

**PATTERNS OF TRANSNATIONAL TERRORISM, 1970-99:  
ALTERNATIVE TIME SERIES ESTIMATES**

by

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## **PATTERNS OF TRANSNATIONAL TERRORISM, 1970-99: ALTERNATIVE TIME SERIES ESTIMATES**

### **Abstract**

Using alternative time series methods, this paper investigates the patterns of transnational terrorist incidents that involve one or more deaths. Initially, an updated analysis of these fatal events for 1970-99 is presented using a standard linear model with pre-specified interventions that represent significant policy and political impacts. Next, a (regime-switching) threshold autoregressive (TAR) model is applied to this fatality time series. TAR estimates indicate that increases above the mean are not sustainable during high-activity eras, but are sustainable during low-activity eras. The TAR model provides a better fit than previously tried methods for the fatality time series. By applying a Fourier approximation to the nonlinear estimates, we get improved results. The findings in this study and those in our earlier studies are then applied to suggest some policy implications in light of the tragic attacks on the World Trade Center and the Pentagon on 11 September 2001.

## **PATTERNS OF TRANSNATIONAL TERRORISM, 1970-99: ALTERNATIVE TIME SERIES ESTIMATES**

On the morning of 11 September 2001, the world watched in horror as 19 hijackers wreaked death and destruction on the World Trade Center and the Pentagon. The lethality of transnational terrorism attained a new height, greatly out of line with the experience of the last three decades where on average 400-500 people lost their lives each year in transnational terrorist events (US Department of State, 1989-2000). In a matter of an hour, somewhere between 5000 to 6000 innocent individuals from upwards of 62 nations died in four coordinated hijackings. This attack underscores that the security threat confronting industrial nations is more from clandestine groups with perceived grievances than from rogue nations. The reliance of modern industrialized economies on technology makes them especially vulnerable to terrorist attacks, as the events of 11 September 2001 sadly demonstrate.

Terrorism is the premeditated use or threat of use of extra-normal violence or brutality by subnational groups to obtain a political, religious, or ideological objective through intimidation of a huge audience, usually not directly involved with the policymaking that the terrorists seek to influence.<sup>1</sup> Key ingredients of the definition include the underlying political motive, the general atmosphere of intimidation, and the targeting of those outside of the decision-making process. Terrorists choose their targets to appear to be random so that everyone feels at risk, when getting on a plane, entering a federal building, or strolling a market square. Business people, military personnel, tourists, and everyday citizens, rather than politicians, are generally the targets of terrorists attacks. In the case of the World Trade Center, the victims were not directly involved in the political decision-making process associated with the demand (i.e., the removal of the US presence from Saudi Arabia and an end to US support of Israel) that may have been behind the attacks.<sup>2</sup> The incident underscores the importance of applying sophisticated analyses to the study

of international terrorism to better understand its patterns, in the hopes of deriving improved policies and predictions to protect against future attacks.

Although terrorism has plagued civilization from its inception, there has been a heightened awareness since the end of 1967 Arab-Israeli War and the start of Israeli occupation of captured territory, at which point terrorism assumed a greater *transnational* character. Whenever a terrorist incident (e.g., a bombing, plane hijacking, and assassination) in one country involves victims, targets, or institutions of at least one other country, the incident is transnational. Incidents to protest the Israeli occupation resulted in the hijacking of planes on international flights, the murder of Israeli athletes at the 1972 Munich Olympics, and attacks throughout Western Europe, and represented instances of transnational terrorism. Given the perpetrators' citizenship and the multiple nationalities of the victims, the four simultaneous hijackings on 11 September 2001 were transnational terrorist acts. The ability of terrorist events to capture headlines demonstrates the consequences of such tactics to others, who later adopt them for their causes. Terrorism is particularly troublesome for liberal democracies, entrusted with protecting the lives and property of their electorate.<sup>3</sup> If such democracies respond inappropriately to a terrorist threat by either caving in to terrorist demands or overly restricting freedoms, then they can lose legitimacy and be defeated at the next election (Wilkinson, 1986, 2001).

With the availability of sufficiently long time series, economists and others have applied time-series techniques to evaluate anti-terrorism policy effectiveness, to uncover trends and cycles, and to estimate the effects of terrorist activities. A host of policy decisions have been examined, including the usefulness of retaliatory raids (Brophy-Baermann and Conybeare, 1994; Enders and Sandler, 1993), the consequences of UN conventions and resolutions on terrorist activities (Enders, Sandler, and Cauley, 1990), and the impact of media reporting on future events (Nelson and Scott, 1992; Scott, 2001). Past studies have decomposed the series of all

terrorist events into its component series (e.g., assassinations, threats and hoaxes, hostage-taking events, and bombings) so as to identify any trend or cycles.<sup>4</sup> In so doing, it was shown that the time series for each attack mode displays its own cycle, whose length increases with the logistical complexity of the action. Apparently, the attack-counterattack interaction between the terrorists and the authorities give rise to cycles that take longer to play out for more complicated operations such as skyjackings (Enders et al., 1992). In terms of the estimated effects of terrorism, studies have examined the relationship of terrorism and tourism as well as that between terrorism and foreign direct investment.<sup>5</sup>

When incidents involving casualties (i.e., deaths, injuries, or both) are distinguished from those with no casualties, there is a striking difference between the two. Namely, casualties series display more predictability than noncasualties series, which are largely random noise once detrended (Enders and Sandler, 2000). Thus, estimates and policy evaluation should be based on a casualty series such as “DEATH,” where one or more deaths among terrorists or victims resulted from the action, owing to this series’ deterministic factors. This finding suggests that more intense terrorist events are more predictable than those with less consequence such as threats, hoaxes, letter bombings, and other small-scale bombings.

This paper carries on the process of improving policy evaluations and estimates of the patterns of transnational terrorism. At first, time-series-based policy evaluation relied on intervention analysis, in which dummy variables identifying suspected impact points are tested for significance for a single series (Cauley and Im, 1988; Enders et al., 1990). This intervention procedure was later extended to vector-autoregressive (VAR) analysis to capture the interrelationship among two or more series (Enders and Sandler, 1991, 1993, 1996; Nelson and Scott, 1992), so that the introduction of, say, metal detectors in airports may curtail skyjackings but augment hostage-taking events (e.g., kidnappings), not protected by these detectors, as

terrorists substitute among modes of attacks in response to policy-induced changes in relative costs. These VAR studies, like their single-series predecessors, assumed linear representations with no regime-switching possibilities. Hence, the current exercise represents an important departure where nonlinear techniques are also applied to the DEATH series, which displays the greatest deterministic factors. These techniques not only allow the mean of the DEATH series to differ according to the overall intensity of activities, but they also permit the data to indicate points at which things become different.

In the next section, we present the terrorists' choice-theoretical model that underlies some of the empirical findings. This is followed by some important intervention points and a description of the data. The ensuing section distinguishes the dummy-variable intervention analysis from the nonlinear threshold model. Next, the regime-switching model is introduced, followed by the actual estimations. The Fourier-approximation model is estimated in the next section. The next-to-last section addresses the implications of this article and our prior work on the aftermath of the attacks on the World Trade Center and the Pentagon. Concluding remarks are then given.

## THEORETICAL MODEL

Our application is to transnational terrorism which has become much more prevalent during the last thirty years as terrorists have taken advantage of improvements in communication, transportation, and technology to intimidate a global community with threats of violence unless their political demands are met. Transnational terrorist incidents are examples of transboundary externalities, because actions by terrorists or reactions by governments in one country may impose uncompensated costs or benefits on the people or property of another

country.<sup>6</sup> Thus, a government plagued with terrorism on its soil may spend too much on deterrence in an effort to transfer the attack elsewhere, or else a terrorist group may achieve maximum news coverage by staging their attack in a European capital. When an incident is planned in one country, but executed in another, it is a transnational event. The kidnapping or assassination of a citizen from another country in a host country is a transnational terrorist act, as is a bombing directed at one or more foreign citizens. A skyjacking of a flight that originates in country A, but that ends in country B, is transnational. If, however, the targeted flight has passengers from two or more countries, the skyjacking is transnational even if it never takes off. We focus on transnational terrorism not only because of its importance to international studies, but also because of the availability of a long consistently coded time series. Moreover, transnational terrorism poses an important threat to the stability of the global community. The events of 11 September have not only disrupted air travel, but may have pushed the global economy, already on the brink, into recession. By increasing cross-border interactions, globalization can augment the ramifications of catastrophic transnational terrorist events.

Like any agent, terrorists' resources in any period are limited and constrain their actions to pursue satisfaction derived from a political cause. Because our focus is on the entire series of terrorist events, terrorists are depicted as allocating their resources between terrorist events ( $t$ ) and legal actions ( $\ell$ ) so as to maximize their expected utility [ $E(U)$ ]. Terrorist events includes bombings, skyjackings, assassinations, and other actions, while legal activities include propaganda statements and gaining a foothold within a base country or countries of operation. A terrorist group is viewed as allocating scarce resources,  $R$ , between legal activities with a certain gain,  $g^\ell$ , and terrorist activities with an uncertain gain,  $g^t$ . A terrorist incident may end in at least two states: success where the incident is completed as planned, or failure where the incident is either not completed or fails in its goal. Success is a random variable whose probability is  $\pi$ . If

only two states of the world are permitted for terrorist events, then  $(1 - \pi)$  denotes the probability of failure. A terrorist group's expected utility is

$$E(U) = \pi U(W^S) + (1 - \pi)U(W^F), \quad (1)$$

where  $U(W)$  is the standard von Neumann-Morgenstern utility function. Arguments  $W^S$  and  $W^F$  are the net wealth equivalent measures over the two states of success,  $S$ , and failure,  $F$ . These measures equal:

$$W^S = w + g^l(R^l) + g^t(R^t, e_1), \quad (2)$$

$$W^F = w + g^l(R^l) - f(R^t, e_2). \quad (3)$$

In equation (2), the net wealth derived from a successful terrorist incident includes the group's current assets net of current earnings,  $w$ , the monetary equivalent net gains from legal activities, and the monetary equivalent net gains from the terrorist act.  $R^l$  represents the resources assigned to legal actions, and  $R^t$  indicates the resources assigned to terrorism actions. In either state of the world, monetary gains depend directly on the resources (including time) allocated by the terrorists to either legal activities or the terror campaign, and these gains are assumed to display diminishing returns.<sup>7</sup> In equation (2),  $e_1$  represents the environmental factor that also helps determine gain during a successful outcome. For example,  $e_1$  can reflect actions taken by the authorities (e.g., freezing assets, retaliatory raids, freedom of press) that influence the benefits of a terrorist success. As such,  $e_1$  denotes a shift parameter.

In equation (3), the net wealth for a terrorist failure includes a group's current assets plus its net gain from legal activities minus the monetary value of the fine or penalty,  $f$ , from failure. If the group fails but escapes, then this penalty includes wasted resources expended on the unsuccessful event. When, however, the group is captured, the fine refers to the wasted resources (including murdered terrorists), the opportunity costs of incarceration, and any monetary penalties assessed. The loss of one or more terrorists results in the costs of training



replacements. In  $f(\bullet)$ ,  $e_2$  denotes an environmental factor that influences the level of losses during failed campaigns. This factor includes activities taken by authorities, such as the severity of sentences and extradition requests. Once again,  $e_2$  represents a shift parameter of the model.

The terrorist group's resource constraint,

$$R = R^t + R^l, \quad (4)$$

closes the model and indicates that the group's total resources,  $R$ , are divided each period between legal and terrorist activities. Expected utility in equation (1) can be rewritten in terms of the choice variables ( $R^l$ ,  $R^t$ ) and the exogenous shift parameters by substituting equations (2)-(4) into (1). Both the optimal levels of  $R^l$  and  $R^t$  are then determined by maximizing the resulting expression for expected utility. The likely effects of government policy decisions resulting from changes in  $\pi$ ,  $e_1$ , and  $e_2$  are found through comparative-static analysis, where the assumption of the model are used to determine the influence that changes in these policy parameters have on the optimal choice of  $R^l$  and  $R^t$ . Often, additional assumptions concerning the terrorist group's risk attitudes can help sign these comparative-static impacts.

Some results are fairly clear-cut without further mathematical analysis. Actions by the authorities to decrease the terrorists' total resources through raids on their camps, infiltration of the group, or by freezing their assets will curtail both legal and terrorist activities. If a retaliatory raid were to increase the terrorists' perceived gains from terrorist attacks as means of protest,<sup>8</sup> then the terrorists will shift resources out of legal activities into terrorist acts. During periods of high terrorist activities, this ability to sustain even a greater level of terrorist acts is limited in contrast to periods of low activities.

Thus far, we represent the problem as the choice-theoretic decision of a single terrorist group. From the early 1970s, terrorist groups, engaged in transnational acts, have been tied either explicitly or implicitly in networks consisting of left-wing terrorist groups (Alexander and

Pluchinsky, 1992) united in their goal to overthrow democratic governments, Palestinian groups united in their aim to establish a homeland or to destroy Israel, and fundamentalist terrorist groups (Hoffman, 1998; US Department of State, 2001) united in their goal to create nations founded on fundamentalist principles. Since the start of 1980, the number of religious-based groups has increased as a proportion of the active terrorist groups: 11 of 48 groups in 1992, 16 of 49 groups in 1994, and 25 of 58 groups in 1995 (Hoffman, 1997:3). Bin Laden's al-Qaida network includes Islamic extremist organizations in many countries, which are linked through finances, training, and a common enemy. This network includes such groups as Abu Sayyaf (the Philippines), Egypt's Islamic Group, Harakat ul-Mujahidin (Pakistan), Islamic Movement of Uzbekistan, Al-Jihan (Egypt), and Bin Laden's own group (Afghanistan) (US Department of State, 2001). Even left-wing groups and Palestinian groups have been known to train together and to have other ties (Wilkinson, 1986, 2001; Hoffman, 1998), so that separate networks have explicit links to one another. Implicit ties come from copying each other's tactics – the so-called demonstration effect. These networks' common hatred of the United States and Israel means that heightened attacks by groups in one part of the world can spark increased attacks in other parts of the world. This implicit coordination shows up as distinct cycles of peaks and troughs in transnational terrorist activities (Enders et al., 1992; Enders and Sandler, 1999).

Thus far, we have only considered the terrorist choice between legal and terrorist activities. Another choice by the terrorists must, however, be made in allocating  $R'$  among alternative modes of attacks so as to equate the expected marginal gain per dollar spent on alternative operations. Actions by the government to increase the difficulty (i.e., the price) of one kind of attack will cause the terrorists to substitute into other types of attacks that now appear to be relatively cheaper (Sandler, Tschirhart, and Cauley, 1983; Enders and Sandler, 1993). Thus, it is essential for authorities to impose policies that cause the terrorists to substitute

into less harmful modes of attacks. Authorities have not always been successful in this aim – e.g., increased US embassy security led to a decrease in such attacks, which usually resulted in no injuries, and to an increase of assassinations of embassy personnel as they left secure grounds (Enders and Sandler, 1993). In light of these substitutions, the authorities must also raise the difficulty of all modes of attacks – e.g., by limiting terrorist resources or through intelligence on terrorist operations.

## INTERVENTIONS AND THE DATA

Six interventions or suspected changes to the terrorist time series are germane to our analysis and discussion. These interventions are listed in Table 1 along with their abbreviations, description, and initiation period. Although our interest is to apply a methodology that allows for *ex post* data identification of significant changes in the time series, these *ex ante* influences, due to either policy changes (i.e., metal detectors at airports, enhanced embassy security, or a retaliatory raid) or political events (i.e., the rise of religious fundamental terrorism or the start of the post-cold era),<sup>9</sup> are required for updating the linear intervention-based analysis to 1999 and for comparing this latter analysis to the nonlinear techniques presented at a later point. In previous papers, five of these six interventions resulted in significant shifts to the aggregate terrorist series and its various component series. The sole exception is the US retaliatory raid on Libya, which resulted in just an immediate impact that dissipated rapidly as the series returned to its pre-intervention mean.<sup>10</sup>

Data on transnational terrorism incidents are drawn from *International Terrorism Attributes of Terrorist Events* (ITERATE), which records, among other things, the incident date, its location, type of event, and casualties (i.e., deaths or injuries), if any. ITERATE 2 covers

1968-77 (Mickolus, 1982), ITERATE 3 covers 1978-87 (Mickolus, Sandler, Murdock and Fleming, 1989), and ITERATE 4 covers 1988-91 (Mickolus, Sandler, Murdock and Fleming, 1993). To bring the data set up to date, we coded the necessary variables for 1992:1-1999:4 based on written descriptions provided by Mickolus. Coding consistency for ITERATE 2 and its various updates has been preserved by applying the same criteria for defining transnational events and associated variables. This consistency was enhanced owing to an overlap among coders and monitors – e.g., Sandler participated in the coding of the data for 1977:1-1999:4. ITERATE drew its information from the world print and electronic sources including the Associated Press, United Press International, Reuter tickers, major US newspapers (e.g., the *Washington Post* and the *New York Times*), and the Foreign Broadcast Information Service (FBIS). The FBIS *Daily Reports*, which draws from hundreds of world print and electronic media sources, served as the single most important source up through the start of 1996.<sup>11</sup> ITERATE does not contain information about state sponsorship, because countries keep this information secret; hence, we cannot distinguish such events in our analysis.

ITERATE does *not* classify incidents as transnational terrorism that relate to declared wars or major military interventions by governments (e.g., Chechnyan acts against Russian military personnel), or guerilla attacks on military targets conducted as internationally recognized acts of belligency. If, however, the guerilla attacks were against civilians or the dependents of military personnel in an attempt to create an atmosphere of fear to foster political objectives, then the attacks are considered terrorism. Palestinian acts in Israel that do not harm foreigners are not classified as transnational terrorism. While a domestic event may become transnational if a foreigner is the unintended victim, instances of this are rare. If this randomness of victims was great, then the large number of US victims, who are the intended target on average of about 40 percent of all transnational acts (US Department of State, 1989-2001), would

not consistently characterize the data totals each year. Official government-sanctioned acts in response to terrorist attacks, such as the US bombing of Libya or US seizure of an Egyptian plane carrying the terrorists from the *Achille Lauro* incident, are not themselves coded.

ITERATE also excludes unintended acts from the data set. If, for example, a foreign newspaper reporter is killed in the cross fire between government troops and guerillas, the reporter's death is not considered a terrorist assassination. ITERATE, however, does code terrorist acts against foreign aid workers or UN peacekeepers.

We extract three quarterly time series from ITERATE: (i) a DEATH series, where one or more individuals died as a result of the incident; (ii) a WOUNDED series, where one or more individuals were injured, but no one died, as a result of the incident; and (iii) a NONCASUALTIES series, where no one died or was injured as a result of the incident. We use terrorist incident “count” data computed on a quarterly, rather than weekly or daily, basis to eliminate zero-valued observations, inconsistent with the underlying normal distribution assumption of the various autoregressive (AR) analyses (Harvey, 1989). Based on Enders and Sandler (2000), we shall focus on the DEATH series, which has the most deterministic factors of the three series owing to its intensity. This earlier study showed the NONCASUALTIES series to be essentially random after detrending and the WOUNDED series to be less deterministic than the DEATH series. Nevertheless, we shall apply our analysis to all three series.

#### DUMMY VARIABLES VERSUS THE THRESHOLD MODEL

A number of papers have tried to estimate and forecast transnational terrorist events. One key issue is to ascertain the effects of various policy interventions and political events on the occurrence of transnational terrorism. For example, Enders and Sandler (2000) estimated the

following autoregression (with  $t$ -statistics in parentheses):

$$\begin{aligned}
 y_t = & 4.037 + 0.406 y_{t-1} + 5.62 METAL_t - 0.26 EMB76_t - 5.92 EMB85_t \\
 & (1.77) \quad (3.22) \quad (2.28) \quad (-0.11) \quad (-3.20) \\
 & - 7.93 LIBYA_t + 4.17 FUND_t + 6.77 POST_t \\
 & (-1.30) \quad (1.89) \quad (3.19)
 \end{aligned} \tag{5}$$

where  $y_t$  is the quarterly number of incidents with one or more deaths.  $METAL_t$ ,  $EMB76_t$ ,  $EMB85_t$ ,  $LIBYA_t$ ,  $FUND_t$ , and  $POST_t$  are all dummy variables that represent the various intervention points as defined previously in Table 1.

The use of dummy variables in this fashion yields some interesting findings. The impact of metal detectors in airports is estimated to have increased the number of incidents with deaths by 5.62 incidents per quarter, implying a substitution from skyjackings into more deadly events.<sup>12</sup> The steady-state value of this increase rises to 9.46 [= 5.62/(1 – 0.406) ] incidents per quarter. Fortification of U.S. embassies in 1985, but not in 1976, is found to decrease the short-run number of incidents with deaths by 5.92 incidents per quarter, but with a long-run effect of 9.97 fewer incidents per quarter. Moreover, the break-up of the Soviet Union is found to have a large positive impact on terrorism: the immediate impact effect is estimated to be 6.77 incidents per quarter rising to a total of 11.4 incidents per quarter. In Figure 1, incidents per quarter are measured on the vertical axis and the years on the horizontal axis. The dashed line represents the actual number of fatal incidents, while the vertical lines indicate the four significant intervention dates. The solid locus with horizontal segments shows the estimated magnitudes of the effects of the interventions. To depict the impact of each intervention, we set  $y_1$  equal to the actual value of death incidents in 1970:1 and generated the remaining values using equation (5). It is clear from Figure 1 that the mean number of incidents rose from about 6.5 to about 16 per quarter after the installation of metal detectors in 1973. The values are shown through only 1996:2 since equation (5) was estimated using data from 1970:1 to 1996:2.

Some words are instructive about the political events behind some of the various peaks in Figure 1. The peaks in 1976 and 1977 are primarily attributed to activities of Palestinian groups outside of Israel and left-wing European terrorists (Mickolus, 1982). The spikes in 1981, 1983, and 1985 are due to terrorist activities by left-wing groups in Europe and South America, as well as from spillover terrorism from the Middle East (Mickolus et al., 1989). The Libyan retaliatory raid by the United States and the backlash it caused are behind the peak in 1986. Numerous Middle-East-motivated deadly terrorist attacks, coupled with Afghan rebel attacks in Pakistan, led to the spike in 1988 (US Department of State, 1989). Finally, the peaks in the early 1990s are rooted in religious fundamentalism (by HAMAS and others) and in separatism (in Sri Lanka) (US Department of State, 1990-96). Actions by the Kurdish Workers Party in Turkey and by narcoterrorists in Colombia also contributed to these totals. The Afghanistan War trained many individuals with fundamentalist views, who account for many lethal events in the 1990s and beyond.

The use of multiple dummies, however, raises a number of concerns as follows:

1. There is a danger of *ex post* fitting if the break points' dates are chosen *as a result of an observed change* in the variable of interest, then test statistics lose their importance. Clearly, with enough dummy variables, any series can be fitted to any degree desired. The problem is reinforced by the fact that the starting dates for the FUND and POST variables were found by a grid search method, for which the two starting dates were those that maximized the overall fit of the regression (Enders and Sandler, 1999, 2000). There is, however, less of a problem if interventions are chosen *ex ante* based on hypothesized changes to the data that are then tested for significance.

2. Other incidents that roughly coincide with the break point dates may, in part, be responsible for the observed change in the series. For example, events surrounding the demise of

the Soviet Union (as measured by POST) came about the time of the war in Kuwait. As recognized by Enders and Sandler (2000), it is exceedingly difficult to distinguish between the influences of two near, but distinct, events.

3. The efficacy of the estimates cannot rely on the usual asymptotic properties of an autoregression. If there is a single break point, Lutkepohl (1991) showed that the standard asymptotic properties hold if it is assumed that observations on both sides of the break increase as sample size increases, but that a “logical problem” arises in the presence of multiple breaks. Given that there are a fixed number of observations lying between EMB76 and EMB85, increasing the sample size does nothing to increase the number of points lying between these two break points. Lutkepohl (1991:410) stated that “... the large sample  $\chi^2$ -distribution ... may be used if the periods between the interventions is reasonable large. Since no small sample results are available it is not clear, however, how large is large enough to obtain a good approximation to the asymptotic  $\chi^2$ -distribution.”

4. The interventions need not be modeled as [0, 1] dummy variables; for example, Enders et al. (1990) used an alternative form for the METAL dummy. Although the United States began installing metal detectors in its airports in the first quarter of 1973, it took almost a full year for installation to be completed internationally at major airports. As such, they used an intervention variable equal to 1/4 in 1973:1; 1/2 in 1973:2; 3/4 in 1973:3; and 1 in 1973:4. More generally, interventions can have temporary or permanent effects on a series that may grow or fade over time. The standard way to determine the ‘best’ form of the intervention variable is to use the one that provides the best in-sample fit.

5. The effects of the different dummies may overlap each other. This could be especially problematic if there is any misspecification in the way that each dummy is allowed to affect the system. For example, instead of being a 0 versus 1 dummy, suppose that the importance of



Islamic fundamentalism has grown over time. The POST variable will then capture some of this effect, leading some of the subsequent increase in terrorism resulting from FUND to be wrongly attributed to POST.

6. The effects of the interventions are allowed to affect only the mean of the series, even though the autoregressive coefficient(s) may themselves be affected by the changes.

7. Finally, there may be other events that influence terrorism, not included in the model – e.g., political events in the Middle East or Latin America may have had profound effects on the terrorism series.

Some of the problems with multiple dummy variables are apparent when we re-estimate equation (5) using an updated version of ITERATE with observations for 1996:3-1999:4. After incorporating these 14 additional observations into the data set, we obtain the following regression estimates of the DEATH series:

$$\begin{aligned}
 y_t = & 4.10 + 0.423 y_{t-1} + 4.71 METAL_t - 0.479 EMB76_t - 4.91 EMB85_t \\
 & (2.10) \quad (4.98) \quad (1.89) \quad (-0.201) \quad (-2.65) \\
 & - 8.64 LIBYA_t + 4.02 FUND_t + 2.50 POST_t, \quad AIC = 1008.2, SBC = 1030.4, \quad (6) \\
 & (-1.37) \quad (1.82) \quad (1.48)
 \end{aligned}$$

where AIC is the Akaike Information Criteria and SBC is the Schwartz Bayesian Criteria.<sup>13</sup> If we omit  $EMB76_t$  and  $LIBYA_t$ , we obtain:

$$\begin{aligned}
 y_t = & 4.15 + 0.417 y_{t-1} + 4.54 METAL_t - 5.29 EMB85_t + 3.80 FUND_t + 2.87 POST_t, \quad (7) \\
 & (2.13) \quad (4.93) \quad (1.99) \quad (-2.88) \quad (2.11) \quad (1.72) \\
 & AIC = 1006.3, SBC = 1022.9.
 \end{aligned}$$

Even if we use equation (7), it is striking that  $METAL_t$  is barely significant at the 5% level and  $POST_t$  is not significant at the 5% level. Moreover, the absolute values of the magnitudes of the coefficients and the associated  $t$ -statistics for  $EMB85_t$  and  $FUND_t$  are all closer to zero than in equation (5). Thus, when we use the updated data, it appears that the interventions were not that important for the DEATH series after all. To explain the erosion in the coefficients and their

significance, we note that the number of incidents with deaths declined throughout the updated sample period (see the extended portion of the dashed line in Figure 1), so that the magnitude of the jump in incidents attributed to the demise of the Soviet Union was not sustained. Moreover, the decrease in the overall mean of the incident series pushed the  $t$ -statistics for the previously significant interventions closer to zero. Quite simply, the recent decline in the number of DEATH incidents makes it difficult to interpret the importance of the previous interventions. Perhaps, the importance of  $POST_t$  had just a temporary effect lasting only a few years (see our previous point 4); there may have been other influences not captured by the interventions (see point 7); or the original effect of  $POST_t$  was due to overfitting (see point 1). Of course, it would be possible to capture the decline in terrorism with yet another dummy for the 1996:3-1999:4 period, but, this simply compounds the problems encountered when using multiple interventions.

A word of caution and clarification is in order before we present some nonlinear time series methods for addressing these issues. Linear intervention analysis has its place if intervention points are chosen *ex ante* based on theoretical priors. For a skyjacking time series, the significance of metal detectors would remain even with the addition of another few years of data because these detectors had such a large and sustained impact on skyjackings. The influence of metal detectors on the DEATH series, which includes all incidents and not just skyjackings, is apt to be more tenuous as equations (6)-(7) indicate. Thus, our exploration of alternative time series methods is not intended to dismiss intervention analysis when used with theoretical priors in the proper setting.

## REGIME-SWITCHING ESTIMATION

One way to circumvent some of the above problems is to estimate the DEATH series

using a type of regime-switching model. Intuitively, there may be several states of the world and the severity of terrorism may differ in each. Suppose, for example, that a political event or policy intervention occurs that causes the amount of terrorism to switch into the high state. Since terrorists are using relatively large amounts of their scarce resources, it would be surprising to find that attacks exhibit a high degree of persistence in the high state. Terrorism could persist in this high state for a while until another event takes place that switches the system into the low state. Terrorism could then remain low until yet another political or policy shock of sufficient magnitude occurs that switches the system back into the high state. If our theoretical model about resource allocation is correct, then we anticipate that activity levels above the estimated mean of the series for the high state cannot last for long, unlike the low-state scenario where terrorist resources are not stretched and departures from the mean can persist. The cause of the shock sufficient to switch the system could be unknown to the researcher; nevertheless, it is possible to estimate the behavior of the terrorist incidents in the various states.

Consider a two-regime version of the *threshold autoregressive* (TAR) model developed by Tong (1983, 1990):

$$y_t = I_t \left[ \alpha_0 + \sum_{i=1}^p \alpha_i y_{t-i} \right] + (1 - I_t) \left[ \beta_0 + \sum_{i=1}^p \beta_i y_{t-i} \right] + \varepsilon_t, \quad (8)$$

where  $y_t$  is the series of interest, the  $\alpha_i$ , and  $\beta_i$  are coefficients or constants to be estimated,  $\tau$  is the value of the threshold,  $p$  is the order of the TAR model, and  $I_t$  is the Heaviside indicator function:

$$I_t = \begin{cases} 1 & \text{if } y_{t-1} \geq \tau \\ 0 & \text{if } y_{t-1} < \tau. \end{cases} \quad (9)$$

The nature of the system is that there are two states of the world. In the high-terrorism state,  $y_{t-1}$  exceeds the value of the threshold  $\tau$  so that  $I_t = 1$  and  $(1 - I_t) = 0$ , where  $y_t$  follows the

autoregressive process,  $\alpha_0 + \Sigma\alpha_i y_{t-i}$ . Similarly, in the low-terrorism state,  $y_{t-1}$  falls short of the threshold  $\tau$ , so that  $I_t = 0$  and  $(1 - I_t) = 1$ , where  $y_t$  follows the autoregressive (AR) process,  $\beta_0 + \Sigma\beta_i y_{t-i}$ . There are essentially two attractors or potential “equilibrium” values: the system is drawn toward  $\alpha_0/(1 - \Sigma\alpha_i)$  in the high state and toward  $\beta_0/(1 - \Sigma\beta_i)$  in the low state. Moreover, the degree of autoregressive decay will differ across the two states if for any value of  $i$ ,  $\alpha_i \neq \beta_i$ . The key feature of the TAR model is that a sufficiently large  $\varepsilon_t$  shock can cause the system to switch between states.

The momentum threshold autoregressive (M-TAR) model used by Tong and Lim (1980) and Enders and Granger (1998) allows the regime to change according to the *first-difference* of  $\{y_{t-1}\}$ . Hence, equation (9) is replaced with

$$I_t = \begin{cases} 1 & \text{if } \Delta y_{t-1} \geq \tau \\ 0 & \text{if } \Delta y_{t-1} < \tau. \end{cases} \quad (10)$$

The M-TAR model is useful in capturing situations in which the degree of autoregressive decay depends on the direction of change in  $\{y_t\}$ . For example, Enders and Granger (1998) showed that interest rate adjustments to the term-structure relationship display M-TAR behavior. If, however, all  $\alpha_i = \beta_i$ , then the TAR and M-TAR models are equivalent to an AR( $p$ ) model.<sup>14</sup>

If  $\tau$  is known, then the estimation of the TAR and M-TAR models is straightforward. Simply set the indicator function according to equations (9) or (10) and form the variables  $I_t y_{t-i}$  and  $(1 - I_t) y_{t-i}$ . The coefficients of equation (8) can be estimated using ordinary least squares (OLS), and the lag length  $p$  determined as in an AR model.<sup>15</sup> When  $\tau$  is unknown, Chan (1993) showed how to obtain a super-consistent estimate of the threshold parameter. For a TAR model, the procedure is to order the observations from smallest to largest such that:

$$y^1 < y^2 < y^3 \dots < y^T. \quad (11)$$

For each value of  $y^j$ , let  $\tau = y^j$ , set the Heaviside indicator according to equation (9), and estimate

an equation in the form of equation (8). The regression equation with the smallest residual sum of squares contains the consistent estimate of the threshold. In practice, the highest and lowest 15 percent of the  $\{y^j\}$  values are excluded from the grid search to ensure an adequate number of observations on each side of the threshold. For the M-TAR model, equation (11) is replaced by the ordered first-differences of the observations.

Notice that the TAR model overcomes a number of the problems involved with the use of dummy variables. Most importantly, the dates of the regime switch at which the series passes the threshold are not specified *ex ante* by the researcher; instead, the data itself determine whether the series is in the high- or low-terrorism state. Since there are no specific intervention points, the standard asymptotic properties of the estimates hold. For example, the asymptotic properties of the estimates are such that individual coefficients can be tested using standard *t*-statistics and joint restrictions – such as the symmetry restriction that all  $\alpha_i$  equal all  $\beta_i$  – can be tested using an *F*-test. Obviously, there are no overlapping dummy variables and the alternative regimes are allowed to affect the degree of autoregressive decay as well as the mean of each series. If, therefore, the goal is to determine the magnitude of any specific intervention, such as the effect of the end of the Cold War, then the TAR model is not especially useful, because it includes no exogenous variables. This again emphasizes that alternative time series methods can fulfill different purposes making them complementary.

### THE ESTIMATED THRESHOLD MODEL

We begin by estimating the DEATH series as a threshold autoregressive process with a single lagged value. As indicated by equation (7), we search over all potential thresholds to obtain (with *t*-statistics in parentheses):

$$y_t = [ 19.95 + 0.07y_{t-1} ] I_t + [ 7.09 + 0.47y_{t-1} ] (1 - I_t), \quad (12)$$

(4.63) (0.38) (3.10) (2.39)

where the estimate of the threshold is  $\tau = 18$ . If we purge the model of the insignificant lagged coefficient occurring whenever  $y_{t-1} \geq 18$  and re-estimate the model, we obtain:<sup>16</sup>

$$y_t = [ 21.53 ] I_t + [ 7.09 + 0.47y_{t-1} ] (1 - I_t), \quad (13)$$

(23.02) (3.12) (2.41)  $AIC = 1005.4, SBC = 1016.5.$

Diagnostic checking indicates that the model is appropriate. For example, the first eight autocorrelations of the residuals are less than 0.13 in absolute value and the Ljung-Box  $Q$ -statistics for 4, 8, and 12 lags indicate that there are no significant residual correlations at conventional levels. We also estimate the model setting  $p = 2$ , and find that the coefficients of  $y_{t-2}I_t$  and  $y_{t-2}(1 - I_t)$  are both insignificant. We set the indicator function using the M-TAR specification. Our estimated models never fit the data as well as the TAR models reported above.<sup>17</sup> Finally, Tsay's (1989) method of arranged autoregressions do not yield any evidence of multiple thresholds.

For comparison purposes, we estimate the DEATH series as a linear autoregression. The best-fitting model is the following AR(1) equation:

$$y_t = 6.81 + 0.56y_{t-1}, \quad AIC = 1012.1, SBC = 1017.7. \quad (14)$$

(5.03) (7.25)

Notice that  $AIC$  and  $SBC$  both select the TAR model over the linear model. In addition, as measured by either criteria, the TAR model fits better than either intervention model reported in equations (6) and (7). This is particularly important since the TAR model *makes no use* of the “explanatory” variables employed in the intervention model. In fact, the  $SBC$  actually selects the linear model over either of the intervention models!

The threshold model yields very different implications about the behavior of the terrorism DEATH series than the linear models. The linear AR(1) model indicates that the sequence

convergences to the long-run mean of approximately 15.5 incidents per quarter [  $6.81 \div (1.0 - 0.56) \approx 15.5$  ]. Moreover, the degree of autoregressive decay is always constant. Regardless of whether the number of incidents is above or below the mean, the degree of persistence is estimated to be 56%. In contrast, the estimated threshold model in equation (13) suggests there is no single long-run equilibrium value for the number of incidents, since there are high- and low-terrorism regimes or states. In the low state, the system gravitates toward 13 incidents per quarter [  $7.09 \div (1.0 - 0.47) \approx 13$  ]. The point estimates of this low-state regime are similar to those of the linear AR(1) model. When the number of incidents exceeds the 18-incident threshold, there tends to be an immediate jump to 21.53 incidents per quarter. Whenever the number of incidents exceeds 21.53, we estimate that there will be an immediate decline to 21.53 incidents in the subsequent quarter, so that, there is no persistence for terrorist activity exceeding the key value of 21.53 incidents.<sup>18</sup> The high-incident state can be maintained until a shock of sufficient magnitude causes a switch of regime; but, the number of events in this high-incident state cannot be maintained at more than 21.53 incidents. Since the estimated standard deviation of  $\{\varepsilon_t\}$  is equal to 6.14, the magnitude of a typical shock is likely to cause a regime switch. In fact, we uncover a number of short-lived terrorist campaigns of heightened activity (including one immediately following POST) – see Figure 1.

We also examine other incident series for threshold autoregressive effects. We find no evidence of any autoregressive behavior in the non-causality series, which is dominated by threats, hoaxes, letter bombs, and other low-intensity activities. As these incidents use few resources, it is to be anticipated that they contain no predictable pattern. The number of incidents containing wounded individuals (but no deaths) appeared to be a symmetric AR(2) process. One explanation is that a TAR specification is not appropriate to capture the form of the non-linearity in this series. Another is that these incidents use few resources relative to incidents

with deaths, so that there may not be any important differences in the persistence of this type of terrorism.

### THE FOURIER APPROXIMATION

As indicated above, the TAR model cannot ascribe the effects of a regime switch to any particular event. An alternative way to capture any potential non-linearity's in the data is to use the methodology of Ludlow and Enders (2000), where a simple modification of the autoregressive framework allows the autoregressive coefficient to be a time-dependent function denoted by  $\alpha(t)$ . For simplicity, consider an AR(1) process without an intercept term. If  $\alpha(t)$  is an absolutely integral function, for any desired level of accuracy, then it is possible to write:<sup>19</sup>

$$y_t = \alpha(t)y_{t-1} + \varepsilon_t, \quad (15)$$

$$\text{with } \alpha(t) = A_0 + \sum_{k=1}^s \left[ A_k \sin \frac{2\pi k}{T} \bullet t + B_k \cos \frac{2\pi k}{T} \bullet t \right],$$

where  $s$  refers to the number of frequencies contained in the process generating  $\alpha(t)$ .<sup>20</sup>

The key point is that the behavior of any deterministic sequence can be readily captured by a sinusoidal function even though the sequence in question is not periodic. As such, non-linear coefficients may be represented by a deterministic time-dependent coefficient model without first specifying the nature of the asymmetry. The nature of the approximation is such that the standard ARMA model emerges as a special case. If the actual data-generating process is linear, all values of  $A_k$  and  $B_k$  in equation (15) should be zero. Thus, instead of positing a specific model, the specification problem is transformed into one of selecting the proper frequencies to include in equation (15). Ludlow and Enders (2000) called the approximation in equation (15) an F-ARMA process. Since the value of  $s$  can be large, the estimation problem is



to determine the particular Fourier coefficients to include in the analysis.

More generally, both the intercept and the degree of autoregressive decay may fluctuate over time and it is possible to apply the method to both coefficients. Because the nonlinear estimation may be quite complicated, we restrict ourselves to only two frequencies for the intercept and only one (possibly different) frequency for the degree of autoregressive decay. We use nonlinear optimization methods to obtain the maximum-likelihood estimates of:

$$y_t = c_0 + c_1 \sin\left(\frac{2\pi k_1}{T} \bullet t\right) + c_2 \cos\left(\frac{2\pi k_1}{T} \bullet t\right) + c_3 \sin\left(\frac{2\pi k_2}{T} \bullet t\right) + c_4 \cos\left(\frac{2\pi k_2}{T} \bullet t\right) + a_1 y_{t-1} + a_2 \sin\left(\frac{2\pi k_3}{T} \bullet t\right) y_{t-1} + a_3 \cos\left(\frac{2\pi k_3}{T} \bullet t\right) y_{t-1} + \varepsilon_t. \quad (16)$$

The interpretation of equation (16) is that the magnitudes of any fluctuations in the intercept term are captured by nonzero values of  $c_1$  through  $c_4$ . Similarly, fluctuations in the degree of autoregressive decay are captured by nonzero values for  $a_2$  and  $a_3$ . The frequencies of the fluctuations in the intercept are given by  $k_1$  and  $k_2$ , while the frequency of the fluctuations in the autoregressive parameter is given by  $k_3$ . Clearly, the linear AR(1) model is the special case of equation (16) where the  $c_1 = c_2 = c_3 = c_4 = a_2 = a_3 = 0$ . Because we are not interested in the very high frequency changes, we limited the analysis to frequencies no greater than 10. With 100 observations, Ludlow and Enders (2000) found that the critical values for  $a_2$  and  $a_3$  are each 2.06, 2.39, and 3.02 at the 10%, 5%, and 1% significance levels, respectively. Similarly, Davies (1987) found that the critical values for the  $F$ -statistic of  $c_1 = c_2 = 0$  ( $c_3 = c_4 = 0$ ) are 10.66, 12.18, and 15.63 at the 10%, 5%, and 1% significant levels.

The Fourier approximation in equation (16) is something quite different from the standard Spectral Analysis. The periodiogram used in Spectral Analysis is obtained from the Fourier expansion:

$$y_t = c_0 + \sum_{k=1}^{T/2} [c_k \sin(2\pi kt / T) + c_k \cos(2\pi kt / T)] + \varepsilon_t. \quad (17)$$

In particular, Spectral Analysis uses all possible integer frequencies in the interval  $k = [1, T/2]$  in order to assess relative contribution of high, medium, and low frequencies to the total variation of  $\{y_t\}$ . Instead, equation (16) uses *only the two most significant frequencies* in order to approximate a time-varying intercept term. This is supplemented by a (possibly) third frequency to approximate a time-varying degree of autoregressive decay. Estimating (16) and eliminating the coefficient with  $t$ -values less than 1.96 in absolute value, we obtain:<sup>21</sup>  $c_0 = 11.84$  (11.77),  $c_1 = -3.24$  (-5.63),  $c_3 = -2.85$  (-5.31),  $a_1 = 0.24$  (4.05) and  $a_3 = -0.14$  (-2.96), where  $t$ -statistics are in parentheses. In addition, the frequencies are  $k_1 = 2.105$ ,  $k_2 = 3.23$ , and  $k_3 = 6.80$ .

Given that there are two frequencies for the intercept and that the degree of autoregressive decay oscillates, the time path for the estimated series is highly nonlinear. In order to depict the estimated movements of  $\{y_t\}$ , we set  $y_1$  equal to the actual number of incidents in 1970:1 and generated the values through 1999:4 using our estimated coefficient values. The resulting series is shown as the fluctuating solid line in Figure 2.<sup>22</sup> For comparison purposes, we also include the actual number of incidents and the effects of the interventions (now updated through 1999:4) that were shown in Figure 1.

The intervention and the F-ARMA models both suggest (i) an increase in DEATH incidents after the installation of metal detectors in 1973 (METAL), (ii) an increase near 1979 (around the time of FUND), (iii) a sharp decline at the time of embassy fortifications in 1985 (EMB85), and (iv) a relatively constant time profile through 1992. Overall, the F-ARMA model tracks the actual series much better than the intervention model. There are, however, some interesting comparisons to be drawn from the different estimates of the intervention and Fourier models. As displayed in Figure 2, the intervention model in equation (7) estimates that metal detectors had a long-run impact of 7.79 incidents per quarter with the full impact on the DEATH series being attained almost immediately. The Fourier model tells a different story. Beginning

in 1973:1, the estimated number of DEATH incidents rose steadily until the third quarter of 1976. If all of this increase can be ascribed to the deployment of metal detectors, the estimated long-run impact is 14 DEATH incidents per quarter (22 estimated incidents for 1976:3 minus eight estimated incidents in 1972:4). Part of the discrepancy between the two estimates might be that the installation of the detectors was not immediate. The installation of these detectors in US airports was immediate in 1973:1, while their installation in non-US airports took place more gradually (Enders et al., 1990).

A very interesting comparison emerges with respect to the POST variable. The intervention results in equation (7) give the long-run impact of POST to be 4.92 additional DEATH incidents per quarter. In contrast, the Fourier model estimates that the DEATH series gradually rose from approximately 11 to 27 incidents throughout the 1991-94 period. Thereafter, DEATH incidents steadily declined until the end of the sample period.

## IMPLICATIONS AND POLICY RECOMMENDATIONS

In this section, we shall draw some implications and policy recommendations in regards to the events of 11 September 2001, based on the analysis of this paper and our cumulative work on examining terrorist time series. The attack on the World Trade Center and the Pentagon came during a time when transnational terrorism was in a relatively low-activity period. Retaliatory strikes typically produce a shock to the time series that generates higher levels of attacks as terrorists protest the action (Enders and Sandler, 1993). An intertemporal substitution occurs as terrorists move attacks planned for the future into the present to demonstrate their displeasure. The TAR analysis findings indicate that this heightened activity can be sustained for a long period, because it will be coming during a low-activity period when resources can be shifted

from nonterrorist activities of these terror networks. Thus, nations associated with the alliance forged by the United States must be vigilant for these increased attacks not only during the period of military action begun on 7 October 2001, but also well after this period. This means that national guard at US airports may need a longer deployment than originally planned (i.e., longer than six months).

All time series associated with terrorist events display cyclical behavior (Enders et al., 1992; Enders and Sandler, 1999). This is also true of the time series with one or more casualties (i.e., death or injuries). In Enders and Sandler (2000:322), the length of the cycles for the casualties time series is just under two years. Thus, the trough in Figure 2 at the end of 1999 is anticipated to be followed by a peak toward the end of 2001, which proved to be an accurate prediction. Our work<sup>23</sup> on the relationship between the rise of fundamentalist terrorism and heightened casualties from terrorist attacks suggests that terrorist attacks as a reaction to retaliatory strikes will involve a greater number of casualties than, say, the increased terrorism following the US retaliatory raid on Libya in April 1986.

If there is a basic message from our work on the effects of policy interventions, it is that *piecemeal policy is ineffective*.<sup>24</sup> That is, efforts to secure US airports and borders will cause terrorists to stage their attacks at other venues and in other countries against Americans. Quite simply, terrorists respond to “higher prices” for one mode of attack stemming from a policy intervention (e.g., better metal detectors and security screening at airports) by substituting into an alternative mode where measures have not been taken. The installation of metal detectors in airports cut down on skyjackings but was associated with an increase in other kinds of hostage-taking events (Enders and Sandler, 1993). Despite recent events in New York and Washington, DC, Americans are still most vulnerable abroad. Consider the statistics for 2000, during which there were 423 transnational terrorist attacks worldwide. Although *not a single such attack*

occurred in the United States, 200 of these attacks were against US people or property (US Department of State, 2001:1). This poses a real dilemma for the United States, because security measures abroad cannot be dictated to other countries. Actions by the United States to protect its diplomatic and military personnel abroad will make its unprotected citizens more inviting targets.

The kinds of actions that work best accomplishes one of two outcomes: a reduction in the resources of terrorists or an increased difficulty associated with *all* modes of attack. Coordinated strikes to hit the al-Qaida network throughout the world are required to attain the first outcome. Cooperative efforts worldwide to freeze al-Qaida's assets would also foster the first outcome. To raise the "price" of all modes of terrorist attacks, countries would have to increase security throughout society, which impinges on personal freedoms in liberal democracies. Moreover, such massive actions would be prohibitively costly to countries. A cheaper means for accomplishing the second outcome would be better field intelligence so that any kind of planned terrorist incidents can be stopped in the planning stage.

The fight against transnational terrorism presents a serious collective action problem to nations confronting the threat of terrorist acts. Destroying a global terrorist network represents a pure public good to all targeted nations, because its destruction yields benefits that are both nonrival and nonexcludable among nations (Sandler, 1997:129-138). As such, nations are apt to free ride on the efforts of the country or countries that perceive the greatest benefits from such actions. Given the events of 11 September 2001, the country with the most at stake from destroying this network is the United States, followed by the United Kingdom, which lost the second greatest number of its citizens in the World Trade Center attack. The US interest is bolstered by it being the primary target of transnational terrorism for the last couple of decades (US Department of State, 1989-2001). Despite the invocation of Article 5 of the NATO Treaty,

the rooting out of the al-Qaida and other networks is anticipated to be primarily an American operation. There is an irony here, because collective action among terrorist groups in sharing training and financing has been quite substantial. To date, this suggests that terrorists are more united in their common goals than are countries in addressing the transnational terrorist threat. Perhaps, the recent horrors will change this collective action failure.

In the terrorists' attempt for greater brutality and casualties to capture media attention, it will be difficult to outdo the carnage or terror of 11 September. The casualties from the four simultaneous skyjackings are equal to the cumulative deaths from all transnational terrorist events between 1985 and 2000 (US Department of State, 1989-2001). This suggests that symbolic targets at home and abroad that rival the World Trade Center or the Pentagon may be chosen for the annual spectacular event that has characterized transnational terrorism over the last 30 or so years. Another means for achieving greater casualties would be to resort to weapons of mass destruction (e.g., biological or chemical agents) as portended by the Sarin attack on the Tokyo subway on 20 March 1995 by Aum Shinrikyo.<sup>25</sup> Clearly, transnational terrorism has taken on a new threat level since 11 September.

This heightened threat level suggests that this date should be investigated as an intervention point in future time series studies as time progresses. Have the events of this day changed the pattern of transnational terrorism? For example, do future attacks involve greater numbers of casualties? Has the mix of attack modes or where terrorist incidents are staged changed since 11 September? These are questions for future time series investigations. Another issue concerns the war on terrorism coordinated by the United States that started on 7 October 2001. The effectiveness of this war can be evaluated using intervention analysis, intervention-VAR techniques, and TAR methods. Given its greater objective to root out terrorist networks, this retaliatory war might have a more permanent impact than past episodic retaliations.

## CONCLUDING REMARKS

Each advance in the study of time series provide a new method that can be applied to the analysis of transnational terrorism. In the current paper, we have used a regime-switching model to find turning points in the time series of events, for which one or more persons die. The so-called DEATH series is used because it is more predictable than less-intense series where individuals are either injured or unscathed. A regime-switching model offers a better fit than either a linear AR(1) representation or an intervention representation, with one or more dummy variables for policy changes. With the regime-switching depiction, increases in activity above the mean are not sustainable during high-terrorism eras, while there is a 56% persistence for changes around the mean during low-terrorism eras. This finding has implications for policy or political decisions that may result in either a regime switch or else a shock, insofar as the persistence of such shocks depends on whether terrorist activities are already running high or low.

We also applied a Fourier approximation to the nonlinear estimates of the DEATH series for 1970:1-1999:4. In so doing, we derive better estimates than those that characterize earlier articles. Our Fourier-series-based estimates are superior in identifying recent downturns in the lethality of transnational terrorism in the post-cold war era.

The appropriate technique depends on the issue under investigation – there is no time series method best for all issues. The TAR model is best applied to a single time series at a time in contrast to the VAR model. If, for example, the effectiveness of a policy intervention – e.g., heightened security measures at US airports in the wake of the 11 September attacks – is under scrutiny, then intervention analysis applied to the study of multiple time series is the preferred

methodology. When a single time series is pertinent, TAR and intervention analysis can be both applied to determine which results have the better statistical properties. In the case of the DEATH series, TAR appeared to be the more appropriate representation.



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## Footnotes

1. This definition captures the essential features of those in the literature. See Hoffman (1988, chap. 1), Mickolus (1982), and Schmid and Jongman (1988).

2. Since no claim of responsibility or demands have been made in wake of the attacks, no one knows for sure what these atrocities were intended to achieve. If the attacks were directed by Osama Bin Laden, as the evidence suggests, then his demands are the ones listed in parentheses.

3. The seminal study on the terrorist dilemma confronting a liberal democracy is Wilkinson (1986).

4. Articles that analyze trends and cycles include Cauley and Im (1988), Enders, Parise, and Sandler (1992), and Enders and Sandler (1999). A pioneering analysis by Midlarsky, Crenshaw, and Yoshida (1980) was the first to employ the autocorrelation function in the study of terrorist time series.

5. The causality between transnational terrorism and Spanish tourism was investigated by Ender and Sandler (1991), whereas the relationship between terrorism and foreign direct investment for a few select countries was studied by Enders and Sandler (1996).

6. On these transboundary externalities, see Sandler and Lapan (1988).

7. Diminishing returns to terrorists' resources are reflected by  $g_R^t > 0$ ,  $g_R^\ell > 0$ ,  $g_{RR}^t < 0$ , and  $g_{RR}^\ell < 0$ , where subscripts on the respective gain function indicate first- and second-order partial derivatives. These partials indicate that resources have a positive, but declining, marginal impact on gain.

8. Studies on the aftermath of retaliatory raids have consistently found an heightened level of terrorism following such raids (Enders and Sandler, 1993; Brophy-Baermann and Conybeare, 1994).

9. With the start of the post-cold war era, there is a ratcheting down of the number of terrorist events as state-sponsors reduced their support of transnational terrorism, and Russia and the United States had few faceoffs (Enders and Sandler, 1999, 2000; Hoffman, 1998).

10. The impact of these interventions was shown in Enders and Sandler (1993, 1999, 2000) and Enders et al. (1990).

11. For a more in-depth description of the sources for ITERATE, consult Mickolus, Sandler, and Murdock (1989, vol. 1, pp. ix-xxvi). This source also has the working definition for transnational terrorism that the coders were instructed to apply.

12. This substitution into more deadly events is also shown in Enders and Sandler (1993).

13.  $AIC$  is calculated as  $T \cdot rss + 2 \cdot k$ , where  $T$  = number of usable observations,  $rss$  = residual sum of squares, and  $k$  = number of parameters estimated.  $SBC$  is calculated as  $T \cdot rss + \ln(T) \cdot k$ . Note that the  $SBC$  tends to select the more parsimonious model since it heavily penalizes the inclusion of additional coefficients ( $k$ ).

14.  $AR(p)$  refers to an autoregressive model with a lag length of  $p$  periods.

15. To allow for the different intercepts, we must include  $I_t$  and  $(1 - I_t)$  as regressors.

16. For the TAR model, the value of  $\tau$  has to be estimated. Hence, we include it as a parameter when calculating the  $AIC$  and the  $SBC$  (i.e., we add 1 to the value of  $k$ ).

17. To save space, we do not report the estimated M-TAR models. Moreover, Tsay's (1989) method of arranged autoregressions do not yield any evidence of multiple thresholds or of a delay parameter other than unity. Details are available from the authors on request.

18. Similarly, when there are more than 18, but less than 21.53 incidents, we estimate that there will be a jump to 21.53 units in the subsequent period. Thus the skeleton of the system is such that there are two long-run equilibria: 13 and 21.53 DEATH incidents per quarter.

Because the equilibrium value in the high-terrorism state is close to the threshold value of 18, shocks are more likely to cause the system to shift from the high to the low state than from the low to the high state.

19. Let the function  $\alpha(t)$  have the Fourier expansion:

$$\alpha(t) = \alpha_0 + \sum_{k=1}^{\infty} \left[ A_k \sin \frac{2\pi k}{T} \bullet t + B_k \cos \frac{2\pi k}{T} \bullet t \right]$$

and define  $F_s(t)$  to be the sum of the Fourier coefficients:

$$F_s(t) = \sum_{k=1}^s \left[ A_k \sin \frac{2\pi k}{T} \bullet t + B_k \cos \frac{2\pi k}{T} \bullet t \right].$$

Then, for any arbitrary positive number  $h$ , there exists a number  $N$  such that:

$$| \alpha(t) - F_s(t) | \leq h \text{ for all } s \geq N.$$

20. The Fourier approximation can also be applied to any changes in the intercept term and/or any moving-average terms.

21. Davies (1987) provides critical values for the  $F$ -statistic but does not provide critical values for the individual  $t$ -statistics. The eliminated coefficients for the mean (i.e.,  $c_2$  and  $c_4$ ) each had a  $t$ -statistics of less than 1.4 in absolute value. As these coefficients are small relative to their standard error, the time path of the Fourier model, later shown in Figure 2, is virtually unaffected by the exclusion.

22. Note that these are not 1-step ahead forecasts – instead, they are analogous to the fitted values from the intervention model. The series shown represents the fitted values of  $\{y_t\}$  if all values of  $\{\text{edd}_t\}$  had been equated to zero.

23. Enders and Sandler (2000) showed that in recent years, each incident is almost 17 percentage points more likely to result in death or injuries. This increased lethality was related to the shift away from left-wing terrorism to fundamentalist terrorism.

24. For a theoretical model on the ineffectiveness of piecemeal policy, see Sandler and Lapan (1988).

25. During rush hour, eleven sarin-filled bags planted on five subway trains created terror, pandemonium, and injuries at fifteen Tokyo subway stations, resulting in the deaths of twelve people and the hospitalization of more than 5,000.