequential assumptions are that violence is the only tool to affect political out-

comes and holding office is the only outcome parties care about. Again, we later present extensions to the model which loosen these assumptions without changing our core conclusions. Before getting to these more realistic models, we illustrate our core point about the intertemporal substitution of violence in our simple baseline model.

Solution

Our solution concept (formally defined below) requires that the level of violence chosen in each period maximizes the opposition expected payoff for the rest of the game given the future equilibrium violence choices.¹¹ To compute the optimal violence choice in period t , the party in opposition has to compare the expected payoff for the remainder of the game entering the next period as incumbent or opposition. In the last period, this is relatively straightforward, as the values of ending the game in either role are the exogenously given $\pi_I^*(T+1)$ and $\pi_O^*(T+1)$. So, the payoff for the party that is the opposition in the final period as a function of their violence choice is

$$\underbrace{\sum_{t=1}^{T-1} \delta^{t-1} u_t}_{\text{past payoffs}} - \underbrace{\delta^{T-1} c(v_T)}_{\text{period } T \text{ payoff}} + \underbrace{\delta^T \{p(v_T; k_T) \pi_I^*(T+1) + [1 - p(v_T; k_T)] \pi_O^*(T+1)\}}_{\text{continuation value}}$$

Since the past payoffs are fixed, when characterizing the optimal level of violence it is simpler to work with the *net present value* of the game starting in period t , which only considers the payoffs beginning in period t and normalizes by the discount rate. So, for the last period this is given by¹²

$$\pi_O(T, v_T) = -c(v_T) + \delta \{p(v_T; k_T) \pi_I^*(T+1) + [1 - p(v_T; k_T)] \pi_O^*(T+1)\}$$

To be sequentially rational, the violence level in the last period must maximize $\pi_O(T, v_T)$. Taking the first order condition, an interior optimal violence choice in the v_T solves

$$\underbrace{\frac{\partial p(v_T; k_T)}{\partial v_T}}_{\Delta \text{Pr}(\text{take over})} \underbrace{\delta [\pi_I^*(T+1) - \pi_O^*(T+1)]}_{\text{discounted value of taking over}} = c'(v_T). \quad (1)$$

⁹ While the specific values chosen for $\pi_O^*(T+1)$ and $\pi_I^*(T+1)$ can have a large impact on the equilibrium levels of violence in the final periods, when the game is long (i.e., T is large), the continuation values at the end have little effect on the behavior for most of the game. In our illustrations we set the continuation values to avoid changes in behavior due to the game ending; see the Online Appendix for a derivation of this stationary value.

¹⁰ See Little and Pepinsky 2016 for a more general discussion of the role of simplification in models of comparative politics.

¹¹ The probabilistic nature of who enters each period as the incumbent means this is a game with incomplete information, so subgame perfection does not apply. We do not introduce extra notation for the beliefs held by the parties since the uncertainty is symmetric and the probability of taking office function is a primitive of the model.

¹² That is, the payoff for the entire game for the party in opposition for any time t given the future violence choices can be written $\sum_{i=1}^{t-1} \delta^{i-1} u_i + \delta^{t-1} \pi_O(t, v_t)$. Since the past payoffs are not a function of v_t , optimizing this equation is equivalent to optimizing $\pi_O(t, v_t)$.

The left-hand side of [equation \(1\)](#) is the marginal benefit to committing more violence in period T , which is equal to the change in the probability of ending the game as the incumbent times the discounted difference between ending the game as the incumbent versus as opposition. The right-hand side of this equation is the marginal cost to committing more violence. Since there are diminishing returns to committing more violence and an increasing marginal cost, this equation has a unique solution v_T^* where the marginal benefit equals the marginal cost.¹³

The optimal violence choice in every period has this general form: the opposition commits the level of violence where the marginal cost of committing more violence equals the marginal benefit via increasing the chance of taking over office in the next period. The only complication—which will drive the intertemporal substitution effects we aim to model—is that the benefit of taking over office in the next period depends on the future effectiveness of violence. However, once we know the violence level in period T (derived above), we can compute the net present value of entering period T as incumbent versus opposition, which gives the optimal level of violence in period $T - 1$. This gives the net present value of entering the next to last period in each role, and hence the optimal violence level in period $T - 2$, etc.

Formally, the opposition objective function ($\pi_O(t, v_t)$), optimal violence choice (v_t^*), and the net present values for entering period t in each role ($\pi_O^*(t)$ and $\pi_I^*(t)$) can be defined recursively as

$$\begin{aligned} \pi_O(t, v_t) = & c(v_t) + \delta\{p(v_t; k_t)\pi_I^*(t+1) \\ & + [1 - p(v_t; k_t)]\pi_O^*(t+1)\}, \end{aligned} \quad (2)$$

$$v_t^* \in \arg \max_{v_t \geq 0} \pi_O(t, v_t), \quad (3)$$

$$\pi_O^*(t) = \pi_O(t, v_t^*), \quad (4)$$

$$\begin{aligned} \pi_I^*(t) = & \psi + \delta\{p(v_t^*; k_t)\pi_O^*(t+1) \\ & + [1 - p(v_t^*; k_t)]\pi_I^*(t+1)\}. \end{aligned} \quad (5)$$

An equilibrium to the model is characterized by sequences v_t^* , $\pi_O^*(t)$, and $\pi_I^*(t)$ that solve equations (2)–(5) for $t = 1, \dots, T$. It is also convenient to write the difference between the net present value of entering period t as the incumbent versus the as the opposition as $\Delta_t^* \equiv \pi_I^*(t) - \pi_O^*(t)$. So, the first order condition for an interior level of violence v_t is

$$\delta \frac{\partial p(v_t; k_t)}{\partial v_t} \Delta_{t+1}^* = c'(v_t). \quad (6)$$

¹³ More precisely, since p is concave and bounded above by one, the left-hand side is positive, decreasing, and approaches zero as $v_T \rightarrow \infty$. Since c is convex and equal to zero at $v_T = 0$, this ensures a unique intersection, which by the concavity of the objective function is the unique global maximizer.

As long as $\Delta_{t+1}^* > 0$ —which means it is better to enter the next period as the incumbent rather than as the opposition—this optimization problem has a unique interior solution v_t^* . If it is better to enter period $t + 1$ as the opposition rather than as the incumbent, there is no benefit to violence and hence it is optimal to pick $v_t^* = 0$.¹⁴ So:

Proposition 1 *The baseline model has a unique equilibrium where v_t^* solves [equation \(6\)](#) when $\Delta_{t+1}^* > 0$ and $v_t^* = 0$ otherwise.*

Proof. Follows from the above analysis; see the Appendix for details. \square

Next we analyze how changing the effectiveness of violence in a given period affects the pattern of violence throughout the game. For simplicity we only consider the plausibly realistic case where it is better to enter as the incumbent in every period (i.e., when $\Delta_t^* > 0$ for all t); see the Online Appendix for discussion of how loosening this restriction affects the results.

The direct effect of increasing the effectiveness of violence in period t is that by increasing the marginal effect of v_t on taking over office, the marginal benefit to violence increases, leading to a higher choice in period t . Formally, implicitly differentiating [equation \(6\)](#) gives that $\frac{\partial v_t^*}{\partial k_t} > 0$.

To formalize the indirect effect, consider how making violence more effective in future periods (i.e., $t' > t$) affects behavior in period t . (By sequential rationality, violence levels in previous periods $t' < t$ do not affect the choice in period t .) Referring back to [equation \(6\)](#), this will depend on how the future effectiveness of violence changes the relative value of entering the next period as the incumbent (Δ_{t+1}^*). When $t' = t + 1$, the result is straightforward: making violence more effective in the next period unambiguously makes the opposition better off and the incumbent worse off entering this period. This reduces the relative value of entering the next period as the incumbent, so there is less violence in period t . For periods $t' > t + 1$ the technical analysis is more subtle, but for all of the examples we present in our illustrations, reducing the effectiveness of violence at *any* future period decreases the level of violence today (see the Online Appendix for examples where this does not hold). Intuitively, as long as it is better to enter each period as the incumbent, and taking control of the government by force is rare, anything that makes doing so easier in the future reduces incentives to commit violence today. Formally:

Proposition 2 *The equilibrium level of violence in time period t_1 is*

- (i) increasing in k_{t_1} ,
- (ii) decreasing in k_{t_1+1} , and
- (iii) provided $\delta[1 - 2p(v_{t_1}^*; k_{t_1})] > 3 \frac{\partial v_{t_1}^*}{\partial \Delta_{t_1+1}^*} c'(v_{t_1}^*)$ for $t \in \{t_1, \dots, t_2 - 1\}$, decreasing in k_{t_2} for $t_2 > t_1 + 1$.

¹⁴ One way this can happen is if violence is extremely effective in period $t + 1$ but less effective after that, meaning it is better to enter period $t + 1$ as the opposition in order to take control before violence becomes less effective again.

Proof. See the Appendix. \square

While the model has not yet explicitly addressed elections, this result formalizes the central intuition about the direct and indirect effects of making violence more effective in a given period. The obvious direct effect is that there is more violence in this period. However, making violence more effective in period t has an indirect effect of *decreasing* violence in periods $t - 1$, and potentially in all periods prior to period t .

The idea that political actors time their actions is fairly well documented, especially in the terrorism literature. For instance, the Boston Marathon bombers had initially planned their attack for the July 4 festivities (Boston 2013), and the so-called “underwear bomber” had timed his attack for Christmas Day (Hudson 2013). Such violent actors are also known to specifically wait for elections so that their attacks would have a greater impact. A recent prominent example of such an approach is the the 2004 train bombings in Madrid that took place three days before the Spanish voters went to the ballot, and is now known to have been timed specifically to influence the election outcome (Richburg 2004). Other similar instances include the Kurdistan Workers’ Party (PKK) attacking Turkish security forces to sway the electorate in April 2015 (Aksoy 2015), and intelligence reports indicating that Pakistani terrorists planning suicide attacks timed for the Indian elections (Shukla 2014). Violence (including but not limited to terrorism) may also be more prevalent during seasons when it is easier to recruit fighters, for example because wages are lower outside of harvest seasons (Guardado and Pennings 2015).¹⁵

Proposition 2 indicates that this intuition can apply to the incentives to commit violence to gain political power. While some of these examples are from groups with no stated aspiration to actually take control of the government, in Section 4 we further argue that the logic applies to a wide class of political violence committed by various actors and various aims.

ELECTIONS IN THE BASELINE MODEL

With this general solution in place we now examine how periodic elections change aggregate levels of violence under the assumption that violence is more effective in electoral periods. For simplicity, we begin with a stark comparison between patterns of violence in a society with *no* elections versus one with periodic elections. We then turn to the question of how making elections more consequential and other more fine-grained changes affect patterns and aggregate levels of political violence.

A Simple Example

Suppose in a society without elections, the effectiveness of violence is $k_t = k_n$ for all periods. In a society with elections, the effectiveness of violence is $k_e > k_n$ in electoral periods and k_n for other periods.

¹⁵ As these examples indicate, elections are not the only times when violence could become more effective.

A simple microfoundation for this assumption is that the opposition can commit “nonelectoral” violence in any period, but electoral violence is only possible (or only useful) in electoral periods. So, in electoral periods, the opposition—and, as formalized in Section 4, other actors—have multiple ways to influence political outcomes with violence. While electoral violence can look much different than other forms of violence, for our purposes adding a new violent technology during elections is equivalent to assuming that violence is more effective in electoral periods (see the Online Appendix for a formal statement of this point). More broadly, we make this seemingly unusual assumption because our primary goal is to show how elections can reduce violence even if fighting peaks around elections. So this assumption constitutes a “hard case” for our aims.¹⁶

As demonstrated by Proposition 2, introducing elections in this manner has a direct effect of increasing the level of violence in electoral periods but also an indirect effect of decreasing violence in the periods before elections, and potentially all nonelectoral periods. To show that either effect can be larger, we present several illustrative cases. For all of these examples, $c(v_t) = v_t^2$ and $p(v_t; k_t) = k_t[1 - (1 + v_t)^{-1}]$.

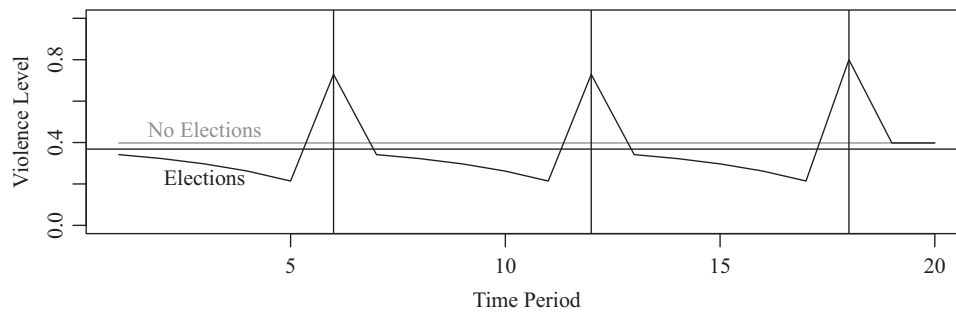
Figure 3 presents a comparison of violence levels in two societies that only vary in the presence of elections. In both societies, there are 20 periods, and the effectiveness of violence in nonelectoral periods is $k_n = 0.3$. Without elections (the grey line), all periods are nonelectoral, and the equilibrium violence choice is constant.¹⁷ In the second society (black curve), there are elections in periods 6, 12, and 18 (the vertical lines), where the effectiveness of violence increases to $k_e = 1$. The horizontal black line represents the average violence level with elections.

The black curve presents a similar (if tidier) pattern as shown in the cases of Kenya and Ghana in Figure 1 with spikes in levels of violence in electoral periods (or years). While we cannot directly know what the counterfactual level of violence would be without elections using observational data, with the theoretical model we can make this comparison by looking at violence levels in an otherwise identical society with no elections. In this case, the black line is below the grey line, indicating that the spikes in electoral periods are more than offset by the decrease in violence in nonelectoral periods, leading to less fighting on average.¹⁸ This example

¹⁶ In terms of arguing whether elections are “good” or not, we are also setting aside other positive benefits of democracy such as giving citizens a voice in how they are governed.

¹⁷ This requires setting the continuation values at the end of the game such that the different between the expected payoff for entering each period in each role is stationary; see the Online Appendix.

¹⁸ A subtle difference between the pattern of violence from the theoretical model and the empirical evidence is that in Figure 3 violence is decreasing throughout the nonelectoral period, reaching its lowest points right before the electoral periods. This is because the violence-detering effect of future elections is strongest when the election is near. That is, there is less incentive to wait for the election when it is far away. However, this disconnect is not inherent to the model itself, but to the fact that electoral violence is only available in the electoral

FIGURE 3. Comparison of Levels of Violence with No Elections (grey line) and Elections (black line)

illustrates the first main result of the article in a simple fashion: the existence of a political violence cycle does not imply societies would become more peaceful without elections.¹⁹

Next, we consider how general this example is by examining how changing various parameters of the model affects patterns and aggregate levels of violence. Unfortunately, analytic results on this relationship in the baseline model prove very difficult (stronger results along these lines emerge in the model with nonviolent actions in the next section). However, it is straightforward to simulate the model for a wide range of parameters and functional forms for the c and p functions to explore how this affects average levels of violence. The Online Appendix contains an extensive analysis of how changing individual parameters affects violence levels for randomly drawn values of the other parameters. In the main text, we focus on several results from this exercise that are of substantive interest and are generally robust to varying other parameters.

Consequential/Competitive Elections

First, Figure 4 shows a counterintuitive and empirically relevant example of how the degree to which violence is more effective during elections affects the average level of violence. The left panel illustrates the per period violence levels with increasingly dark lines as k_e increases. Increasing the effectiveness of violence in the electoral periods leads to bigger spikes of violence during the election, but also larger decreases in violence in nonelectoral periods.

period itself, while some electoral violence occurs in the months leading up to the election. As shown in the Online Appendix, when assuming that violence is also somewhat more effective in the period before the election, a more smoothly cyclical pattern of violence arises.

¹⁹ It is possible that higher volatility in violence is itself bad. This could be formalized by specifying a society welfare function that sums up some convex function of the period violence choices. In general this will make elections less beneficial from a welfare perspective, though in the model with substitution elections can lead to less violence in every period. Further, concentrating the times when political actors have incentives to commit violence may also make it easier for international actors to more effectively monitor and deter violence in at-risk countries (Matanock N.d.).

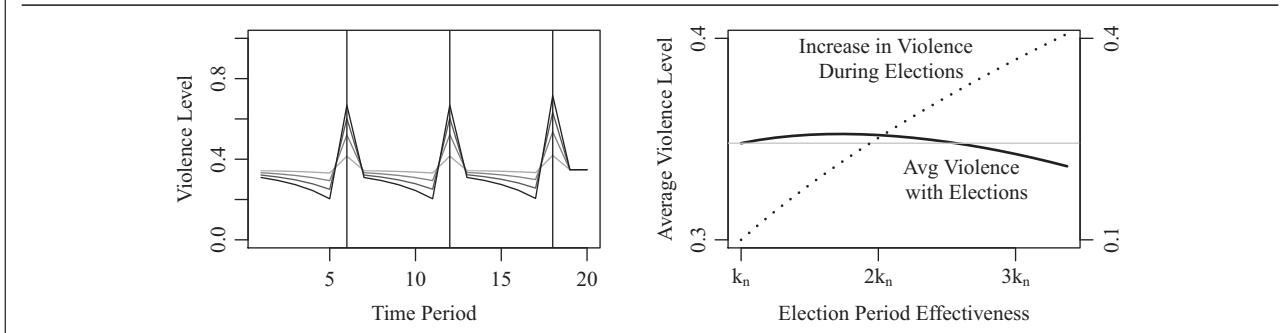
The right panel shows how this affects the average levels of violence (solid line) and the difference between the average level of violence in electoral periods versus nonelectoral periods (dotted line). While making violence slightly more effective in electoral periods increases the average amount of violence, making violence much more effective leads to less violence overall. However, increasing the effectiveness of violence unambiguously increases the *difference* between violence levels in electoral versus nonelectoral periods. So, for part of the parameter space, making electoral period violence more effective leads to bigger spikes of violence in electoral periods but less violence overall.

While this effect is just from one set of simulations (again, see the Online Appendix for an illustration of how this relationship changes for random draws of the other parameters) and the changes in the average violence level are not large, this illustration has important empirical and policy consequences. First, it is interesting in light of empirical findings that competitive elections outside of consolidated democracies tend to be particularly violent (Hafner-Burton, Hyde, and Jablonski 2014; Straus and Taylor 2012), as well as the sharper spike of violence in elections where the chief executive is at stake shown in Figure 2.

Elections with higher stakes can be directly interpreted as ones where k_e is higher.²⁰ Connecting the competitiveness of elections to this parameter is less straightforward. However, when elections are close there can be a higher marginal return to any political activity that will lead to more votes, including violence.²¹ So, in that sense, we might expect that competitive elections are ones where the marginal returns to violence are high, which is precisely what we mean by k_e being high. Under this interpretation, it is the competitiveness of the election that depresses violence before the

²⁰ See Durant and Weintraub (2014) for a discussion on how to reduce the stakes in postconflict elections.

²¹ For example, if a party only cares about winning the majority of votes, and their vote share is equal to a costly action a plus a normally distributed variable with mean m and standard deviation σ , then the marginal return to a is $\frac{\partial}{\partial a} \{\Phi[(a+m-0.5)/\sigma]\} = \sigma^{-1} \phi[(a+m-0.5)/\sigma]$ where Φ and ϕ are the CDF and PDF of a standardized normal random variable. For the first marginal unit of a , this is maximized at $m = 0.5$, i.e., a perfectly competitive election.

FIGURE 4. The Effect of Making Elections more Consequential on Average Levels of Violence

election: there is less of an incentive to commit violence today if the opposition has a real chance to take office in an upcoming election.

On the policy end, given that nearly every country holds some kind of election and few argue they should be abolished entirely, the comparison between more or less consequential elections is more relevant than the contrast between elections and no elections at all. Interestingly, this simulation suggests that to reap the benefits of elections in terms of peace it may not be enough to have elections that are only slightly consequential. Conversely, this example raises the possibility that making elections less consequential will lead to smaller spikes in violence during elections but also more violence overall.

Other Simulations

Figure 5 shows how changing several other parameters affects the difference in average levels of violence with and without elections. The left panel examines the effect of the discount rate. Changing δ has a nonmonotone effect. When the parties are extremely impatient ($\delta \rightarrow 0$) the optimal violence choice is always zero since the benefits of taking over office do not accrue right away. So if parties are completely impatient, there is no violence at all regardless of whether elections are held. For moderate levels of patience there can be more violence with elections, and the parties are patient enough to get a benefit from using violence but not patient enough for the prospect of future elections to outweigh the direct effect. When δ gets large, the indirect effect becomes stronger and elections lead to less violence overall.²² For this particular parameterization, a discount rate of 0.88 is where elections go from promoting to preventing violence.

The middle panel examines the value of holding office (ψ). For this parameterization (and, as shown in the Online Appendix, the majority but not all of our simulations), increasing ψ always leads to elections having a more pacifying effect. A potential explanation for this is that there will be more violence in general when there

are more spoils to fight over. When there is already a high level of violence in the nonelectoral baseline, the marginal effect of making violence more effective in electoral periods is relatively low compared to potential to decrease violence by making it more effective in the future.

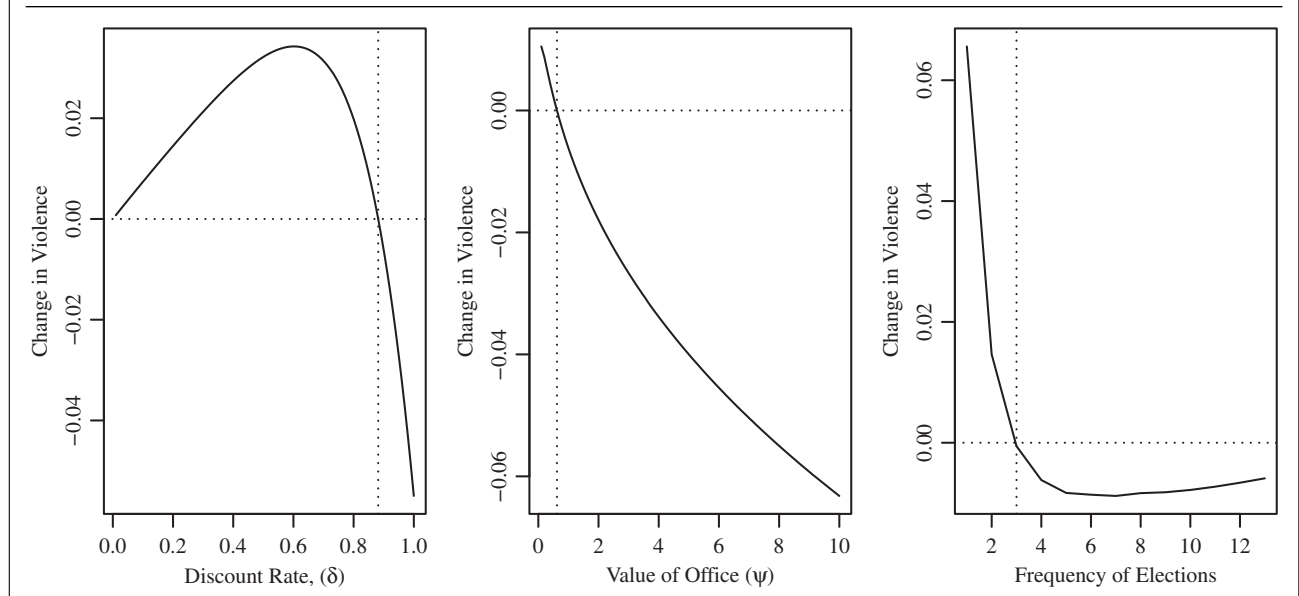
Finally, the right panel examines the frequency of elections. When elections are extremely frequent, they lead to more violence, as there is not enough time between elections for the indirect effect of making nonelectoral periods more peaceful to outweigh the direct effect. When elections are very rare, they lead to slightly less violence since it takes a long time to wait until the next election, weakening the indirect effect. So, the optimal election timing is intermediate, where nonelectoral periods are short enough that the indirect effect matters for the entire time between elections, but long enough that the indirect effect adds up to matter more than the direct effect.

EXTENSIONS

Several simplifying assumptions utilized so far raise doubts about the scope conditions for the model. First, by assuming that elections only increase the effectiveness of violence, we cannot yet say how providing nonviolent means to contest for power affects the patterns we describe. Second, much if not most political violence is perpetrated by the government and their agents, not just the opposition as in the baseline model. Third, so far we have only modeled violence committed to take over the government, while political violence often has other (and more incremental) goals. As our goal is to assess how elections affect broad patterns of political violence, it is important to check that similar results can come out of models with more realistic and general assumptions.

Fortunately, the results are robust and often even stronger when extending the model in several ways. In particular, we address these concerns with three modifications to the model that allow for nonviolent political technology, multiple actors committing violence, and violence to obtain goals other than taking over office. Doing so also provides more detailed empirical insights about when certain political actors are more or less apt to commit violence.

²² The requirement that actors be patient in order to accept peaceful allocation of power also shows up in (Przeworski 1991, 2005; Przeworski, Rivero, and Xi 2012).

FIGURE 5. Comparative Statics on Change in Violence with Elections by the Discount Rate (left panel), Value of Office (middle panel), and Frequency of Elections (right panel)

Bullets and Ballots

A central idea in the literature on democracy is that elections allow parties to compete for power with non-violent means. Further, there are a number of empirical examples where armed groups have either delayed or renounced violence in the presence of nonviolent alternatives. For example, the Irish Republican Army (IRA) agreed to give up arms in Northern Ireland in 2005 when its political arm, Sinn Fein, made inroads in Northern Ireland and in the Irish Republic (Lavery and Cowell 2005). Similarly, the Free Aceh Movement (GAM) in Indonesia give up violence as part of an agreement that included Indonesia allowing regional political parties to participate in national elections (Simanjuntak 2008).

To combine our argument with the canonical claim that elections reduce violence by providing an alternative means to contest for power, we present an extension where the opposition can also use nonviolent actions. In short, we find that this leads to a substitution away from violence that can make society substantially more peaceful even though there is still a cycle of violence around elections.

To formalize this, suppose that in an electoral period, the opposition party can also choose to take nonviolent actions to increase their probability of becoming the incumbent following the election. Let x_t represent the amount of nonviolent activity in period t , which could represent campaigning, mobilizing voters on election day, or other less desirable but nonviolent tactics like vote buying. Let the probability of taking office in an electoral period be $p(x_t + v_t; k_t)$ with the same functional form assumptions as above.²³ So, now the k_t

parameter reflects the increased effectiveness of political activity in general. To simplify the analysis, we assume that nonviolent political action is not available or ineffective in nonelectoral periods.

In addition to the cost $c(v_t)$ paid to take violent actions, the opposition also pays a partial cost $c(x_t)/\beta_t$ for the nonviolent actions, for some $\beta_t > 0$. So, β_t reflects the relative cost of violent political activity in period t : when $\beta_t > 1$ violent activity is more efficient and when $\beta_t < 1$ nonviolent action is more efficient.²⁴

Our solution concept (formalized in the Appendix) is analogous to the main model, except now the joint choice of violent and nonviolent action must be sequentially rational. Following standard optimization procedures, the first order condition for the opposition's choice in period t is now the (v_t, x_t) that jointly solve

$$\delta \frac{\partial p(x_t + v_t; k_t)}{\partial v_t} \Delta_{t+1}^* = c'(v_t), \quad (7)$$

$$\delta \frac{\partial p(x_t + v_t; k_t)}{\partial x_t} \Delta_{t+1}^* = c'(x_t)/\beta_t, \quad (8)$$

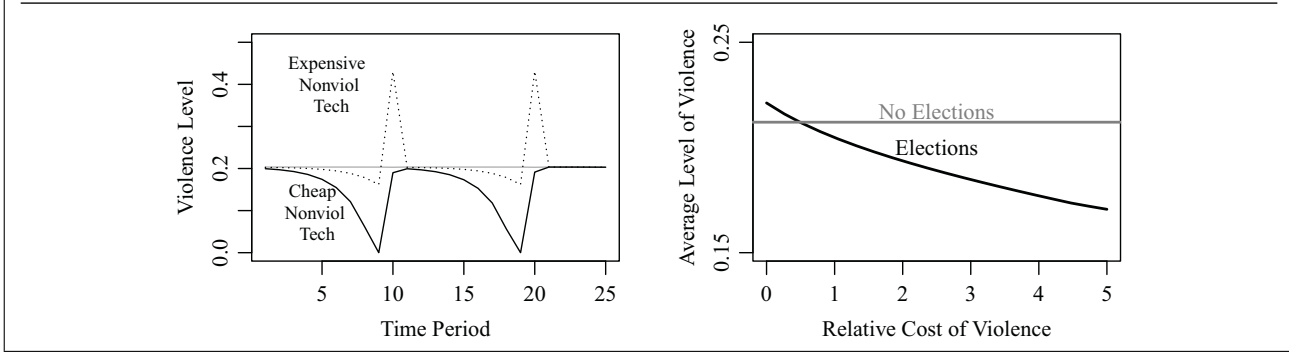
where Δ_{t+1}^* is again the difference between the net present value of entering period $t + 1$ as the incumbent versus opposition. This implies $c'(v_t^*) = c'(x_t^*)/\beta_t$, which by the convexity of c ensures a unique pair (x_t^*, v_t^*) meeting these conditions. So, by an identical argument to the baseline model, there is a unique equilibrium level of violence and nonviolent activity (v_t^*, x_t^*) in each period characterized by Equations (7) and (8) when $\Delta_t^* > 0$ and $v_t^* = x_t^* = 0$ when $\Delta_t^* \leq 0$.

Figure 6 illustrates the impact of nonviolent activity on how much violence is chosen in equilibrium, with

²³ That is, p is increasing and concave in its first argument, and the cross partial with respect to the two arguments is positive.

²⁴ This parameter could also reflect how easy it is to attain political power through normal institutional channels.

FIGURE 6. The Effect of Introducing Nonviolent Technologies on the Level of Violence



$c(v_t) = -v_t^2$ and $p(v_t + x_t; k_t) = k_t[1 - (1 + v_t + x_t)^{-1}]$. As before, the flat line in the left panel is the level of violence with no elections. The dotted curve represents the level of violence chosen where nonviolent technology is very expensive, and the spike in violence is large during the election is large relative to the dip in violence in no-electoral periods, resulting in more violence on average with elections despite some substitution to nonviolent activity.

In the solid curve, the nonviolent technology is cheaper (high β_t , set to a constant β for all electoral periods), leading to a stronger substitution away from using violence during electoral periods. The availability of effective nonviolent technology also augments the intertemporal effects of the baseline model, as there is less reason to commit violence when it is possible to contest for power peacefully in future electoral periods. As a result, the level of violence is not only lower on average, but lower in *every* period than it would be without elections. The substitution effect is so large that violence peaks after the election, when (1) the nonviolent technology is not available, but (2) the next election is far enough away that it is worth committing violence to try and take over office. This pattern matches the case of Burkina Faso in Figure 1; we revisit the relationship between this example and several theoretical and empirical papers on postelection protest in the discussion. Still, the presence of elections induces a cyclical pattern of violence that, without thinking of the proper counterfactual, could erroneously lead to conclusions that elections encourage violence.

The right panel of Figure 6 plots the average level of violence as a function of the relative cost of violent actions (β). Unlike the previous graphs, making the nonviolent action cheaper (higher β) has an unambiguous and large effect in decreasing the average levels of violence. In this parameterization, elections would lead to more violence in the absence of a nonviolent technology ($\beta \rightarrow 0$), but as long as the nonviolent technology is less than twice as expensive as violence the presence of elections will decrease the average level of violence.

Proposition 3 *The model with non-violent technology has a unique equilibrium, where:*

(i) *the level of violence in electoral period t is decreasing in the relative cheapness of nonviolent technology (β_t), and*

(ii) *when the nonviolent technology becomes extremely cheap in period t , the level of violence approaches zero (as $\beta_t \rightarrow \infty$, $v_t^* \rightarrow 0$).*

Proof. See the Appendix. □

In other words, with substitution to non-violent technology the direct effect in the baseline model is weakened if not reversed, potentially leading to less violence in electoral periods. The logic of the indirect effect of reducing violence in non-electoral periods remains, and so elections can unambiguously reduce violence on average and even in every period (as in Figure 6).

Incumbent and Opposition Violence

Next, we analyze a case where both the incumbent and opposition can commit violence. In this section, we assume the probability that the opposition becomes the incumbent in period $t + 1$ as a function of their violence choice (now $v_{O,t} \geq 0$) and the incumbent violence choice ($v_{I,t} \geq 0$) is

$$p(v_{O,t}, v_{I,t}; k_t) = \begin{cases} k_t \frac{v_{O,t}}{v_{O,t} + v_{I,t}} & v_{O,t} + v_{I,t} > 0 \\ p_0 & v_{O,t} + v_{I,t} = 0 \end{cases}$$

for some $k_t \in [0, 1]$ and $p_0 \in (0, 1)$. (The $v_{O,t} + v_{I,t} = 0$ case is to avoid division by zero, and the exact value of p_0 has no impact on the analysis.) This functional form meets all of the assumptions with respect to $v_{O,t}$ and k_t in the baseline model as long as $v_{I,t} > 0$ (which will always be true in equilibrium).

Let the opposition cost for committing violence level $v_{O,t}$ be exactly $v_{O,t}$, and let the cost of committing violence for the incumbent be $\gamma v_{I,t}$ for some $0 < \gamma < 1$. That is, we assume that violence is “cheaper” for the incumbent, or, equivalently, the incumbent gets a higher return to violence.²⁵

²⁵ Some of the results require more caveats analogous to those in part (iii) Proposition 2 without this assumption. In this section the cost function is not convex (and $c'(0) > 0$) as this is not necessary to ensure interior solutions when both actors choose violence.

The rents for being the incumbent are again ψ . So, actor J 's net present value of committing violence level $v_{J,t}$ in period t (given the future violence choices) is

$$\begin{aligned}\pi_O(t, v_{O,t}; v_{I,t}) &= -v_{O,t} + \delta[p(v_{O,t}, v_{I,t}; k_t)\pi_I^*(t+1) \\ &\quad + [1 - p(v_{O,t}, v_{I,t}; k_t)]\pi_O^*(t+1)], \\ \pi_I(t, v_{O,t}; v_{I,t}) &= \psi - \gamma v_{I,t} + \delta[p(v_{O,t}, v_{I,t}; k_t)\pi_O^*(t+1) \\ &\quad + [1 - p(v_{O,t}, v_{I,t}; k_t)]\pi_I^*(t+1)].\end{aligned}$$

Our solution concept now requires that the violence choices are mutual best responses given future violence choices (see the Appendix for a formal statement) By a standard analysis, whenever $\pi_I^*(t+1) > \pi_O^*(t+1)$ the equilibrium violence choices are given by:

$$v_{O,t}^* = \frac{k_t \delta [\pi_I^*(t+1) - \pi_O^*(t+1)]}{(1 + \gamma^{-1})^2}, \quad (9)$$

$$v_{I,t}^* = \frac{\gamma^{-1} k_t \delta [\pi_I^*(t+1) - \pi_O^*(t+1)]}{(1 + \gamma^{-1})^2} \quad (10)$$

and if $\pi_I^*(t+1) < \pi_O^*(t+1)$ both actors choose no violence (see the Appendix for detail). Since $\pi_I^*(T+1) > \pi_O^*(T+1)$, the level of violence chosen in the last period is positive for both actors: $v_{J,T}^* > 0$.

It immediately follows from equations (9) and (10) that the level of violence chosen by both actors in period t (when strictly positive) is increasing in the effectiveness in period t . Further, since $\gamma < 1$, the incumbent always chooses more violence than the opposition, and hence always remains the incumbent with a probability greater than $1/2$. As $\gamma \rightarrow 0$, the incumbent commits far more violence than the opposition, indicating this extension can capture cases where the vast majority is committed by government forces.

Using these violence levels to compute the net present value for entering period t as each party, the difference between these payoffs is

$$\Delta_t^* = \pi_I^*(t) - \pi_O^*(t) = \psi + \delta \left(1 - 2 \frac{k_t}{1 + \gamma^{-1}} \right) \Delta_{t+1}^*. \quad (11)$$

Since $\gamma < 1$, whenever Δ_{t+1}^* is positive, Δ_t^* is positive as well, so by induction Δ_t^* is positive for all t and hence both actors choose a strictly positive level of violence in each period. Further, Δ_t^* is decreasing in k_t : when violence is more effective in period t , the difference between entering this period as the incumbent versus opposition decreases. So, there will be less violence committed in period $t - 1$ as k_t increases.

The same inductive argument then implies that Δ_{t-1}^* is decreasing in k_t , as is $\Delta_{t'}^*$ for any $t' < t$, and hence $v_{J,t-1}^*$ is decreasing in k_t for both $J = I$ and $J = O$. Combined with the fact that the violence levels in period t are increasing in k_t :

Proposition 4 *In the two actor model, the level of violence committed by both actors in period t is increasing k_t and decreasing in $k_{t'}$ for all $t' < t$.*

Proof. See the Appendix. \square

The intuition for the opposition violence choice is similar to the main model: if violence will be more effective in the future (e.g., because of an election), the opposition invests less in violence anticipating it will be more effective later. The fact that violence will be more effective in the future also leads the incumbent to choose less, as even if they are ousted they will have an opportunity to take power back during the election.

Another intuition for the incumbent violence choice is that they are reacting to anticipated violence choices by the opposition, and increasing the violence choice by the opposition gives the incumbent an incentive to commit more violence to counteract this. Formally, the marginal benefit for the incumbent violence choice is increasing in $v_{O,t}$ as long as $v_{O,t} < v_{I,t}$, which is always true in equilibrium. That is, making violence more effective for the opposition during elections can lead to more incumbent violence. During elections, this can lead to a spiral effect where the incumbent reacts to opposition violence with even more of their own. However, there is a similar but peaceful spiral effect in nonelectoral periods: since the opposition would rather wait to use violence, the government has less reason to repress them.

Continuous Policy Outcomes

Finally, a drawback of the models so far is that they only consider violence committed to take control of the government, while much political violence has more incremental goals. To show that the logic of our model applies to this more general class of political violence, we briefly present a variant of the model where a single political actor chooses a level of violence to affect a continuous policy outcome. Unlike before, there is only one actor and no ‘‘incumbency’’; i.e., the same actor chooses a violence level in each period to influence the policy in their preferred direction.

Formally, the actor chooses violence level v_t in each of $T > 1$ periods. The policy in period $t + 1$ is

$$y_{t+1} = (1 - k_t)y_t + k_t v_t,$$

where $k_t \in [0, 1]$. That is, the policy in each period is a weighted average of the past policy and the efforts of the political actor. When k_t is higher, violence will be more effective in period t , or, equivalently, the status quo is ‘‘less sticky.’’ The period utility as a function of the policy and violence choice is

$$u_t = y_t - c v_t^2$$

and the payoff for the entire game is

$$\sum_{i=1}^T \delta^{i-1} u_i + a \delta^T y_{T+1},$$

where $a > 0$ represents the relative importance of the policy at the end of the game.

The main insight from this model is that violence committed in period t increases the policy in every future period. However, the impact on periods beyond the next one is diminished by the fact that future policies are also shaped by future violence choices. In particular, a marginal increase in violence in period t increases y_{t+1} by k_t , y_{t+2} by $k_t(1 - k_{t+1})$, and for any $\tau > t + 1$, y_τ by $k_t \prod_{i=t+1}^{\tau-1} (1 - k_i)$. So, the total return to violence today is increasing in k_t and decreasing in the effectiveness of violence in every future period:

Proposition 5 *In the continuous policy model, the amount of violence committed in period t is*

- (i) *increasing in k_t ,*
- (ii) *decreasing in $k_{t'}$ for all $t' > t$.*

In addition to demonstrating that the results in the baseline model extend to “policies” other than who controls the government, this model provides an alternative intuition for why elections may reduce violence overall. When committing violence today, political actors are not just attempting to change the status quo for the “next period,” whether that be a day, year, or electoral cycle. Since policy tends to be sticky, the marginal benefit to violence today is a discounted sum of how violence today affects policy for every future period. The effective discount rate for the future is not just a function of patience, but whether whatever political gains made today could be reversed in the future. So, if elections increase the chance that any political gains may be reversed, there is less reason to commit violence in nonelectoral periods.

DISCUSSION

The central conclusion from all of the models is that comparisons between levels of violence in electoral versus nonelectoral periods using observational data can lead to misleading conclusions about the efficacy of elections for reducing the overall amount of violence in society. Put another way, that elections are violent is theoretically consistent with the general result that societies with more meaningful elections generally have lower levels of conflict (Cheibub and Hays 2016, Gleditsch and Ruggeri 2010; Hegre et al. 2001; Poe and Tate 1994).

More specifically, the models also provide insight into several recent empirical studies of when certain types of elections in certain contexts are particularly violent. First, several recent studies examine the prevalence of postelection protests (Daxecker 2012; Hyde and Marinov 2014; Rozenas 2012), and Straus and Taylor (2012) find that in Africa most violence is perpetrated by regimes, but the relative share of violence perpetrated by opposition groups is higher after elections. Figure 7 shows this differential pattern from the SCAD data used before for progovernment and antigovernment violence. While progovernment violence tends to be higher leading up to and during election day, antigovernment violence is highest just

after the election. (Of course the regime may respond to these protests with violence of their own; see e.g., Arriola 2014).

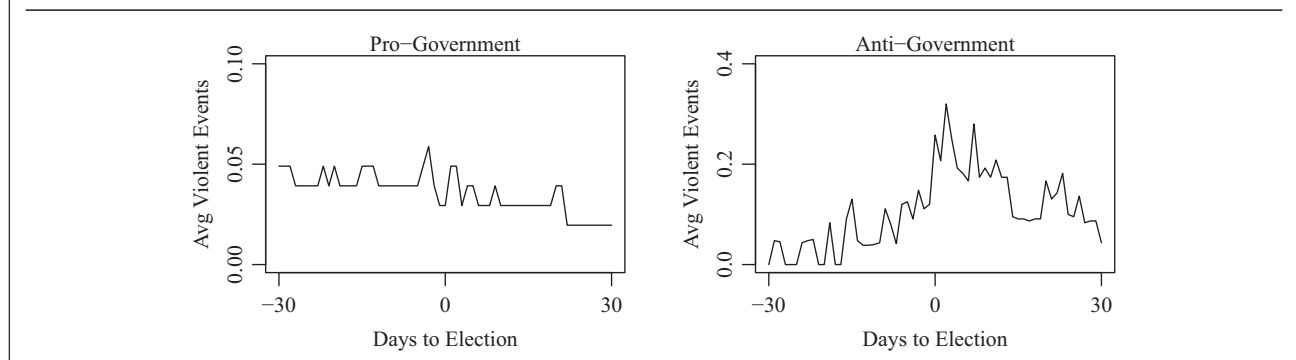
Most theorizing about postelection protest is backward looking, in the sense that groups are motivated to protest the process or outcome of the election (Daxecker 2012; Hyde and Marinov 2014; Rozenas 2012). This idea can be incorporated in our model by interpreting the time immediately after the voting as part of the electoral period, and postelection protest contributing to violence being more effective in electoral periods.

Our approach also highlights a more nuanced and forward-looking explanation for why opposition groups turn to violence after elections. Violence is particularly attractive to electoral losers in times just after defeat for several reasons. First, if parties are more apt to use violence when the status quo is unfavorable, parties losing elections will have more to gain by turning to violence. Second, as demonstrated in the extension with substitution, violence can peak after elections because this is a time when nonviolent political activity is relatively ineffective (compared to electoral periods) and it is the time when the opposition has the longest to wait until nonviolent technologies become available (and violent actions more effective) at the next election. That is, when a party has to wait a long time to affect policy via elections they are more apt to turn to violence to affect the status quo in the short term.

Our argument also provides insight into studies about what institutional contexts are most prone to spikes of violence around elections. Aksoy (2014) finds that terrorism in democracies tends to cluster around elections in systems with lower “electoral permissiveness,” meaning it is harder for small parties to have a formal role in politics. This can be interpreted in light of the model with violent and nonviolent technology. If low electoral permissiveness means that nonviolent technologies are not effective, marginalized groups resort to violence during the election as that is their only choice and the most effective time to do so.

What does our model have to say in terms of novel predictions for future empirical work? We view the generality and small number of parameters in the model as a feature which provides confidence that the core of our argument holds across many political settings. However, this also means there are few comparative static predictions about how different institutions or other political and economic variables affect how much violence will be used during elections or the difference between violence levels in electoral versus nonelectoral periods. So, one way to push the literature forward both theoretically and then empirically would be to write models that combine the forces we introduce here with political institutions to generate comparative static predictions on variables which we could map to data.

Perhaps more importantly, future empirical work could aim to examine our more general contention that the ability to attain political goals during elections, whether with violence (parts (ii) and (iii) of Proposition 2) or other nonviolent tactics (part (i) of Proposition 3)

FIGURE 7. Patterns of Pro- and Antigovernment Violence Around Elections

makes politics more peaceful in nonelectoral periods. Isolating variables that only change the effectiveness in electoral periods (but not elsewhere) could prove difficult. One potential avenue for doing so would be to examine how (preferably exogenous) changes to expectations about how competitive future elections will be affect violence in time periods after this revelation but before the election. Another potential empirical avenue would be to examine the effect of elections in places that hold both scheduled and early elections, and analyze whether it leads to a political violence cycle similar to the available evidence on budget cycles (Khemani 2004).

CONCLUSION

Elections play an important role in democracies but they are often accompanied by violence against both candidates and voters. We have shown that the spike in conflict levels around elections does not necessarily imply that elections cause more political violence in general. When elections are the central means to contest for political power, they may also become the most effective times to use political violence. It is precisely the expectation of the ability to use violence effectively in a future electoral period that results in relatively lower levels of violence in nonelectoral periods. When elections also provide a nonviolent means to contest for power, there is even less reason to commit violence both during electoral and nonelectoral periods. Elections can be peaceful for two reasons: either they are not a serious means to contest for power, or they provide such an effective nonviolent means to contest for power that violence is no longer a useful tool.

More generally, the model highlights cycles of any political activity surrounding elections, whether fiscal policy, repression, or interest group attempts to influence policy do not mean these activities would be more or less prevalent if elections were less consequential. When the actions spiking around elections are “bad” it is easy to associate elections with negative consequences, but concentrating the time window in which these bad actions are most effective may leave citizens better off in the long term. So, empirical work examining how elections affect patterns of any political activity must keep in mind the effects of intertemporal substi-

tution when thinking through the broader implications of their findings.

APPENDIX

Data

Figure 8 shows how the patterns we identify are less stark but still clear when looking at wider time windows around elections.

For this and the graphs in the main text, we use two main data sources to examine the empirical patterns of violence around elections. Violence data are obtained from the Social Conflict Analysis Database (SCAD), Version 3.0 (Hendrix and Salehyan 2012). This dataset provides information on different types of violent events (protests, riots, strikes, and other social disturbances) in Africa and Latin America from 1990 to 2012. The main source of these events are based on the Associated Press and *Agence France Presse* news wires, indexed by the Lexis-Nexis news service.²⁶ Election dates and characteristics are from the National Elections Across Democracy and Autocracy (NELDA) Dataset (Hyde and Marinov 2012). This dataset provides information on election events for all countries during the period 1945–2010.²⁷

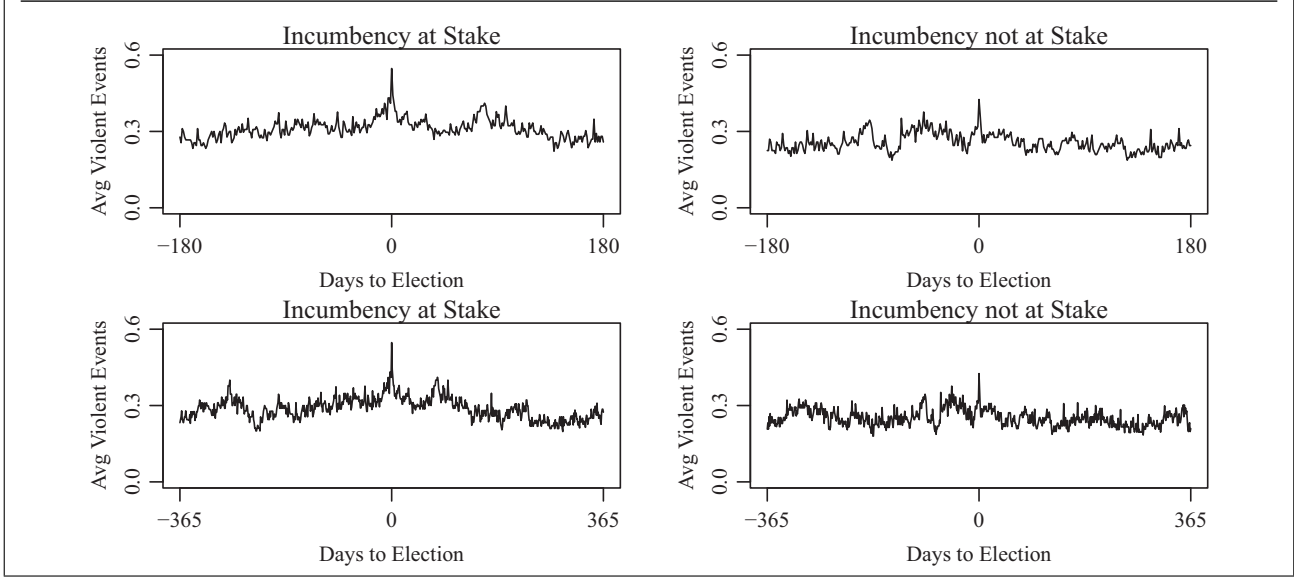
To generate these figures, we first reshape the SCAD data into a “country-day” unit of analysis. Second, for each country and each day we determined the distance to the nearest election using the NELDA data. For example, if the previous election in a country was 200 days ago and the next is in 201 days, the distance to election variable is -200 . In the next day when the previous election was 201 days ago and the next is in 200 days, the distance variable becomes 200. Figures 2, 7, and 8 plot the average levels of violence levels by this distance to election variable, sometimes for subsets of the data identified by other characteristics.

For Figure 2, we distinguish between elections when the incumbent leader’s office was in contention versus when it was not. This was done using the variable in the NELDA dataset that captured whether the office of the incumbent leader was contested in a given election.

²⁶ For more information on the search methodology and the coding procedure, see the Social Conflict Analysis Database, Version 3.0 codebook.

²⁷ For more information on what constitutes an election, see the NELDA codebook.

FIGURE 8. Violence Around Elections for Wider Time Windows



For Figure 7, distinguished between pro- and antigovernment violence around elections, progovernment violence was identified using the variable in the SCAD dataset that captures “distinct violent events waged primarily by government authorities, or by groups acting in explicit support of government authority, targeting individual, or ‘collective individual,’ members of an alleged opposition group or movement.” Antigovernment violence was identified using whether the “central government the target of the event,” and whether any of the issue areas involved elections.²⁸

Proof of Proposition 1

Equation (3) has a unique solution for $t = T$, which gives unique values of $\pi_O^*(T)$ and $\pi_I^*(T)$, which then implies the optimal v_{T-1}^* by equation (6). Further, if there is a unique $\pi_O^*(t)$ and $\pi_I^*(t)$, this leads to a unique v_{t-1}^* , which is given by equation (6) when $\Delta_t^* \leq 0$ and equal to zero otherwise. So, by induction there is a unique triple of sequences $(\pi_I^*(t), \pi_O^*(t), v_t^*)$ which solve equations (2)–(5) for all t . □

Proof of Proposition 2

Figure 9 illustrates the logic of how changing k_t affects the violence choices and relative value of incumbency for periods up to t .

The most direct effect of increasing k_t is to increase the level of violence in period t , which can be demonstrated by implicitly differentiating equation (6) with respect to k_t :

$$\frac{\partial v_t^*}{\partial k_t} = \frac{-\frac{\partial^2 p(v_t; k_t)}{\partial v_t \partial k_t} \Delta_{t+1}^*}{\frac{\partial^2 p(v_t; k_t)}{\partial^2 v_t} \Delta_{t+1}^* - c''(v_t^*)} > 0,$$

where the inequality is true because the numerator is negative and the denominator is negative at v_t^* since it is at a local maximum.

The effect of increasing k_t on v_{t-1}^* is determined by how increasing k_t affects Δ_t^* , which in turn affects v_{t-1}^* . Formally,

$$\frac{\partial \Delta_t^*}{\partial k_t} = \frac{\partial \pi_I^*(t)}{\partial k_t} - \frac{\partial \pi_O^*(t)}{\partial k_t}.$$

The effect of increasing k_t on $\pi_I^*(t)$ is entirely through the fact that doing so increases $p(v_t^*; k_t)$, both directly by increasing k_t and indirectly by increasing v_t^* . So

$$\frac{\partial \pi_I^*(t)}{\partial k_t} = -\delta \Delta_{t+1}^* \frac{dp(v_t^*; k_t)}{dk_t} < 0.$$

For the change in the value of entering as the opposition the analogous calculation has more terms as they incur a higher cost to commit more violence, but by the envelope theorem this effect drops out, giving

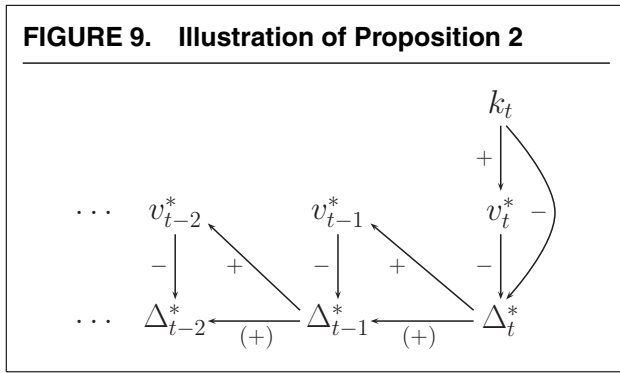
$$\begin{aligned} \frac{\partial \pi_O^*(t)}{\partial k_t} &= -\frac{\partial v_t^*}{\partial k_t} c'(v_t^*) + \delta \Delta_{t+1}^* \frac{dp(v_t^*; k_t)}{dk_t} \\ &= -\frac{\partial v_t^*}{\partial k_t} \left(-c'(v_t^*) + \delta \Delta_{t+1}^* \frac{\partial p(v_t^*; k_t)}{\partial v_t^*} \right) \\ &\quad + \delta \Delta_{t+1}^* \frac{\partial p(v_t^*; k_t)}{\partial k_t} \\ &= \delta \Delta_{t+1}^* \frac{\partial p(v_t^*; k_t)}{\partial k_t} > 0. \end{aligned}$$

Since $\frac{\partial \pi_O^*(t)}{\partial k_t} > 0$ and $\frac{\partial \pi_I^*(t)}{\partial k_t} < 0$, $\frac{\partial \Delta_t^*}{\partial k_t} < 0$. Since there is less benefit to entering period t as the incumbent, this decreases the incentives to commit violence in period $t - 1$:

$$\frac{\partial v_{t-1}^*}{\partial k_t} = -\frac{\frac{\partial p(v_t; k_t)}{\partial v_t} \frac{\partial \Delta_t^*}{\partial k_t}}{\frac{\partial^2 p(v_t; k_t)}{\partial^2 v_t} \Delta_{t+1}^* - c''(v_t)} < 0.$$

²⁸ For more information on these variables, see the SCAD codebook.

FIGURE 9. Illustration of Proposition 2



The effect on even earlier periods is more nuanced. As shown in Figure 9, how k_t affects violence in $t' < t - 1$, depends on how k_t affects $\Delta_{t'}^*$, which in turn depends on how k_t affects $\Delta_{t'+1}^*$. This is given by

$$\frac{\partial v_{t'}^*}{\partial k_t} = -\frac{\frac{\partial p(v_{t'}; k_{t'})}{\partial v_{t'}} \frac{\partial \Delta_{t'+1}^*}{\partial k_t}}{\frac{\partial^2 p(v_{t'}; k_{t'})}{\partial v_{t'}^2} \Delta_{t'+1}^* - c''(v_{t'})},$$

which has the same sign as $\frac{\partial \Delta_{t'+1}^*}{\partial k_t}$. To sign this, first write Δ_t^* as

$$\Delta_t^* = \psi - c(v_t^*) + \delta[1 - 2p(v_t^*; k_t)]\Delta_{t+1}^*.$$

So

$$\begin{aligned} \frac{\partial \Delta_t^*}{\partial \Delta_{t+1}^*} &= -\frac{\partial v_t^*}{\partial \Delta_{t+1}^*} c'(v_t^*) \\ &+ \delta \left([1 - 2p(v_t^*; k_t)] - 2\Delta_{t+1}^* \frac{\partial p(v_t^*; k_t)}{\partial v_t^*} \frac{\partial v_t^*}{\partial \Delta_{t+1}^*} \right) \\ &= \frac{\partial v_t^*}{\partial \Delta_{t+1}^*} \left(-c'(v_t^*) - 2\Delta_{t+1}^* \frac{\partial p(v_t^*; k_t)}{\partial v_t^*} \right) \\ &+ \delta[1 - 2p(v_t^*; k_t)] \\ &= -3 \frac{\partial v_t^*}{\partial \Delta_{t+1}^*} c'(v_t^*) + \delta[1 - 2p(v_t^*; k_t)], \end{aligned} \quad (12)$$

where the last line follows from the period t equilibrium condition (equation (6)). Rearranging, $\frac{\partial \Delta_t^*}{\partial \Delta_{t+1}^*} > 0$ if and only if

$$\delta[1 - 2p(v_t^*; k_t)] > 3 \frac{\partial v_t^*}{\partial \Delta_{t+1}^*} c'(v_t^*). \quad (13)$$

From part (ii) we know that $\frac{\partial \Delta_t^*}{\partial k_t} < 0$, and if equation (13) holds for all $t', \dots, t - 1$, then $\frac{\partial \Delta_{t'}^*}{\partial \Delta_{t'+1}^*} > 0$ for each of these periods, and hence by induction $\frac{\partial v_{t'}^*}{\partial k_t} < 0$.

Equilibrium Definition for Extension with Nonviolent Action

An equilibrium to the model with nonviolent action is a x_t^* , v_t^* , $\pi_O^*(t)$, and $\pi_I^*(t)$ that solve

$$\begin{aligned} \pi_O(t, v_t, x_t) &= c(v_t) - c(x_t)/\beta_t + \delta\{p(v_t + x_t; k_t)\pi_I^*(t+1) \\ &+ [1 - p(v_t + x_t; k_t)]\pi_O^*(t+1)\}, \\ (v_t^*, x_t^*) &\in \arg \max_{(v_t, x_t)} \pi_O(t, v_t, x_t), \\ \pi_O^*(t) &= \pi_O(t, v_t^*, x_t^*), \\ \pi_I^*(t) &= \psi + \delta\{p(v_t^*, x_t^*; k_t)\pi_O^*(t+1) \\ &+ [1 - p(v_t^*, x_t^*; k_t)]\pi_I^*(t+1)\} \end{aligned}$$

for $t = 1, \dots, T$. The main difference between this and the main model is that there are two optimizing choices v_t^* and x_t^* .

Proof of Proposition 3

The idea of the proof is to show that if the level of violence is nondecreasing in β_t , then the opposition must use strictly more non-violent technology as β_t increases, which lowers the marginal value of using violence, contradicting the violence choice being nondecreasing. Formally, consider any $\beta^1 > \beta^2$, and let (x_t^1, v_t^1) and (x_t^2, v_t^2) be the equilibrium decisions with these two values of beta. Suppose $v_t^1 \geq v_t^2$. Since c' is increasing, this implies $c'(v_t^1) \geq c'(v_t^2)$, and since $c'(v_t^i) = c'(x_t^i)/\beta_i$, $c'(x_t^1)/\beta_1 \geq c'(x_t^2)/\beta_2$. Combined with $\beta_1 > \beta_2$, this requires $c'(x_t^1) > c'(x_t^2)$ and hence $x_t^1 > x_t^2$. But the equilibrium conditions for the violence choice for both levels of β_t and the concavity of $p(\cdot)$ imply that:

$$c'(v_t^1) = \frac{\partial p(x_t^1 + v_t^1; k_t)}{\partial x_t} \delta \Delta_{t+1}^* < \frac{\partial p(x_t^2 + v_t^2; k_t)}{\partial x_t} \delta \Delta_{t+1}^* = c'(v_t^2)$$

which contradicts $v_t^1 \geq v_t^2$. So, v_t must be strictly increasing in β_t , proving part i.

For part ii, it follows from part i that $c'(v_t^*)$ is decreasing in β_t , so $c'(x_t^*)/\beta_t$ must be decreasing in β_t as well. If this fraction approaches zero as $\beta_t \rightarrow \infty$, then $c'(v_t^*) \rightarrow 0$, which implies $v_t^* \rightarrow 0$. If $c'(x_t^*)/\beta_t$ does not go to zero as $\beta_t \rightarrow \infty$, then it must be the case that $x_t^* \rightarrow \infty$, which implies $\frac{\partial p(x_t^* + v_t; k_t)}{\partial v_t} \rightarrow 0$ and hence $v_t^* \rightarrow 0$.

Equilibrium Definition for Extension with Incumbent Violence

An equilibrium to the model with incumbent and opposition violence is a $v_{O,t}^*$, $v_{I,t}^*$, $\pi_O^*(t)$, and $\pi_I^*(t)$ that solve

$$\begin{aligned} \pi_O(t, v_{I,t}, v_{O,t}) &= c(v_{O,t}) + \delta\{p(v_{I,t}, v_{O,t}; k_t)\pi_I^*(t+1) \\ &+ [1 - p(v_{I,t}, v_{O,t}; k_t)]\pi_O^*(t+1)\}, \\ \pi_I(t, v_{I,t}, v_{O,t}) &= c(v_{I,t}) + \delta\{p(v_{I,t}, v_{O,t}; k_t)\pi_O^*(t+1) \\ &+ [1 - p(v_{I,t}, v_{O,t}; k_t)]\pi_I^*(t+1)\}, \\ v_{I,t}^* &\in \arg \max_{v_{I,t}} \pi_I(t, v_{I,t}, v_{O,t}^*), \\ v_{O,t}^* &\in \arg \max_{v_{O,t}} \pi_O(t, v_{I,t}^*, v_{O,t}). \end{aligned}$$

$$\begin{aligned} \pi_o^*(t) &= \pi_o(t, v_{o,t}^*, v_{i,t}^*), \\ \pi_i^*(t) &= \psi + \delta\{p(v_{i,t}^*, v_{o,t}^*; k_t)\pi_o^*(t+1) \\ &\quad + [1 - p(v_{i,t}^*, v_{o,t}^*; k_t)]\pi_i^*(t+1)\} \end{aligned}$$

for $t = 1, \dots, T$. The main difference between this and the main model is that the incumbent and opposition choices must be mutual best responses, rather than the opposition violence choice being optimal in isolation.

Derivation of equations (9) and (10) and Proof of Proposition 4

The first order conditions if both actors choose a strictly positive level of violence are

$$\begin{aligned} 1 &= k_t \delta [\pi_i^*(t+1) - \pi_o^*(t+1)] \frac{v_{i,t}^*}{(v_{o,t}^* + v_{i,t}^*)^2}, \\ \gamma &= k_t \delta [\pi_i^*(t+1) - \pi_o^*(t+1)] \frac{v_{o,t}^*}{(v_{o,t}^* + v_{i,t}^*)^2}. \end{aligned}$$

If $\pi_i^*(t+1) < \pi_o^*(t+1)$ there can be no solution to these equations: the objective functions are always decreasing in $v_{j,t}$, so in any equilibrium both actors choose $v_{j,t}^* = 0$.

If $\pi_i^*(t+1) > \pi_o^*(t+1)$ and both actors chose no violence, there is an upward discontinuity in the probability of taking over office at $v_{j,t} = 0$, so it is always better to choose an incrementally small level of violence to no violence. If only one actor chose a strictly positive level of violence, the other actor could always deviate to a lower violence level and have the same probability of being the incumbent in the next period. So, when $\pi_i^*(t+1) > \pi_o^*(t+1)$ both violence levels must be interior, and by the preceding system of equation, this implies $v_{i,t}^* = \gamma^{-1} v_{o,t}^*$. Since violence is cheaper for the incumbent, they choose more in equilibrium. This also implies that in equilibrium the probability of a transition of power in each period is $\frac{k_t}{1+\gamma^{-1}}$.

The net present values for entering in each role in period t when choosing the equilibrium level of violence is

$$\begin{aligned} \pi_o^*(t) &= -v_{o,t}^* + \delta \left[\frac{k_t}{1 + \gamma^{-1}} \pi_i^*(t+1) \right. \\ &\quad \left. + \left(1 - \frac{k_t}{1 + \gamma^{-1}} \right) \pi_o^*(t+1) \right], \end{aligned} \tag{14}$$

$$\begin{aligned} \pi_i^*(t) &= \psi - \gamma v_{i,t}^* + \delta \left[\frac{k_t}{1 + \gamma^{-1}} \pi_o^*(t+1) \right. \\ &\quad \left. + \left(1 - \frac{k_t}{1 + \gamma^{-1}} \right) \pi_i^*(t+1) \right] \end{aligned} \tag{15}$$

and the formula for Δ_t^* follows from subtracting these.

For the proposition, part (i) follows immediately from equations (9) and (10). For part (ii), consider what happens when violence becomes more effective in some period t' . By equation (11), $\Delta_{t'}$ is decreasing in $k_{t'}$, which then implies that $v_{j,t'-1}^*$ and $\Delta_{t'-1}^*$ are both decreasing in $k_{t'}$. This in turn implies that $v_{j,t'-2}^*$ and $\Delta_{t'-2}^*$ are decreasing in $k_{t'}$. More generally, $v_{j,t'-j}^*$ and $\Delta_{t'-j}^*$ decreasing implies that $v_{j,t'-j-1}^*$ and $\Delta_{t'-j-1}^*$ are decreasing. The result then follows by induction. \square

Proof of Proposition 5

An equilibrium to the continuous policy outcome model is a sequence of violence choices where each v_t^* maximizes the expected payoff for the remainder of the game given the future violence choices.

So, in period T , the actor chooses v_T to maximize

$$y_T - \delta^{T-1} c v_T^2 + a \delta^T [(1 - k_T) y_T + k_T v_T],$$

giving first order condition,

$$2c v_T = \delta a k_T,$$

and hence $v_T^* = \delta a k_T / 2c$.

In period $T - 1$, the actor picks v_{T-1} to maximize

$$\begin{aligned} &\delta^{T-2} c v_{T-1}^2 + \delta^{T-1} [(1 - k_{T-1}) y_{T-1} + k_{T-1} v_{T-1}] \\ &\quad + a \delta^T \{ (1 - k_T) [(1 - k_{T-1}) y_{T-1} + k_{T-1} v_{T-1}] + k_T v_T^* \}. \end{aligned}$$

Giving first order condition,

$$2c v_{T-1} = \delta k_{T-1} + a \delta^2 [k_{T-1} (1 - k_T)].$$

More generally, taking the discounted sum of the returns (including the continuation value at the end of the game) gives

$$v_t^* = \frac{\delta k_t}{2c} \left(1 + \sum_{i=t+1}^T \prod_{j=i+1}^i \delta (1 - k_j) + a \prod_{j=t+1}^{T+1} \delta (1 - k_j) \right).$$

The result follows from differentiating this equation with respect to k_t and any $k_{t'}$ for $t' > t$. \square

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit <https://doi.org/10.1017/S0003055416000733>.

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