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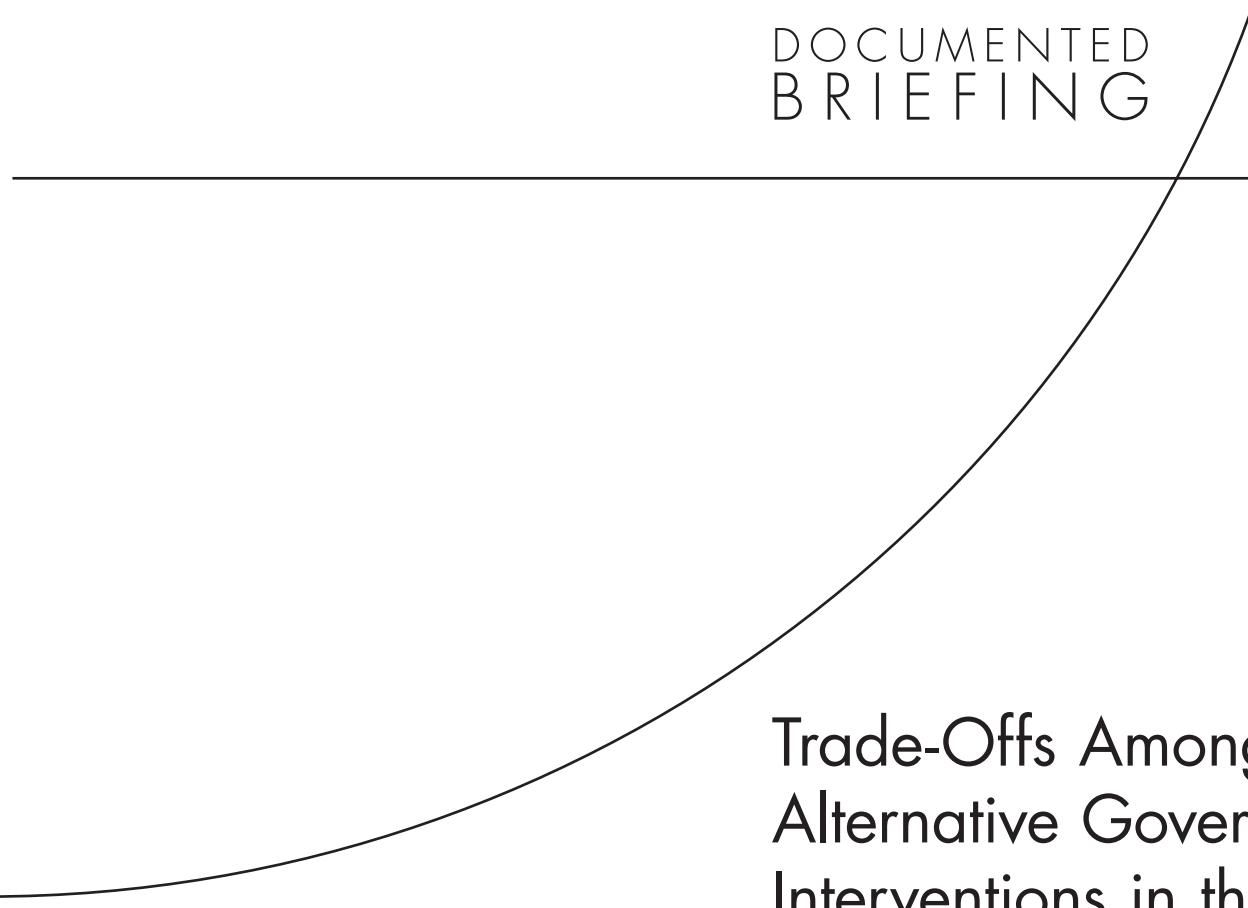
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Trade-Offs Among Alternative Government Interventions in the Market for Terrorism Insurance

Interim Results

Lloyd Dixon, Robert Lempert, Tom LaTourrette,
Robert T. Reville, Paul Steinberg



CENTER FOR TERRORISM RISK MANAGEMENT POLICY

The research reported here was supported by the RAND CTRMP as part of its larger research program focused on terrorism risk, insurance, and other economically focused issues related to the terrorist threat.

ISBN: 978-0-8330-4186-9

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Published 2007 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
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Preface

This documented briefing presents interim findings from a RAND Center for Terrorism Risk Management Policy (CTRMP) project that is seeking to provide data that could help address differences of opinion among stakeholders and the federal government about many fundamental issues that are central to the current debate over extending the Terrorism Risk Insurance Act of 2002 (TRIA), as modified in 2005.

This briefing should be of interest to those who want to better understand the potential consequences of allowing TRIA to expire at the end of 2007 on the take-up rate¹ for terrorism insurance and on the distribution of losses caused by a terrorist attack across various segments of society. It should be of interest as well to those who want to better understand the strengths and weaknesses of policy options for renewing TRIA, particularly on reforms intended to improve the insurability of chemical, biological, radiological, or nuclear (CBRN) attacks. This briefing is also relevant to those interested in the application of robust decisionmaking (RDM) tools.

An upcoming RAND monograph will document complete project results.

The research reported here was supported by the RAND CTRMP as part of its larger research program focused on terrorism risk, insurance, and other economically focused issues related to the terrorist threat.

The RAND Center for Terrorism Risk Management Policy

CTRMP provides research that is needed to inform public and private decisionmakers on economic security in the face of the threat of terrorism. Terrorism risk insurance studies provide the backbone of data and analysis to inform appropriate choices with respect to government involvement in the market for terrorism insurance. Research on the economics of various liability decisions informs the policy decisions of the U.S. Congress and the opinions of state and federal judges. Studies of compensation help Congress to ensure that appropriate compensation is made to the victims of terrorist attacks. Research on security helps to protect critical infrastructure and to improve collective security in rational and cost-effective ways.

¹ *Take-up rate* refers to the proportion of businesses that have insurance coverage for property losses resulting from terrorist attacks. As will be discussed further below, workers' compensation (WC) policies always cover loss, regardless of cause.

CTRMP is housed at the RAND Corporation, an international nonprofit research organization with a reputation for rigorous and objective analysis and the world's leading provider of research on terrorism. The center combines three organizations:

- RAND Institute for Civil Justice, which brings a 25-year history of empirical research on liability and compensation
- RAND Infrastructure, Safety, and Environment, which conducts research on homeland security and public safety
- Risk Management Solutions, the world's leading provider of models and services for catastrophe risk management.

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A profile of CTRMP, abstracts of its publications, and ordering information can be found at <http://www.rand.org/multi/ctrmp/>.

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Summary

This documented briefing presents interim findings from a RAND Center for Terrorism Risk Management Policy (CTRMP) project that aims to provide analysis that can inform the debate over extending the Terrorism Risk Insurance Act of 2002 (TRIA), as modified in 2005.

The study uses robust decisionmaking (RDM), an iterative, analytic process for identifying and assessing key trade-offs among strategies under conditions with considerable uncertainty, to assess three alternative government interventions in the market for terrorism insurance: TRIA; no government terrorism insurance program; and an enhancement of TRIA meant to improve the availability of insurance coverage for chemical, biological, radiological, or nuclear (CBRN) attacks.

We use a computer simulation model to assess the performance of these interventions across a large number of plausible future states of the world. These futures include six attack scenarios: two conventional ones (1- and 10-ton truck bombs) and four CBRN scenarios (a 5-kiloton nuclear bomb, an outdoor anthrax attack, an attack using a radiological device, and an indoor sarin attack in the same metropolitan area). The futures also span a wide range of assumptions about the key uncertainties that underlie the functioning of terrorism risk insurance markets and the response of the government in providing compensation for uninsured losses after an attack. The performance of each intervention is gauged in terms of four outcome measures: (1) fraction of losses that remain uncompensated after an attack, (2) cost to taxpayers, (3) fraction of industry surplus backing commercial property and casualty insurance lines used to compensate losses following an attack, and (4) cost to future policyholders.

The results suggest that TRIA has important positive effects on the market for terrorism insurance, particularly for conventional attacks. TRIA causes the take-up rate² for terrorism coverage for conventional attacks to be higher than it would be without the program, leading to lower costs borne by businesses affected by the attack in a substantial number of the scenarios examined. While TRIA does increase the cost to taxpayers in scenarios involving the largest attacks, the expected cost to taxpayers should a conventional attack occur is lower with TRIA than without TRIA under a wide range of assumptions anchored around existing estimates of the probability of large attacks. Transferring risk for the largest events to taxpayers

² *Take-up rate* refers to the proportion of businesses that have insurance coverage for property losses resulting from terrorist attacks. As will be discussed further below, workers' compensation (WC) policies always cover loss, regardless of cause.

provides benefits in terms of lower uncompensated losses and lower taxpayer costs in the most likely scenarios.

TRIA's performance in the face of CBRN attacks is more mixed. The program cap does reduce risk to the insurance industry, even if insurers may still end up financing some of the losses above the program cap. However, the take-up rate for CBRN coverage on property policies is still very low under TRIA, leading to little change in either the fraction of losses compensated or the burden on taxpayers, compared with no government program.

Given TRIA's mixed performance with CBRN attacks, we considered a simple enhancement of TRIA intended to better address CBRN attacks. Our findings illustrate that any expansion of TRIA to address CBRN attacks must be made with significant care to achieve the desired goals and avoid unintended consequences. More specifically, modifying TRIA to require insurers to offer policies that cover both CBRN and conventional coverage without changes in other program features, such as the insurer deductible or program cap, may have major unintended disadvantages for conventional attacks. In particular, the results for TRIA with a mandatory CBRN offer are very similar to those if TRIA expires for conventional attacks. And, when it comes to its effect on CBRN attacks, we find that TRIA with a mandatory CBRN offer does not improve outcomes much over TRIA as it currently exists.

The results documented here are from work in progress. As such, we are continuing to analyze modifications to TRIA that may better address CBRN attacks and the partial take-up of terrorism insurance that occurs even with TRIA.

Glossary

CBRN	chemical, biological, radiological, or nuclear
CTRMP	RAND Center for Terrorism Risk Management Policy
ISO	Insurance Services Office
L	policy levers
LHC	Latin hypercube
M	measures
PRIM	patient rule induction method
R	relationships
RDM	robust decisionmaking
RMS	Risk Management Solutions
TRIA	Terrorism Risk Insurance Act of 2002
X	uncertainties
XLRM	describes factors contributing to a robust decisionmaking analysis; see also X, L, R, and M.
WC	workers' compensation

Acknowledgments

The authors would like to thank the project advisory board for extremely helpful assistance and feedback during the course of the project. Advisory board members contributed their expertise on the issues relevant to terrorism risk and insurance through interviews, written comments, and attendance at multiple advisory board meetings.

Three reviewers provided insightful comments as part of the formal RAND peer-review process: Eric Helland, jointly at RAND and Claremont McKenna College; Richard Hilles-tad at RAND; and George Zanjani at the Federal Reserve Bank of New York. Howard Kun-reuther and Erwann Michel-Kerjan of the Wharton Risk Management and Decision Processes Center at the University of Pennsylvania each also provided detailed and helpful comments on the draft. We thank them all for their time and the speed with which they turned around their comments.

Access to Risk Management Solutions' (RMS') Probabilistic Terrorism Model was critical to the success of the project, and we thank RMS for making the model and its expertise available.

At RAND, Scot Hickey skillfully ran the RMS model, Benjamin Bryant investigated the factors leading to the vulnerabilities of the alternative government interventions examined, Lisa Bernard did an excellent job editing and formatting the document in a very timely manner, Kim Wohlenhaus expeditiously moved the document through the publication process, and Joye Hunter coordinated the peer-review process. In addition, Rebecca Collins headed RAND's quality assurance process for the briefing, and Michael Wermuth provided useful guidance throughout the project. Their efforts are greatly appreciated.

Introduction



CENTER FOR TERRORISM
RISK MANAGEMENT POLICY

Trade-Offs Among Alternative Government Interventions in the Market for Terrorism Insurance

Interim Results

**Lloyd Dixon, Robert Lempert
Tom LaTourrette, Robert T. Reville,
Paul Steinberg**

This documented briefing presents interim results from a RAND Center for Terrorism Risk Management Policy (CTRMP) project that is seeking to provide empirical information that can inform the debate over the role the federal government should play in terrorism insurance markets. The current government program for terrorism insurance was established by the Terrorism Risk Insurance Act of 2002 (TRIA) and amended in 2005. TRIA will sunset at the end of 2007 unless Congress takes further action.

The specific focus of this briefing is to examine trade-offs among a specific set of alternative government policies for insuring against terrorism.

An upcoming RAND monograph will document complete project results.

Appropriate Government Role in Insurance Markets Hard to Assess: Many Difficult-to-Estimate Uncertainties

- **Where and what types of attacks (conventional or CBRN) occur**
- **Terrorism insurance take-up under alternative government programs**
- **Compensation for insured losses more than the \$100 billion TRIA program cap and source of such payments**
- **How government responds after the attack**
- **What costs are incurred by taxpayers, insurers, the uninsured**

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The debate over the role the federal government should play in providing terrorism insurance is fraught with many uncertainties that both complicate the analysis and confuse the debate. Policy analysis has contributed much to an understanding of the issues, but many of the most contested policy questions depend on uncertain, exceedingly difficult-to-estimate factors, such as those listed here.

For example, one key policy question centers on how frequently and what types of terrorist attacks will occur—an attack using conventional weapons, like the attack on the World Trade Center on September 11, 2001, or a chemical, biological, radiological, or nuclear (CBRN) attack. A second question has to do with what the take-up rate would be among businesses under alternative government programs.¹ When TRIA was enacted, it set a \$100 billion cap on the amount of insured losses for which the insurance industry and federal government would be jointly responsible in the event of a terrorist attack; however, questions remain about whether policyholders will ultimately be compensated for losses above the cap and about the sources of such payments. There are also questions about what compensation the government will provide for uninsured losses and about the ultimate distribution across victims, insurers, and taxpayers of losses caused by an attack.

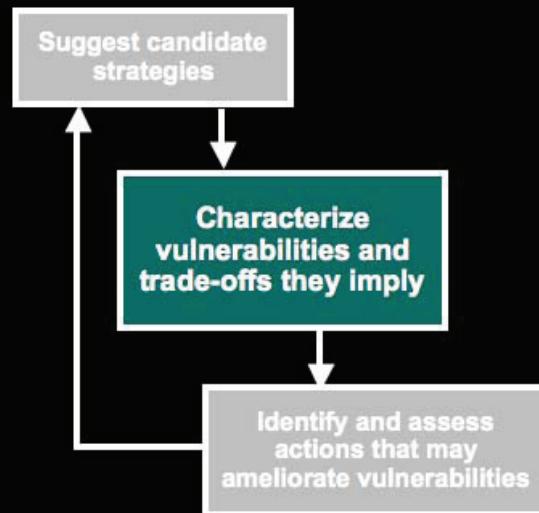
¹ Take-up rate refers to the proportion of businesses with insurance coverage for property losses resulting from terrorist attacks. As will be discussed further below, workers' compensation (WC) policies always cover loss, regardless of cause.

What one believes about the answers to such questions helps determine where one stands on the federal role in terrorism insurance markets. Unfortunately, such questions present what many policy analysts label *deep uncertainty*,² a condition in which policymakers do not know or key parties to the policy do not agree on the system model that characterizes the problem, the prior probabilities of key uncertain parameters, or the appropriate way to value alternative outcomes (i.e., the appropriate utility function). Under such conditions, policies can go awry if policymakers assume that the future is well characterized when it is not. More specifically, uncertainties tend to be underestimated, competing analyses can contribute to gridlock, and misplaced concreteness can blind policymakers to both opportunities and surprises.

² Lempert, Popper, and Bankes (2003). Deep uncertainty is similar to the uncertainty that Knight (1921) first contrasted with risk and to a situation with imprecision in the probabilities and the potential for structural uncertainty.

Under Deep Uncertainty, It Is Wise for Decisionmakers to Seek Strategies Robust Over Many Futures

- Robust decisionmaking (RDM) is an iterative, analytic process
- RDM identifies robust strategies in ways that
 - decisionmakers find credible
 - contribute usefully to contentious political debates
- This study focused on the second RDM step



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Under conditions of deep uncertainty, it is wise for policymakers to seek strategies that will prove to be *robust*—that is, perform reasonably well compared to the alternatives in a wide range of plausible futures. In recent years, the increasing power of computers, the deepening understanding of how people and organizations make decisions when faced with ambiguity, and decisionmakers' increasing sensitivity to the potential for surprise have spawned interest in new quantitative tools based on the idea of robustness. The RAND Corporation has been among the world leaders in this effort to develop and employ such new quantitative tools.

Robust decisionmaking (RDM) is one such quantitative tool that RAND has been developing and employing in a wide range of policy areas. As shown here, RDM is an iterative, analytic process for identifying and assessing robust strategies. An RDM analysis begins with a set of candidate strategies—in this case, the three alternative government interventions in the market for terrorism insurance presented next. The analysis next uses computer simulation models to evaluate the strategies' performance over a large number (hundreds to millions) of plausible future states of the world. In particular, the analysis often seeks to enumerate and succinctly characterize the vulnerabilities of each strategy and summarize the key trade-offs they imply for the choice among the alternative strategies. The analysis then seeks to identify and assess actions that policymakers might take to ameliorate these vulnerabilities and, thus, soften the trade-offs they face.

This briefing focuses on the second of these steps—characterizing the vulnerabilities of alternative government interventions in terrorism insurance markets and the trade-offs these vulnerabilities imply. We consider such a vulnerability to be a future state of the world in which the intervention’s performance, according to one or more outcome measures, falls short of some threshold value.

RDM has been applied to a wide range of decisions under deep uncertainty in a diverse set of policy areas and has often proved useful because it structures deeply uncertain problems in a way decisionmakers and policymakers find credible and can allow participants in contentious political debates to agree on actions even if they do not agree on assumptions (Popper, Lempert, and Bankes, 2005; Lempert and Popper, 2005).

We Describe Our Work to Date Assessing Several Different Government Interventions

- **TRIA**
- **No government program**
- **Mandatory CBRN offer without other changes in TRIA**

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This briefing assesses the performance and trade-offs among three government interventions in the market for terrorism insurance: TRIA, no government terrorism insurance program, and an enhancement of TRIA meant to improve the availability of insurance coverage for CBRN attacks.

TRIA requires property and casualty insurers to make terrorism coverage available to commercial policyholders.³ In return, the federal government agrees to reimburse a proportion of insurer payments to policyholders above certain deductibles for losses from terrorism events. The law requires the government to recoup its payments through surcharges on commercial property and casualty policyholders at least until the total amount of losses paid by insurers plus the policyholder surcharge equals a specified amount (the market retention). The government also retains discretion over whether to recoup a larger amount of its outlays under the program. Insurers set insurance premiums (subject to state regulation),⁴ and purchase of terrorism coverage for property policies is voluntary. The deductible, government copayment for losses above the deductible, market retention, and other program parameters have changed

³ TRIA applies to most commercial lines of property and casualty insurance, including WC insurance, but does not apply to health or life insurance or to personal insurance lines such as home and automobile insurance.

⁴ Insurers typically have substantial freedom in setting rates for commercial property insurance, while WC rates are usually closely regulated.

over the life of the program, and we focus on TRIA as currently configured. Appendix C further describes TRIA and the other interventions analyzed.

TRIA is scheduled to sunset on December 31, 2007, and, as the name implies, the second intervention examined is one in which no government program replaces it.

WC policies and most third-party liability policies provide coverage for losses from terrorism attacks, but, as will become clear, major gaps in coverage for property lost in CBRN attacks remain even with TRIA in place. We are investigating numerous ways to enhance TRIA to better address CBRN attacks; thus, in this briefing, we consider a very simple enhancement that leaves TRIA's structure unchanged but requires insurers to offer coverage for both conventional and CBRN attacks. We do not represent this straightforward extension of TRIA as the best or even as an effective method for addressing CBRN risk. Rather, it provides initial insight into issues that should be considered in designing a program that effectively deals with CBRN attacks.

**We Use Risk Management Solutions (RMS)
Models of Property and WC Losses
(Both Insured and Uninsured)**

Attack Scenario	Losses (\$ billions)			
	WC	Property	Total	Simulated Range
Conventional				
10-ton truck bomb	11	11	22	7–66
1-ton truck bomb	2	5	7	2–21
CBRN				
5-kiloton nuclear bomb	320	310	630	210–1,900
Outdoor anthrax	160	240	400	130–1,200
Radiological attack	0.5	62	63	20–190
Indoor sarin	5	1	6	2–18

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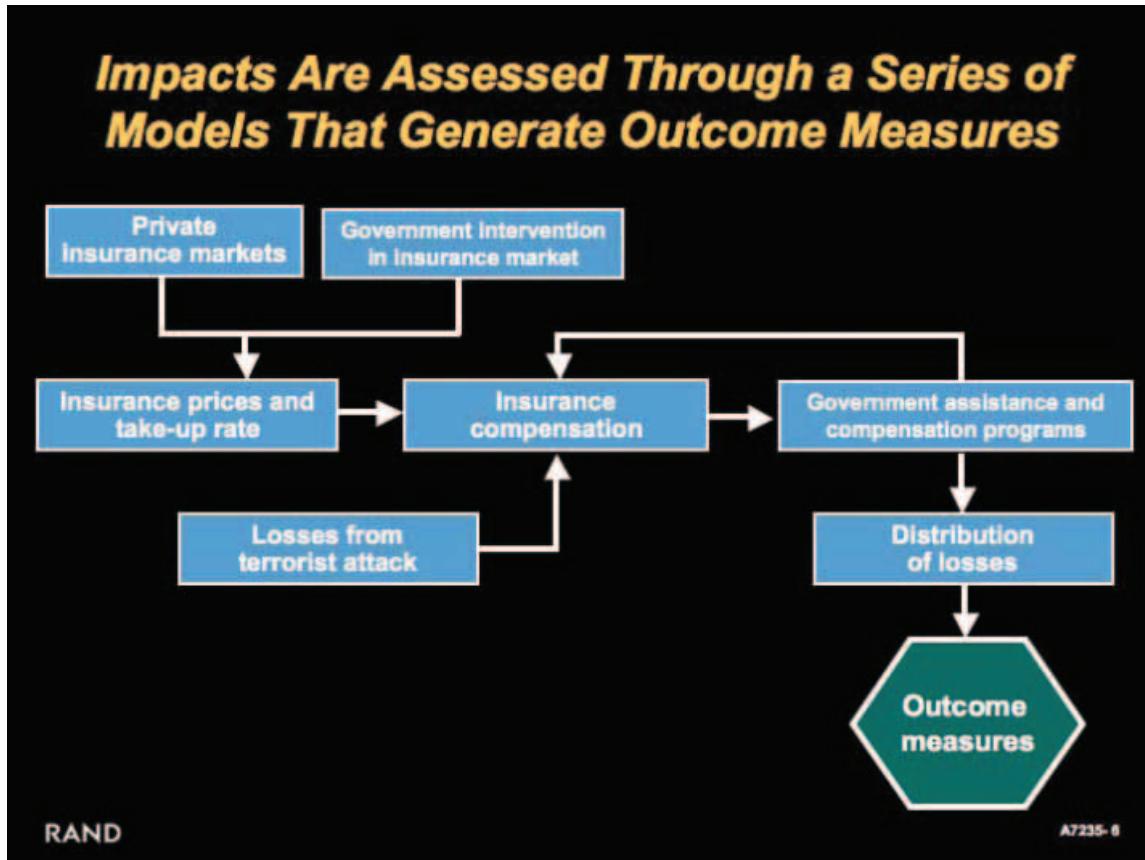
In assessing the interventions described previously, we consider six nominal attack scenarios that cut across two types of attacks: conventional attacks and CBRN attacks. The two conventional attacks involve 1-ton and 10-ton truck bombs detonated in a large metropolitan area on the Atlantic coast. The four CBRN attacks involve a 5-kiloton nuclear bomb, an outdoor anthrax attack, an attack using a radiological device (a dirty bomb), and an indoor sarin attack in the same metropolitan area.

This table shows the sizes of the six attacks in terms of the commercial property and WC losses (regardless of whether the losses are insured) and the split of losses between property and WC losses. The attack scenarios are drawn from an attack loss model developed by Risk Management Solutions (RMS).⁵ The table shows the losses in billions of dollars, as well as the simulated range we use in our modeling. In our analysis, we allow the total losses for each of the attacks to move up and down by a factor of three to account for the potential of multiple attacks and to acknowledge the substantial uncertainty over what losses in any particular attack might be. Thus, for a 10-ton truck bomb, the simulated range covers one-third of the total losses estimated by the RMS model (\$7 billion) up to three times the total estimated losses (\$66 billion). For the first two of the CBRN attacks, our simulated range reaches into

⁵ RMS is a private company that provides products and services for the quantification of management of catastrophic risks (see Risk Management Solutions [undated] for more information).

the trillions of dollars. As shown in Appendix F, the simulated range spans many of the thousands of potential terrorism attacks captured in the RMS model.

In addition to estimates of the losses from these six attacks, RMS also provides estimates of their likelihood. As described in Appendix E, this loss and likelihood information derives from different sources and may have different levels of reliability. In accordance with the RDM approach, we thus keep the loss and likelihood estimates separate for much of our analysis. Most of our results will summarize the consequences of different assumptions about the type and scale of losses from a terrorist attack (combined with many other important assumptions) independent of the likelihood of the resulting scenarios. We will also use the RMS probability estimates in two ways. First, they serve as inputs to our model of the preattack (*ex ante*) behavior of the insurance market as it generates take-up rates for terrorism insurance under different government policy interventions. Second, the RMS probability estimates serve as reference points when we compare the postattack (*ex post*) vulnerabilities of alternative interventions. That is, when comparing the vulnerabilities of alternative interventions, policymakers may use the probability estimates to help assess which vulnerabilities may be of most concern.



We now use the computer simulation model based on the schematic shown here to compare the performance of each of these three alternative government interventions over a wide range of plausible futures defined by the potential terrorist attacks and other uncertainties affecting the behavior of insurance markets and the government before and after any terrorist attack.

The simulation begins with one of the government interventions that, when combined with our model of the insurance industry pricing of terrorism insurance, yields a set of take-up rates for property insurance for both conventional and CBRN attacks. (The take-up rate for WC policies is always 100 percent.) If a terrorist attack occurs, the insurance industry will provide some compensation contingent on the take-up rates. After an attack, the government may or may not choose to also provide some compensation to the uninsured or to cover unpaid claims (i.e., insured losses over the \$100 billion TRIA program cap).

The loss distribution model next determines how the losses from any given terrorist attack are distributed across various segments of society contingent on the preattack take-up rates and any postattack compensation from the government. The model considers losses to four segments of society: to the insurance industry, which pays losses from its equity capital (also known as surplus); to taxpayers, who are assumed ultimately responsible for any costs borne by the federal government; to future holders of commercial property insurance policies, who may be assessed a surcharge to compensate past losses; and to victims who either were not insured or

did not receive payments for insured losses because overall insured losses exceed the program cap.

The simulation model then uses the distribution of losses across these four segments of society to assess the performance of the government intervention.

The value of one or more uncertain parameters governs the behavior of each component of this simulation model. As discussed below, we run the model many times using different combinations of these uncertain input parameters to understand how each government intervention might perform over a very wide range of plausible future states of the world.

The appendixes contain a detailed description of each of the components of this simulation model.

We Summarize Performance of Interventions Using Four Outcome Measures

Measure of Merit	Importance
Fraction of losses uncompensated	<ul style="list-style-type: none"> Focuses burden of attacks on victims Threatens businesses' postevent viability Increases pressure for government assistance
Cost to taxpayers	<ul style="list-style-type: none"> Can lead to higher budget deficits or higher taxes
Fraction of insurance industry surplus used	<ul style="list-style-type: none"> Threatens ongoing health of insurance industry Can increase cost of capital to insurance industry
Cost to future policyholders	<ul style="list-style-type: none"> Source of potential cross-subsidies for terrorism risk

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We use four outcome measures to evaluate each government intervention's performance in each future state of the world. These measures are constructed, as described in Appendix C, from the outputs of the simulation model.

The first measure is the *fraction of losses that remain uncompensated after an attack*. A higher fraction of uncompensated losses focuses the attack's burden on its victims, threatens the viability of firms suffering losses in the attack, and increases the pressure for government assistance after the attack. The fraction of losses uncompensated is the sum of the uninsured losses and unpaid claims divided by the total losses in the attack.

The second measure is the *cost to taxpayers*. This measure is of major concern to federal-level policymakers.

The third measure is the *fraction of industry surplus backing commercial property and casualty insurance lines used to compensate losses following an attack*. This measure reflects the postattack health of insurance markets.

The final measure is the *cost to future policyholders*. This measure reflects the increased cost of insurance policies, in the form of a surcharge placed on commercial property and casualty insurance premiums, and the potential for policyholders in low-risk areas to cross-subsidize policyholders in high-risk areas.

Each outcome measure serves both as a direct measure of the government intervention's performance and as a proxy for a broader social welfare concern. The first two measures shown

in this table broadly represent social outcome measures, while the second two represent outcome measures more focused on the postattack health of the insurance marketplace.⁶

⁶ The outcomes we analyze address the distribution of losses from any given attack across various segments of society. Government interventions in terrorism insurance markets may also influence businesses. For example, insurance cost and availability may influence where a business locates and what types of security measures it adopts. While beyond the scope of this study, the impact of government interventions in these dimensions warrants future analysis. Appendix C discusses this issue further.

Consequences of Allowing TRIA to Expire

Road Map

- **Consequences of allowing TRIA to expire**
 - Outcomes with TRIA
 - Outcomes if TRIA expires (no government program)
- **Consequences of mandatory CBRN offer without other program changes**
- **Conclusions and next steps**

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In the remainder of this briefing, we present the results of our analysis to date for the three government interventions discussed previously. We first examine the consequences of allowing TRIA to expire, which entails comparing the first two government interventions: the outcomes, in terms of the relevant outcome measures, with TRIA in place versus those when there is no government program in place.

We will then turn to presenting the results of our analysis of the third government intervention studied here: the consequences of a mandatory CBRN offer without other program changes.

Finally, we sum up the interim conclusions from the analyses of the three interventions and discuss next steps.

Let's First Focus on TRIA in a Single Example Case for a Conventional Attack

Parameter	Range of Values
Uncertainty About the Attack	
Attack type	Large conventional 10-ton truck bomb
Attack scaling	1.0
Uncertainty Related to Insurance Industry	
Initial surplus	\$180 billion
TRIA conventional property take-up rate	60%
TRIA CBRN property take-up rate	5%
Uncertainty Regarding Postattack Government Compensation	
Government compensation for uninsured losses	45%
Market retention	\$27 billion

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To begin our assessment, we first examine how TRIA performs in a single future state of the world. We create this illustrative scenario by choosing single values for the uncertain parameters shown in this table. In particular, we consider how TRIA would perform in a 10-ton conventional truck bomb attack, with an initial insurance industry surplus of \$180 billion in TRIA lines,¹ with a 60-percent conventional property take-up rate,² a 5-percent CBRN property take-up rate,³ and a postattack government decision to compensate 45 percent of all

¹ An insurer's surplus (also called *policyholder surplus*) is the difference between its assets and its liabilities. It is the financial cushion that protects policyholders in the case of unexpectedly large claims.

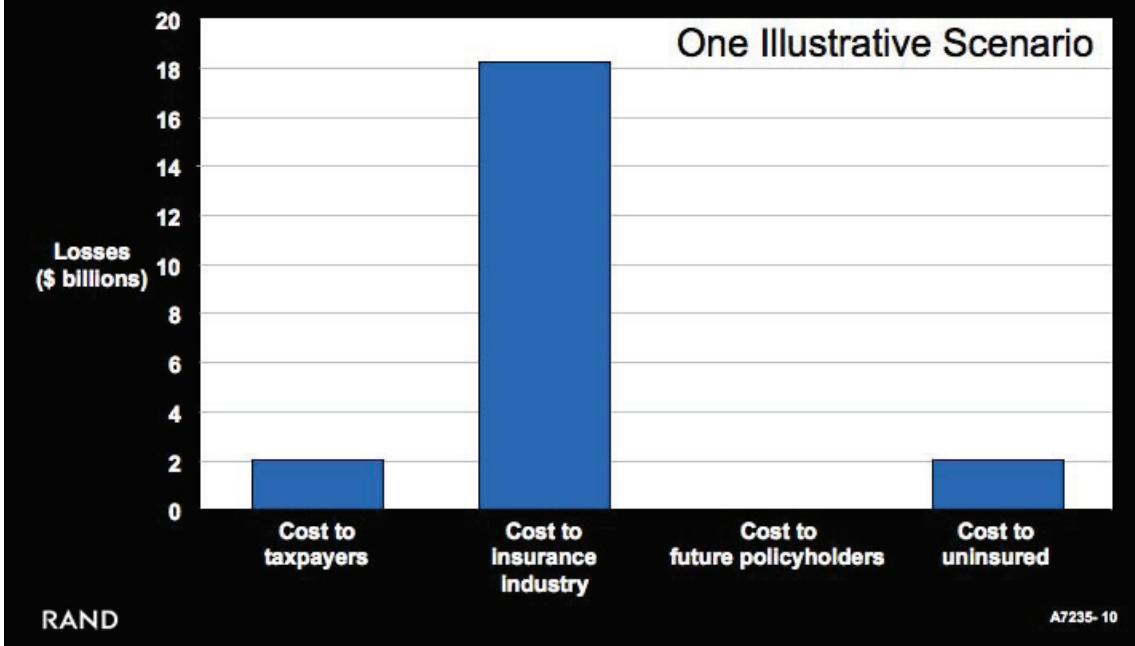
² WC policies cover work-related injuries and death, for the most part regardless of cause. Thus, the take-up rate for terrorism coverage on WC policies is 100 percent for both conventional and CBRN attacks. WC coverage is mandated for all workers, with few exceptions, in every state except Texas.

³ TRIA requires insurers to offer coverage for terrorism losses on the same terms and conditions as losses from nonterrorism events. Because most property policies contain (and have for many years contained) exclusions relating to nuclear and radiological events and contamination events regardless of whether terrorism caused such events, few property policies provide coverage for losses related to CBRN risks; thus, the take-up rate for property policies that cover CBRN attacks is low. Policyholders can, in principle, purchase a separate policy that covers CBRN losses, but such separate stand-alone coverage is seldom offered or purchased.

uninsured losses. We also assume that the government recoups only the minimum amount of claim payments from commercial policyholders required by the act.⁴

⁴ We list these input parameters because they are among the ones that will be varied to create multiple scenarios later in the analysis. As described in the appendixes, the simulation model also has input parameters that we hold constant throughout this study.

In the Example Case, TRIA Leads to Distribution of Losses Among Industry, Taxpayers, and Property Owners



Our simulation model now forecasts the distribution of losses in this illustrative scenario among the four segments of society addressed in this study.

The overall losses from this scenario's terrorist attack total roughly \$22 billion, equally split between WC and property losses as shown previously. Under TRIA, the vast majority of the costs in this illustrative scenario, more than \$18 billion, are allocated to the insurance industry, because all WC losses (\$11 billion) and 60 percent of property losses (about \$7 billion) are insured. The government chooses to compensate roughly half of the remaining \$4 billion of insured losses, so taxpayers suffer about \$2 billion in costs. Uninsured property owners absorb the remaining \$2 billion in losses. Future policyholders suffer no losses in this scenario.

Analysis Explores a Wide Range of Futures for Conventional Attacks

Parameter	Range of Values
Uncertainty About the Attack	
Attack type	1-ton and 10-ton truck bombs
Attack scaling	[0.33, 3]
Uncertainty Related to Insurance Industry	
Initial surplus	[\$120 billion, \$240 billion]
TRIA conventional property take-up rate	[55%, 65%]
TRIA CBRN property take-up rate	[3%, 10%]
Uncertainty Regarding Postattack Government Compensation	
Government compensation for uninsured losses	[0%, 75%]
Market retention	[\$27 billion, \$100 billion]

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We can now use this simulation model to explore how these four segments of society fare under TRIA over a wide range of plausible futures. We create these futures by scanning more than a thousand combinations of parameter values that span the range of the uncertain parameters in this table.

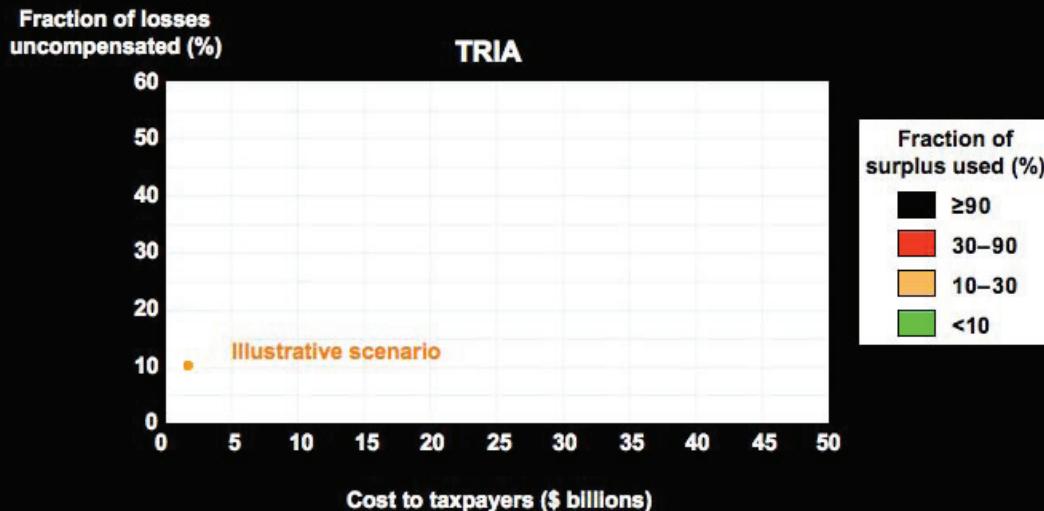
We consider the full range of losses for the 1- and 10-ton truck bombs shown on the earlier slide, a range of values for insurance industry surplus, a range of preattack take-up rates, and a range of postattack government decisions. Table C.1 in Appendix C lists these parameters and indicates where they are discussed in the appendixes, but our assumptions about potential government decisions about postattack compensation warrant discussion here.

Any decisions the federal government might make in the wake of a large future terrorist attack are deeply uncertain if for no other reason than there is little precedent that can be used to predict future choices. Nonetheless, it is useful to note that numerous government programs provide compensation specifically for uninsured losses. For example, the Lower Manhattan Development Corporation administered a federally funded program after the 9/11 attacks that covered the costs of restoring the infrastructure of private utilities not covered by insurance or other federal reimbursement. The Small Business Administration makes subsidized loans to businesses (of any size) to repair or replace disaster damage not covered by other sources.

Such examples suggest that the federal government may choose to compensate some fraction of uninsured losses after a terrorist attack.⁵ However, a great deal of uncertainty about the link between postdisaster government outlays and uninsured losses remains. To address this uncertainty, we simulate outcomes over a very wide range of government compensation for uninsured losses, varying from the case in which there is no relation between the two (government compensates 0 percent of uninsured loss) to a very close relationship (government compensates 75 percent of uninsured loss). As we will show, the important vulnerabilities of, and trade-offs among, alternative government interventions appear fully explored by this range. Appendix F further explores the potential relationship between uninsured losses and government compensation.

⁵ We do not attempt to estimate total government assistance paid after a catastrophe, which will likely be considerably larger than the compensation for uninsured losses that we estimate here. In practice, government outlays may be poorly targeted at uninsured losses or not targeted at these losses at all. However, if widespread uninsured losses increase the dislocation among victims after the attack, the government may be more likely to provide assistance and in greater amounts. This will, in effect, be equivalent to our assumption that compensation is paid directly for uninsured losses.

We Use Scatter Plots to Show TRIA Performance Over a Wide Range of Futures



Plot shows three of four measures of merit for TRIA

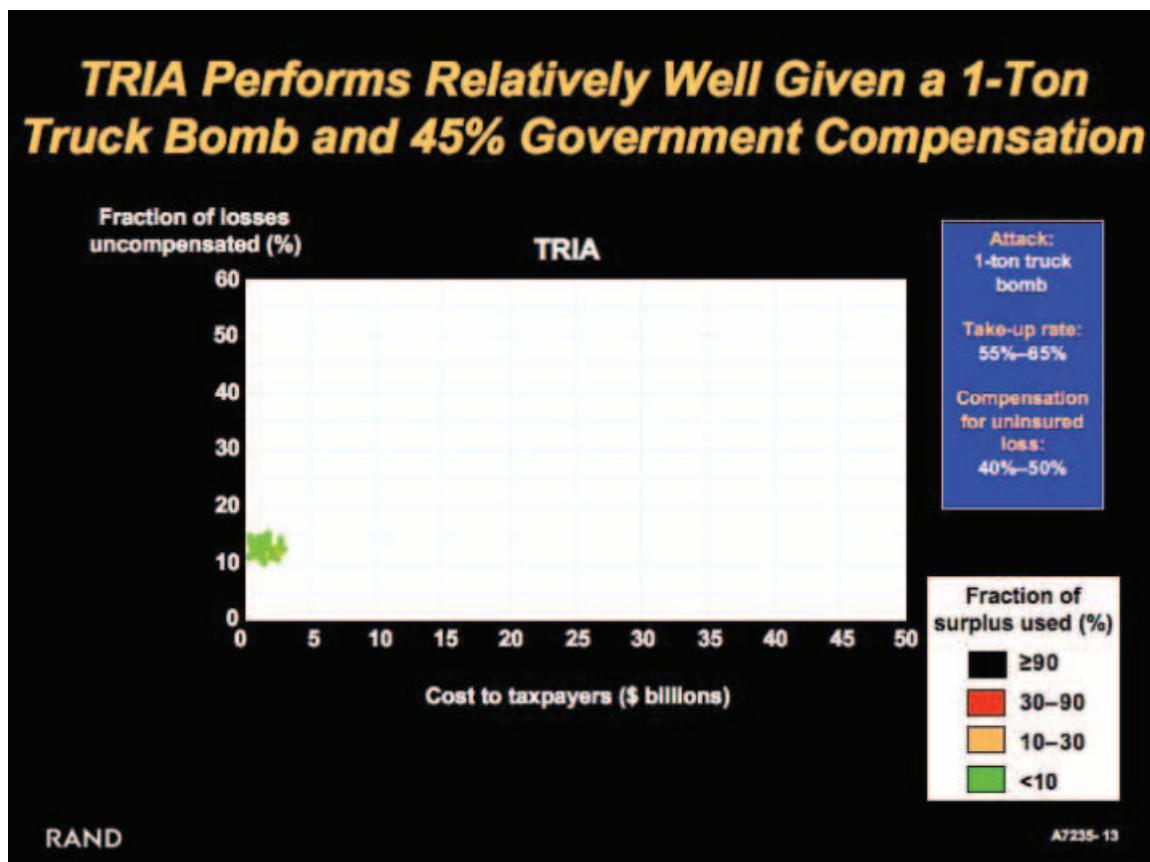
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We find it convenient to use scatter plots to help understand TRIA's behavior over the many thousands of futures considered in this study. This chart shows the single illustrative scenario from the previous bar chart. Subsequently, we will fill this plot with several thousand additional scenarios.

The scatter plot considers three of the four outcome measures: the cost to taxpayers, the fraction of uncompensated losses, and the fraction of industry surplus used. In most of the cases considered in this study, the cost to future policyholders is relatively small compared to these other costs.

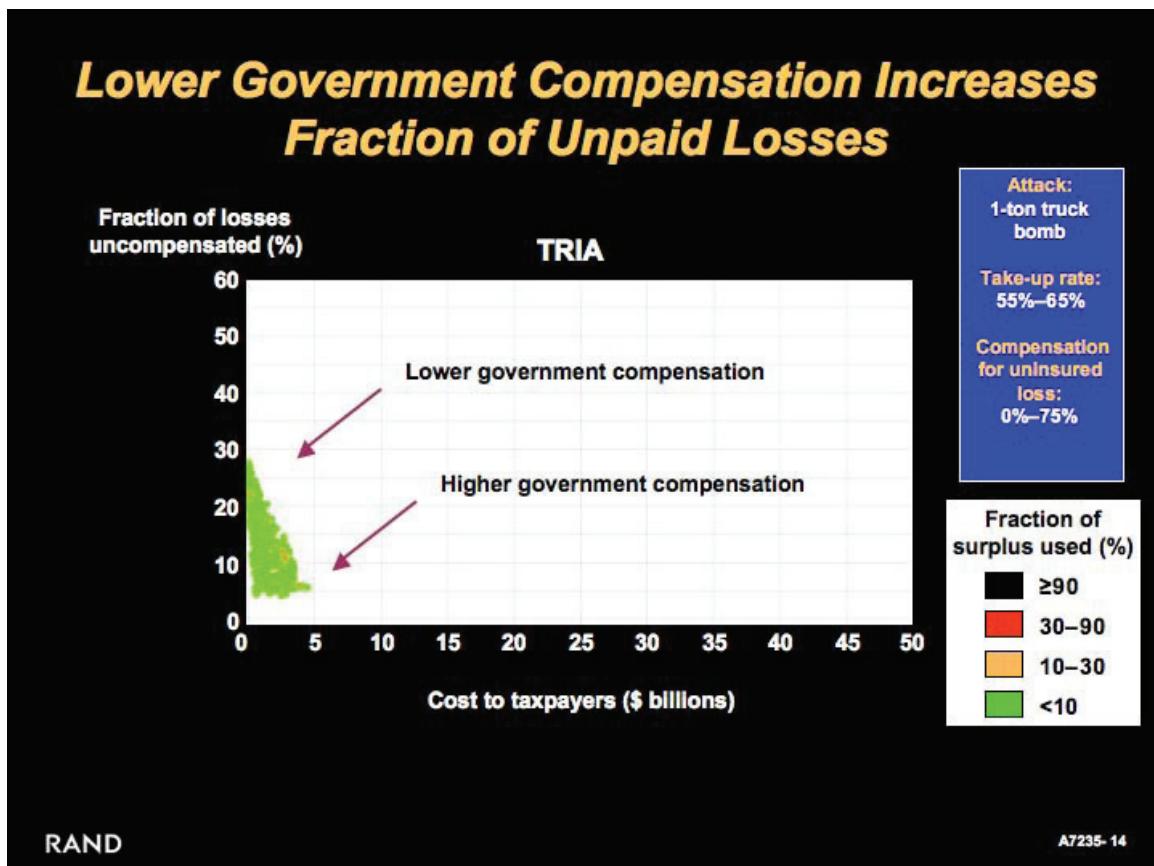
The horizontal axis shows the first measure—the cost to taxpayers, which, in this illustrative scenario, is around \$2 billion. The vertical axis on the scatter plot shows the second measure—the fraction of losses uncompensated, which here is a little more than 10 percent. The color of the plotted dot represents the third outcome measure—the fraction of surplus used, which here is roughly 10 percent. Accordingly, the dot is yellow, which means (as shown in the legend) that between 10 and 30 percent of the industry surplus is used.



This chart shows how TRIA performs over a range of 1-ton truck bomb attacks. The top right box shows the range of parameter values used to create these scenarios. In particular, the TRIA conventional property take-up rate ranges between 55 and 65 percent and government compensation of uninsured losses ranges between 40 and 50 percent. In these scenarios, the government decides to recoup from future policyholders only the minimum required by the act.

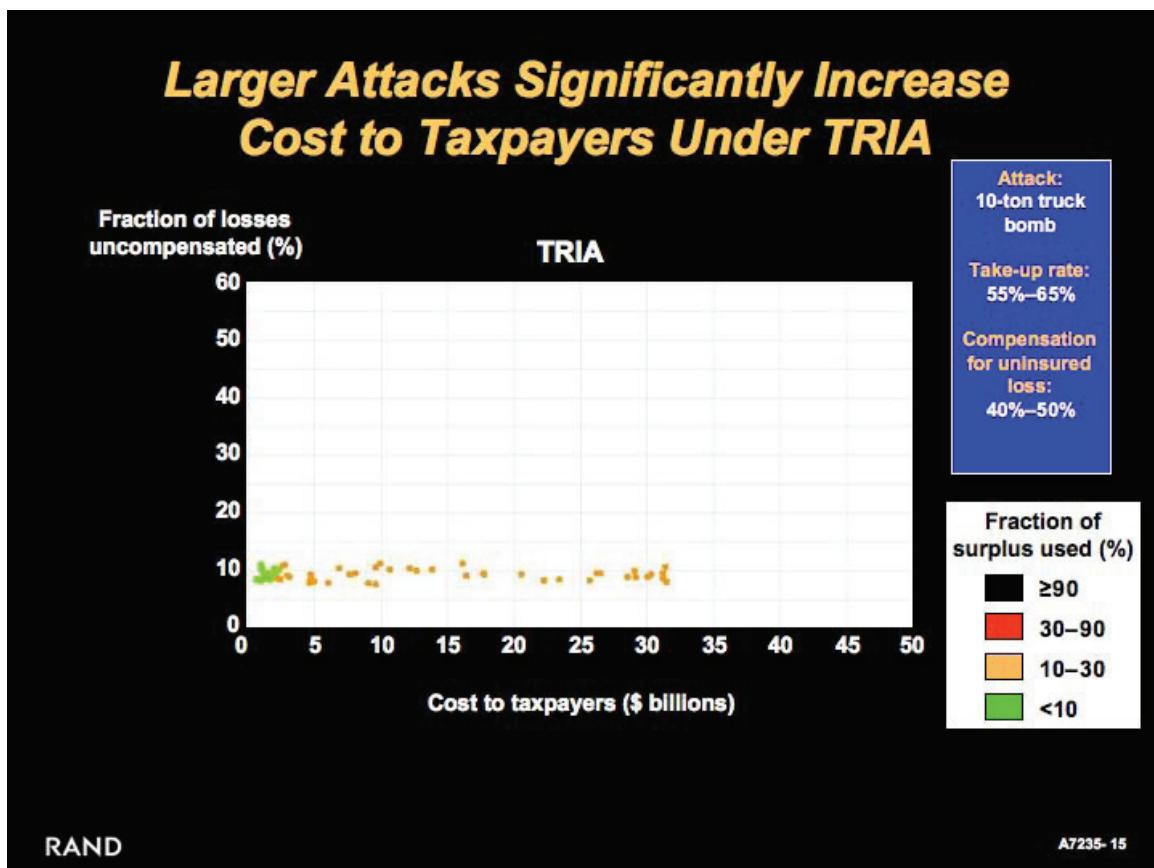
The chart shows that, across these scenarios, the cost to taxpayers ranges from a few hundred million to about \$2 billion, the fraction of losses uncompensated varies from about 10 to 15 percent, and the industry surplus used is generally less than 10 percent.

The variation among these scenarios is explained by noting that these attacks range in size from about \$2 billion to \$21 billion in total losses. In each case, WC accounts for about 30 percent of the total loss, so that, combined with a roughly 60 percent property take-up, about 70 percent of the loss in each scenario, \$1.4 billion to \$14 billion, is the insurance industry's responsibility. The remaining 30 percent of the losses is divided between taxpayers (\$300 million to \$3 billion) and uncompensated losses (roughly 15 percent).



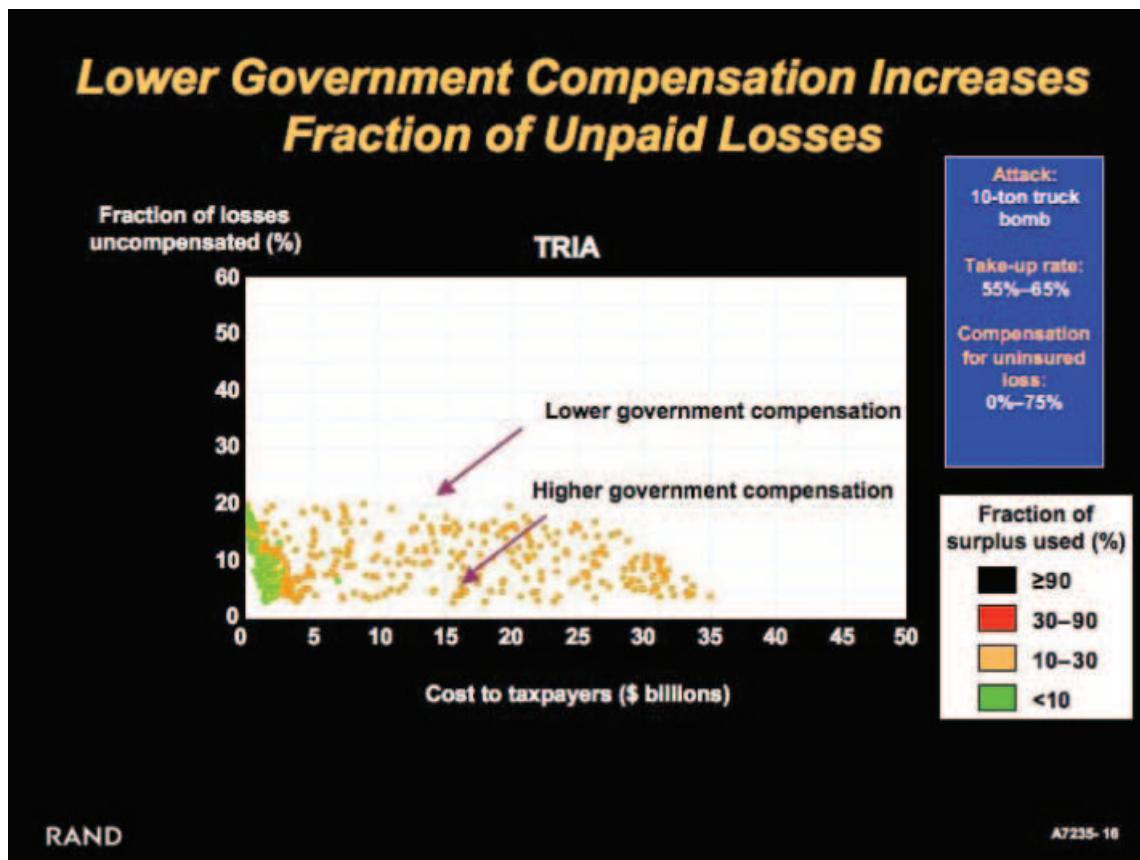
This chart shows how TRIA performs over a range of 1-ton truck bomb attacks when post-attack government compensation ranges between 0 and 75 percent. As noted by the arrows, scenarios in which government compensation is lower have lower taxpayer costs but a higher fraction of uncompensated losses. Higher government compensation has the opposite effect.

As in the previous scatter plots, the range of variation shown in this chart is the result of running the simulation model with many combinations of the input parameters across the ranges shown in the top right box.

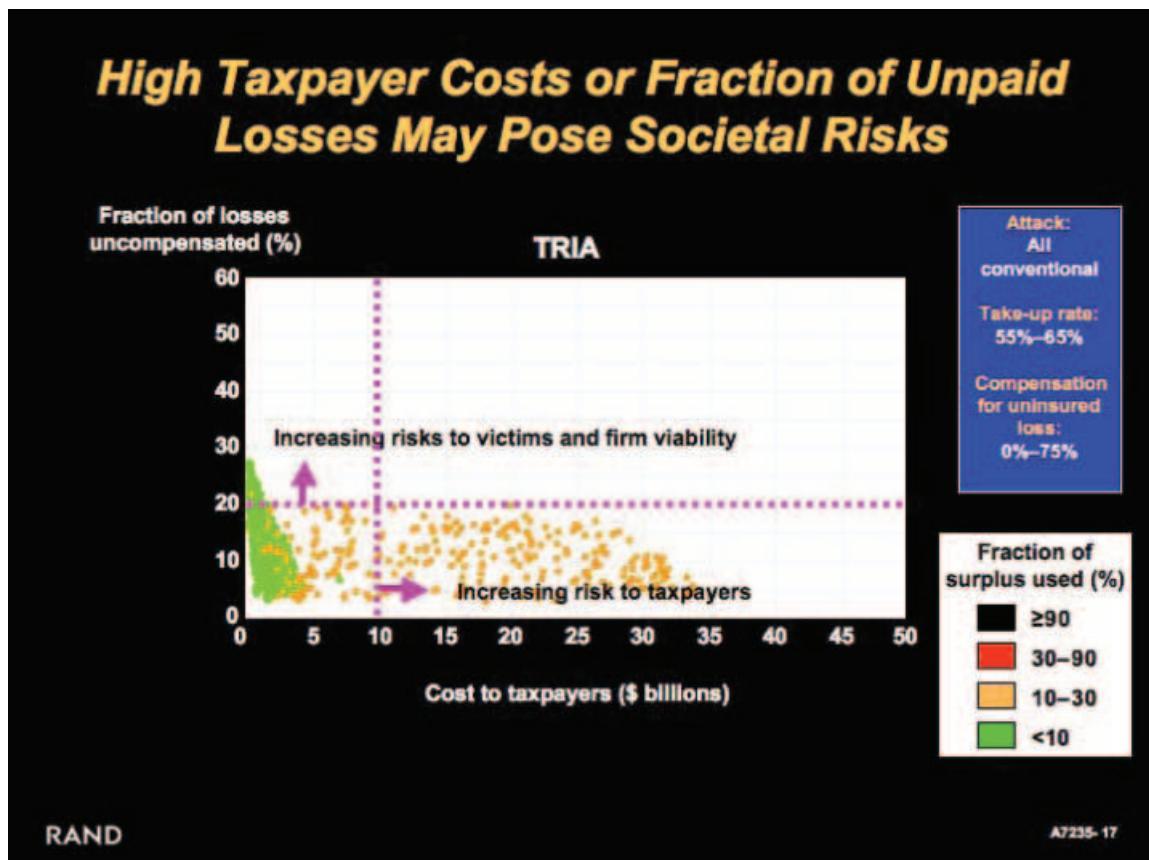


This chart shows how TRIA performs over a range of 10-ton truck bomb attacks (as opposed to the 1-ton truck bomb just considered) when government compensation ranges from 40 to 50 percent. The cost to taxpayers now ranges from roughly \$1 billion to nearly \$35 billion, about 10 percent of losses remain uncompensated, and the fraction of industry surplus used often exceeds 10 percent.

The variation among these scenarios is explained by noting that these attacks range in size from about \$7 billion to \$66 billion in total losses. In each case, WC accounts for about 50 percent of the total loss, so that, combined with a roughly 60 percent property take-up rate, about 25 percent of the loss in each scenario, \$2 billion to \$16 billion, represents uninsured losses. The government compensates about half these losses. Thus, about \$1 billion to \$8 billion, or about 10 percent of the total losses from the attack, remain uncompensated. In addition to this compensation of uninsured losses, under TRIA, taxpayers also reimburse a fraction of industry losses for large attacks that exceed the TRIA deductible. Some of these taxpayer costs are then recovered from a surcharge on future policyholders (not shown on this chart) and the remainder is paid from the industry surplus.



This chart shows how TRIA performs over a range of 10-ton truck bomb attacks when government compensation ranges from 0 to 75 percent. Once again (as the arrows show), lower government compensation increases and higher government compensation decreases the fraction of losses that are uncompensated.



This final chart in the sequence combines all the conventional attack scenarios we consider in this analysis, which include 1- and 10-ton truck bomb attacks, along with the full range of values for government compensation (between 0 and 75 percent), take-up rates, and initial industry surplus. (Appendix G describes, in detail, the choice of these 1,404 scenarios.) The vertical and horizontal dotted lines represent anchoring points that will be used to compare the performance of different government interventions. Outcomes higher up on the vertical axis reflect increasing risks to victims and the viability of business firms hit by a terrorist attack. Outcomes further to the right on the horizontal axis reflect increasing risks to taxpayers. As far as the fraction of surplus used is concerned, the first breakpoint in the color scheme is based on a rule of thumb in the insurance industry that credit rating agencies will lower an insurer's credit rating if an event causes more than a 10-percent reduction in surplus.⁶

⁶ While orange or yellow is often used to indicate cause for concern but not a dire situation, our selection of yellow for declines of surplus between 10 and 30 percent should not be taken to mean that the insurance industry could handle such a decline with only moderate disruption.

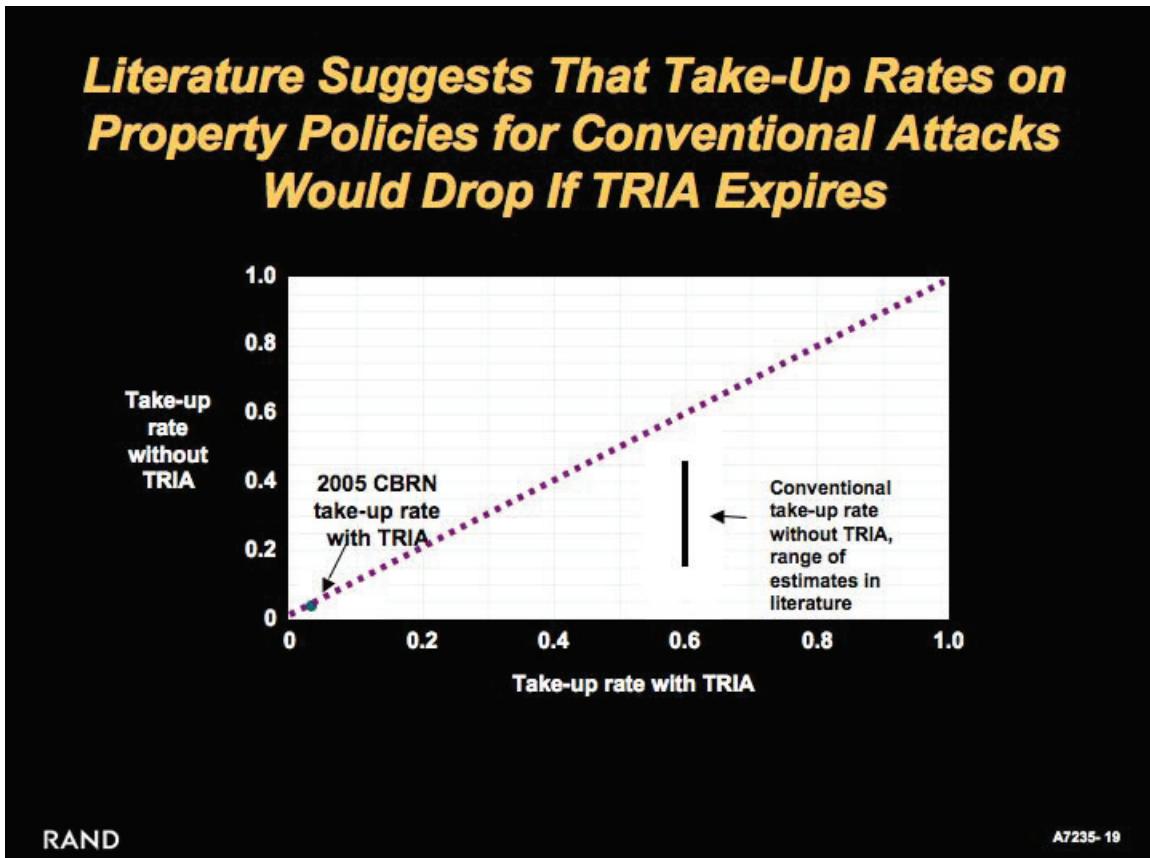
Road Map

- **Consequences of allowing TRIA to expire**
 - **Outcomes with TRIA**
 - **Outcomes if TRIA expires (no government program)**
- **Consequences of mandatory CBRN offer without other program changes**
- **Conclusions and next steps**

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Having discussed the outcomes in terms of the outcome measures with TRIA in place, we now turn to examining the outcomes if TRIA expires or, in other words, if there is no government program for terrorism risk insurance.



A key difference between having TRIA and not having TRIA is what happens to take-up rates. The two axes in the chart show the take-up rate for property policies with TRIA (the horizontal axis), which we can, in principle, measure, and the take-up rate without TRIA (the vertical axis), which we cannot measure directly, because the condition does not exist. As discussed previously, the conventional attack take-up rate for TRIA is about 60 percent, which would put it somewhere on a vertical line drawn at 0.6 on the horizontal axis. If there were no effect on take-up rates of letting TRIA expire, we would expect the plot of the take-up rates with and without TRIA to fall on the 45-degree line where both take-up rates equal 0.6.

However, research on how the expiration of TRIA would affect take-up rates suggests that take-up rates on property policies would fall by 25 to 75 percent (as shown by the vertical line at 0.6 on the horizontal axis). For CBRN attacks, the take-up rates are low with TRIA and are not expected to change much if TRIA expires (as illustrated by the point on the 45-degree line near the origin). WC losses caused by terrorism will continue to be covered with or without TRIA. Appendix D details the studies on which these assumptions are based.

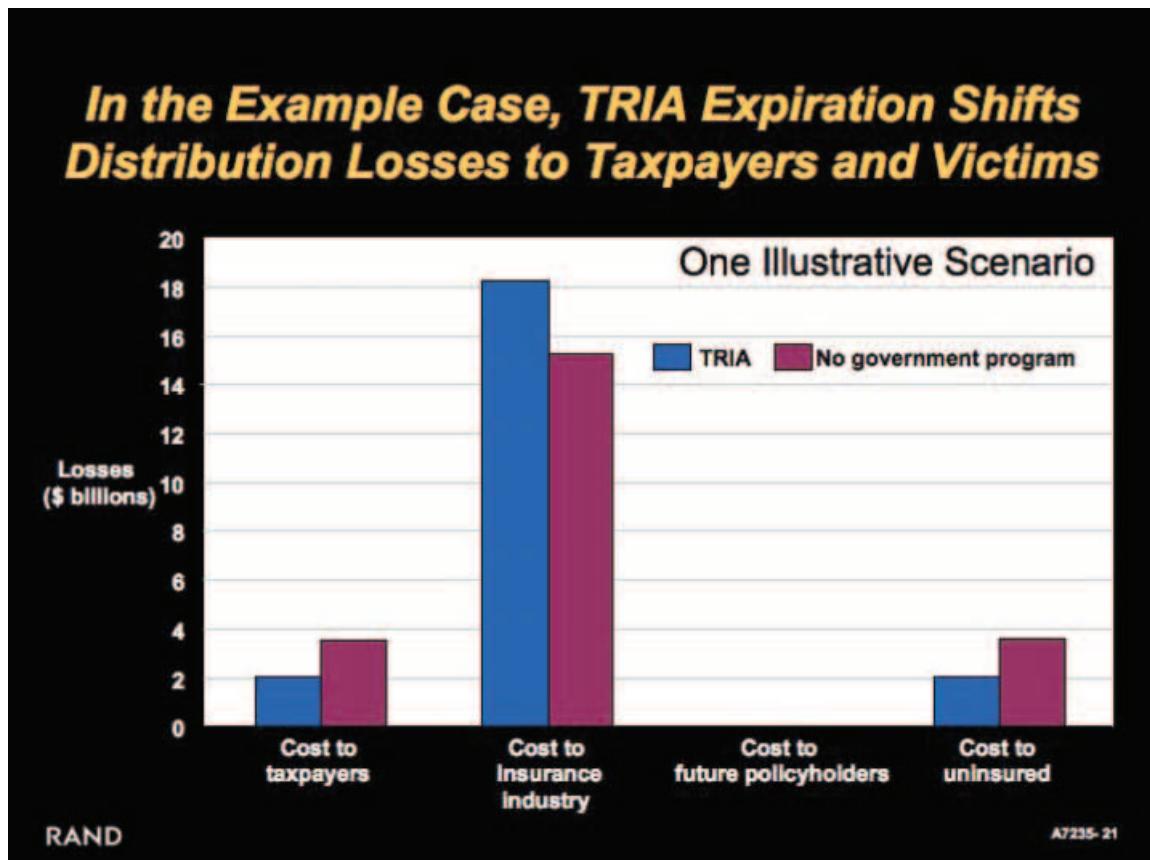
Let's Compare TRIA and No Government Program in the Single Example Case

Parameter	Range of Values
Uncertainty About the Attack	
Attack type	Large conventional 10-ton truck bomb
Attack scaling	1.0
Uncertainty Related to Insurance Industry	
Initial surplus	\$180 billion
No government program conventional property take-up rate	30%
No government program CBRN property take-up rate	5%
Uncertainty About Postattack Government Compensation	
Government compensation for unpaid claims	45%
Market retention	\$27 billion

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We now compare how TRIA performs compared to having no government program in a single future state of the world. The illustrative scenario shown in this table uses the same parameter values as in our previous example, except that some take-up rates are lower because we have let TRIA expire. In particular, this illustrative scenario assumes that the conventional take-up rate drops by half to 30 percent (from 60 percent), which is right around the middle of the range shown in the previous chart. This scenario assumes that the CBRN take-up rate stays the same at 5 percent.



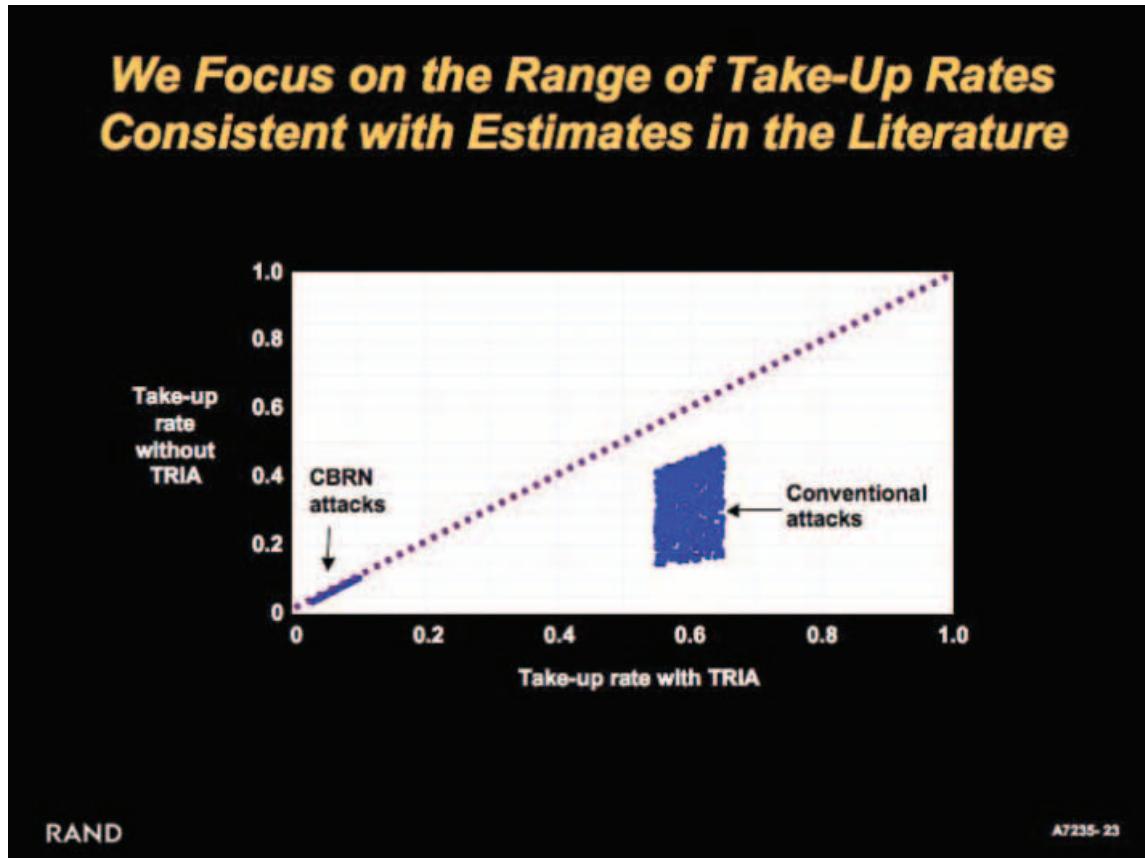
Our simulation model now forecasts the distribution of losses in an illustrative scenario in which TRIA has expired and compares these results to what we found earlier for the similar scenario with TRIA.

In this chart, the blue bars represent what we saw before under TRIA; the red bars show the new allocation of losses if TRIA expires. If TRIA is allowed to expire, the losses shift from the industry to taxpayers and victims. The costs to the industry decrease and uninsured losses increase because the take-up rate is lower. Costs borne by taxpayers increase because the government compensates nearly one-half of the now larger uninsured losses.

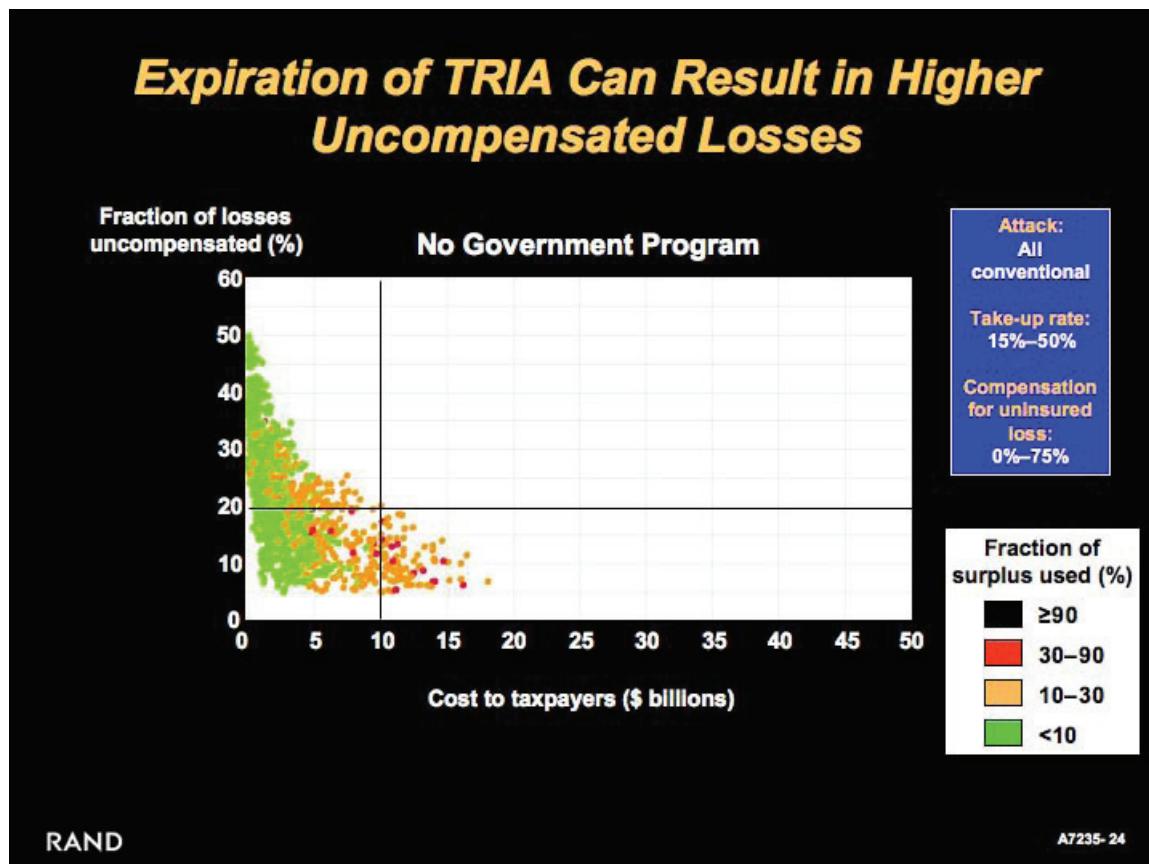


As we move beyond the single scenario, one important uncertainty involves how the take-up rate might change if TRIA were allowed to expire. As shown here, we begin by allowing the take-up rate for property policies under TRIA to vary between 55 and 65 percent for conventional attacks (the width of the blue band, which plots thousands of scenarios). We then use the take-up rate model (detailed in the appendix) to predict how much the take-up rate for conventional attacks would fall if TRIA were to expire for each of the scenarios examined. These scenarios are characterized by particular values for the parameters discussed earlier (e.g., type of attack and government compensation for insured loss), as well as for a number of other parameters that are part of the take-up rate model (such as insurers' risk tolerance). The take-up rate model predicts a wide range of take-up rates for conventional attacks if TRIA were allowed to expire.

As shown in this chart, for certain scenarios examined, TRIA's expiration has no effect on the take-up rate for conventional attacks (the points on the 45-degree line). For others, the reduction in take-up rate can be dramatic. The insurer risk tolerance assumed in the scenario is particularly important in determining the decline.

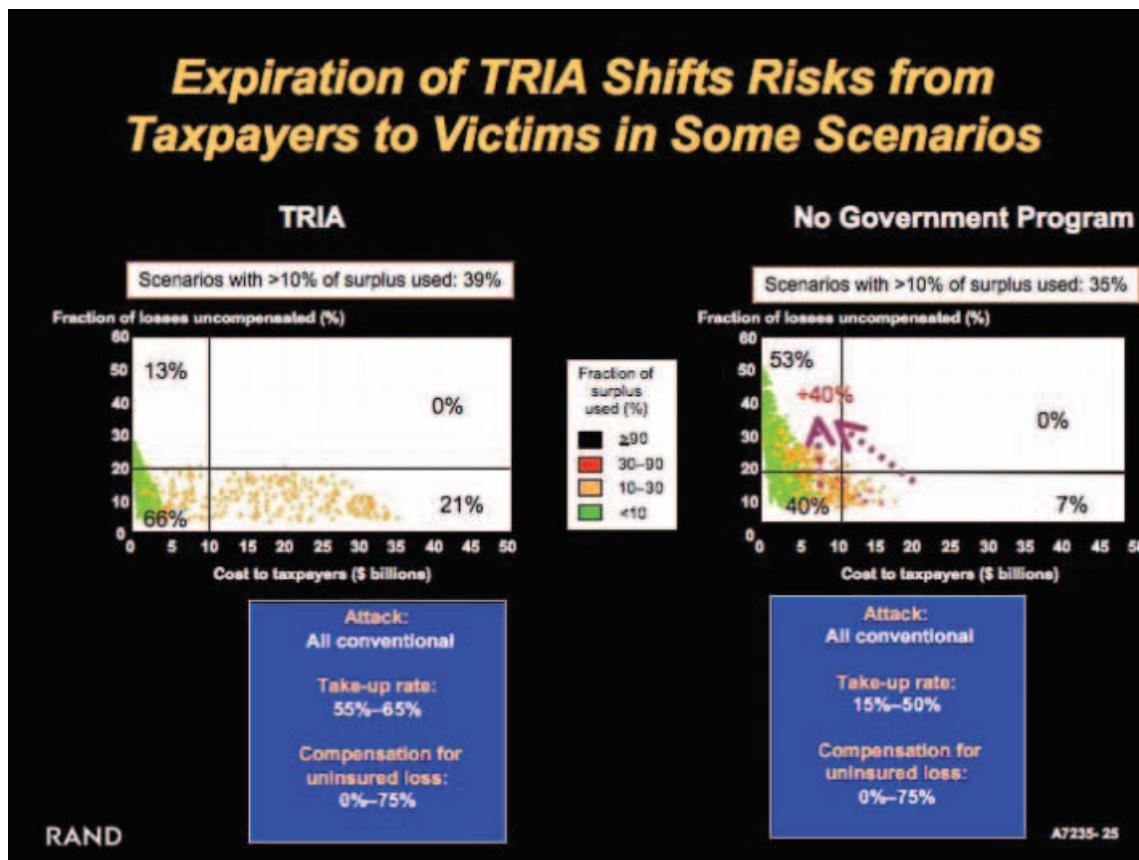


In the remainder of the analysis, we consider only those scenarios that produce changes in take-up rate for property policies that are consistent with the estimates in the literature. Restricting attention to these scenarios is a way of calibrating the take-up rate model. The results that follow use this smaller set of scenarios. However, our conclusions of the advantages and disadvantages of the various government interventions are qualitatively the same for both this smaller set of scenarios and the larger set of scenarios shown in the previous chart.



With that context, we now present results for allowing TRIA to expire (the no government program case). This figure shows the results for all conventional cases—both the 1- and 10-ton truck bomb attacks—and for take-up rates that range between 15 and 50 percent and government compensation ranging between 0 and 75 percent. The anchoring points and the scale are the same as in the previous slides that show outcomes for TRIA.

What we see is that the expiration of TRIA results in high taxpayer costs in some scenarios and a high fraction of uncompensated losses in others. In the chart, the fraction of surplus used is less than 10 percent in a large number of scenarios, but, in many scenarios, it lies between 10 percent and 30 percent.



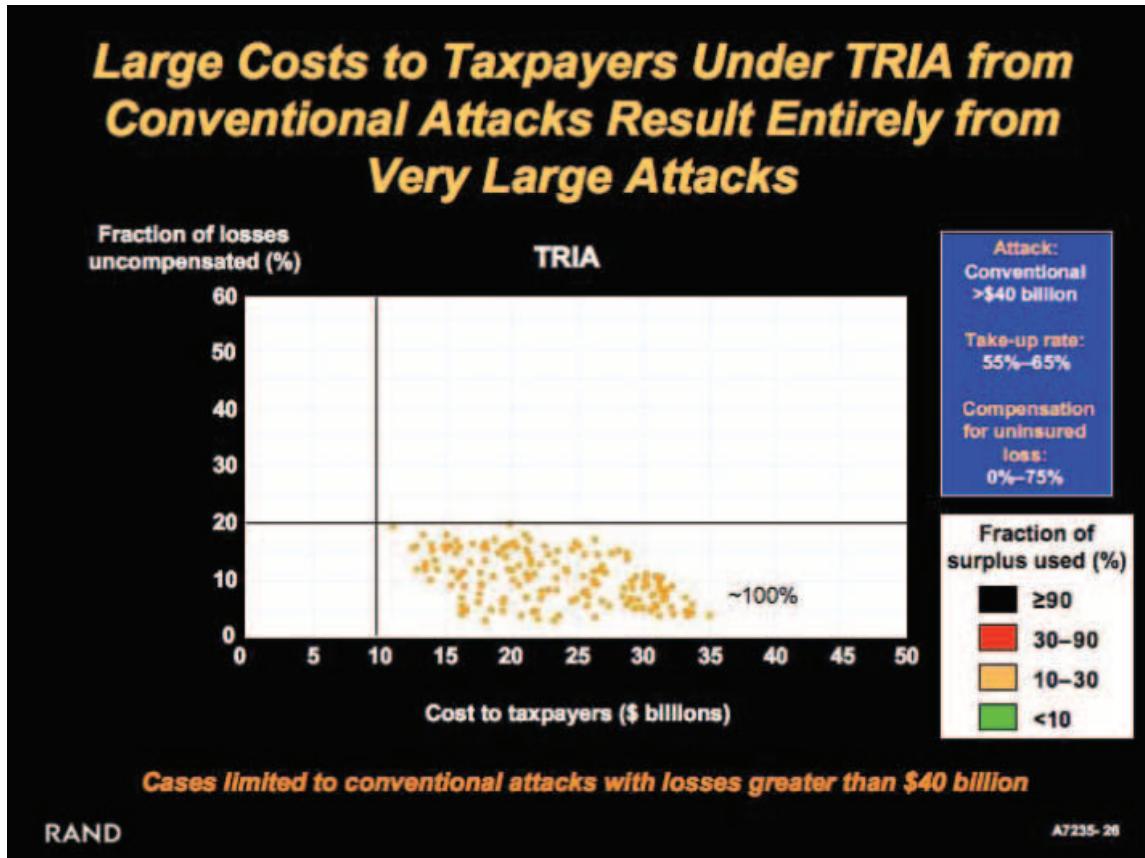
How does letting TRIA expire compare to having TRIA in place? This chart puts the previous charts side by side so that we can compare the two interventions. The expiration of TRIA shifts risks from taxpayers (the costs running along the horizontal axis) to victims (the fraction of uncompensated losses running up the vertical axis). While not shown in these charts, the expiration of TRIA also shifts risk from future policyholders (through policyholder surcharges) to victims.

The vertical and horizontal anchor point lines divide the figures into four quadrants. The percentages reported in each figure (which sum to 100 percent) represent the fraction of the 1,404 scenarios (see Table G.1 in Appendix G) that fall within each quadrant. Thus, with TRIA, more than two-thirds of the scenarios fall within the lower left quadrant, which represents low costs to taxpayers and low fraction of uncompensated losses. A little more than a fifth of the scenarios fall in the lower right quadrant, which represents higher costs to taxpayers but a low fraction of uncompensated losses, while the remainder falls into the upper left quadrant, which represents low costs to taxpayers but a higher fraction of uncompensated losses. (It is important to note that these percentages do not reflect the likelihood of any particular outcome. Rather, they are provided only as a means to better compare how the model's outcomes change under the different government interventions.)

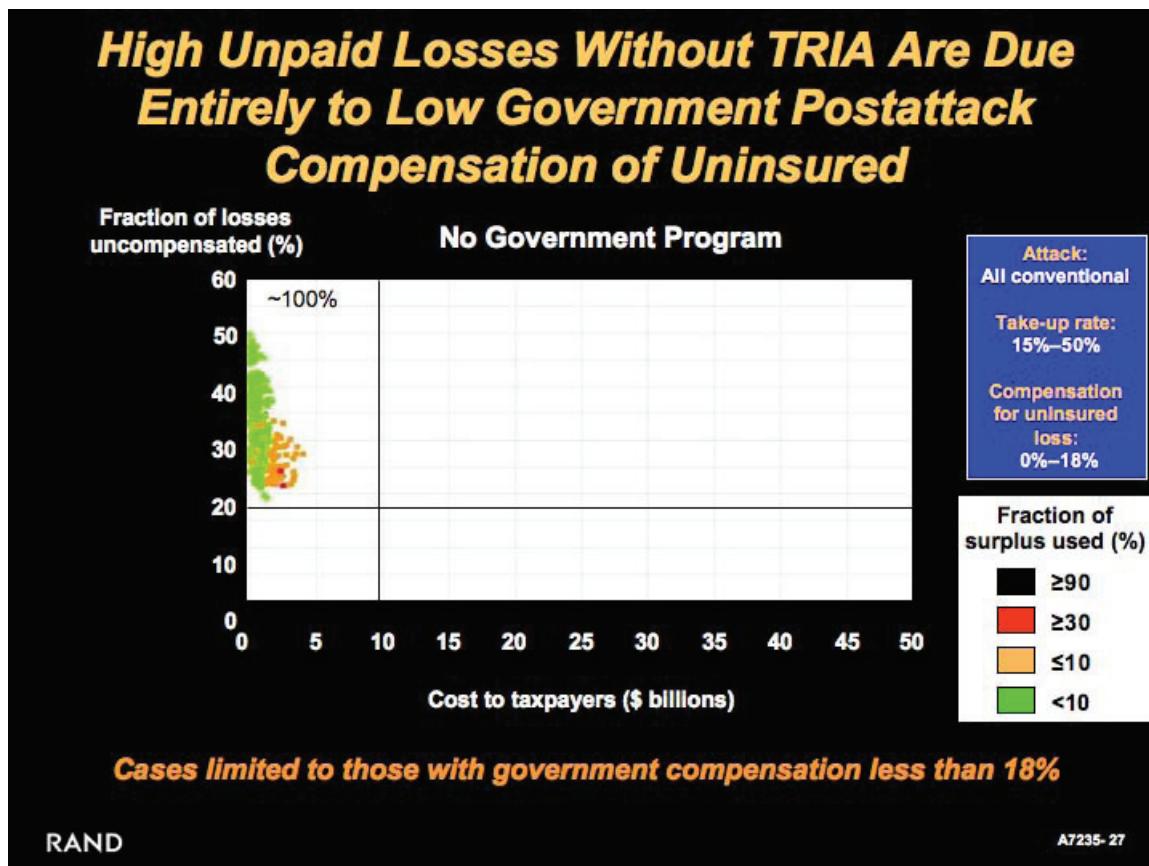
When TRIA is allowed to expire, we see that the distribution of scenarios shifts into the upper left quadrant—low costs to the taxpayers but a higher fraction of uncompensated

claims; the scenarios move from the bottom quadrants. All told, 40 percent of the scenarios move into the upper left quadrant, with 14 percent coming from the lower right quadrant and around 26 percent coming from the lower left quadrant (as shown by the dotted arrows).

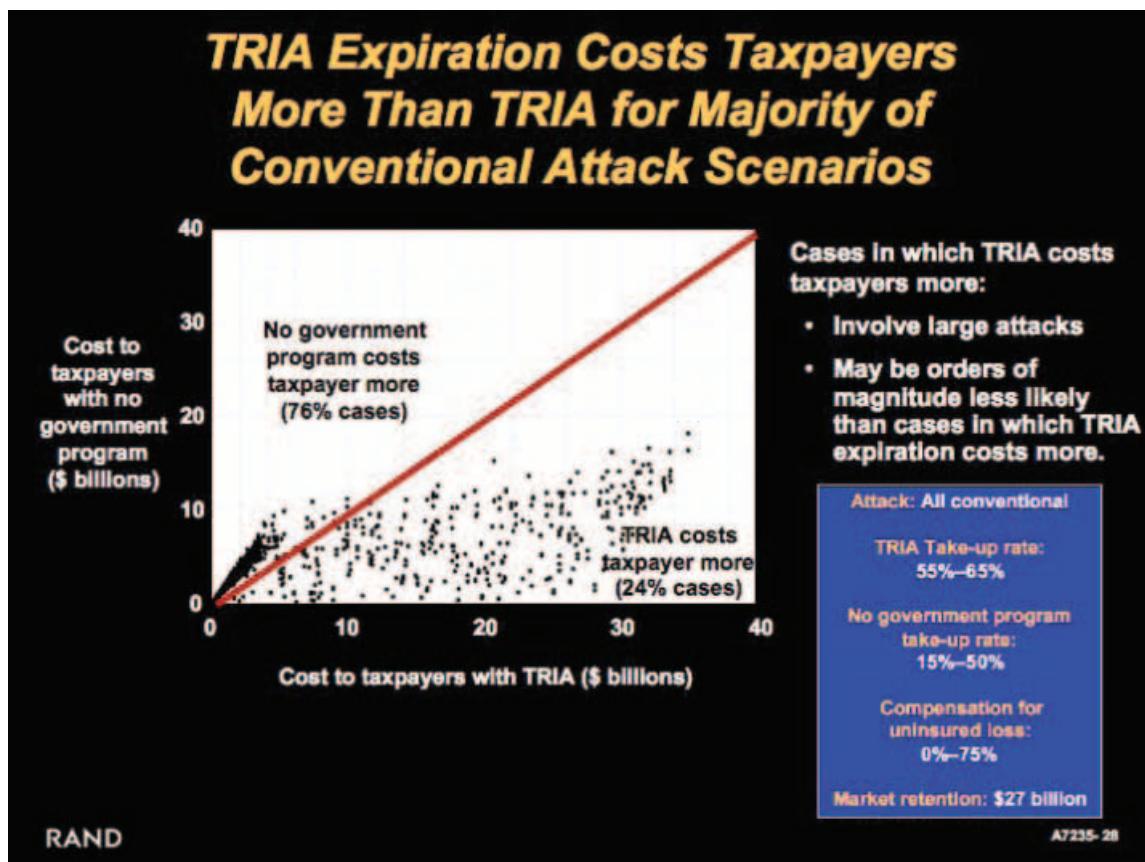
We also see, as shown by the labels above the two plots, that allowing TRIA to expire causes a small decline in the percentage of scenarios that use more than 10 percent of the industry surplus, from 39 percent under TRIA to 35 percent with no government program. The flip side of the rise in uncompensated losses from a drop in take-up rate is that insurers have less exposure to terrorism losses. However, the effect is not great, at least for conventional attacks.



What causes the results we see in the previous chart? As part of the RDM approach, we can now identify the key factors that lead to particular outcomes of interest, in this case outcomes in which TRIA may be vulnerable because it leads to high costs for taxpayers. We examined the scenarios in which taxpayer costs were greater than \$10 billion and found that nearly all of them involved attacks in which the total losses from the attack were greater than \$40 billion. (See Appendix G for a description of this calculation.) This chart plots the 392 scenarios in which total losses are greater than \$40 billion. We see that TRIA has high costs for taxpayers only if the attack size exceeds this very large size.



Conversely, what causes the shift to uncompensated losses if TRIA expires? Here, we restrict the scenarios plotted to only those cases in which government compensation after the attack is less than 18 percent, compared to the full range of 0 to 75 percent. These low government postattack compensation scenarios are the ones responsible for driving the shift toward high uncompensated losses.



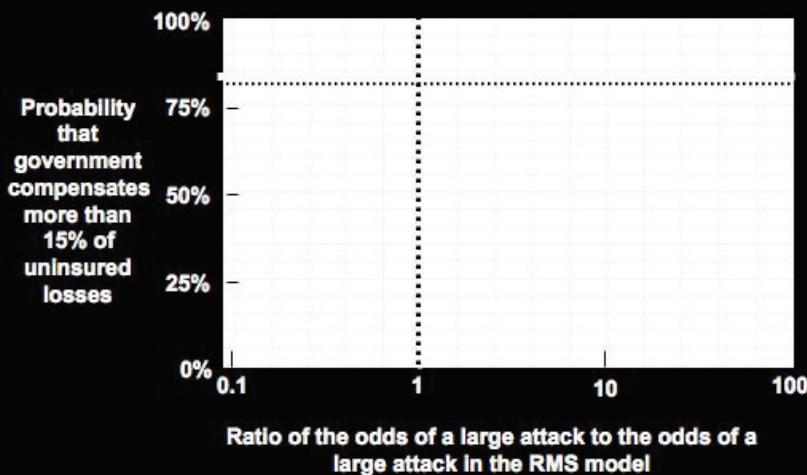
We now compare the cost to taxpayers if TRIA is retained to that if TRIA is allowed to expire. This chart plots the former (horizontal axis) against the latter (vertical axis) for each of the conventional attack cases. The chart suggests that TRIA expiration would cost taxpayers more than retaining TRIA for most of these scenarios, since 76 percent of the scenarios lie above the 45-degree line (where TRIA expiration costs more) and only 24 percent lie below this line (where TRIA retention costs more).

We find that the attack size is the most important factor in determining whether TRIA expiration or TRIA retention costs taxpayers more. TRIA is more costly only if the total losses from the attack exceed \$40 billion. Letting TRIA expire is more costly for taxpayers for all but the largest attacks, because take-up rates and, thus, uninsured losses are lower without TRIA. If the government compensates uninsured losses, then taxpayer costs in smaller attacks will be higher without TRIA, because TRIA imposes additional costs on taxpayers only for attacks larger than the TRIA deductible and mandatory market retention. Below this scale of attack, TRIA places no costs on taxpayers.

However, in those scenarios in which TRIA retention is more costly than TRIA expiration, the cost to taxpayers is generally much higher than in those scenarios in which TRIA expiration costs more (seen by comparing the vertical distance between the points in the chart and the 45-degree line). The expected difference in taxpayer cost across the two interven-

tions modeled (which takes into account the probability of different-sized attacks) is examined next.

Expected Taxpayer Costs with and Without TRIA Are Examined Over a Broad Range of Assumptions



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Which intervention, TRIA or no government program, is likely to cost the taxpayer more if a conventional terrorist attack occurs? The answer to this question depends on how likely one believes it is that the attack will be large (greater than \$40 billion in losses), as well as on how likely one believes it is that the government will provide substantial compensation for uninsured losses in the aftermath of an attack. As implied previously, assuming that an attack occurs at all, the lower the probability of a large attack, the more likely that the expected value of taxpayer cost under TRIA will be less than the expected value should TRIA expire. The expected value of taxpayer cost will also be lower the higher the probability that the government will provide substantial compensation for uninsured losses. Higher compensation for uninsured losses means that the reduction of uninsured losses from higher take-up rates under TRIA will be of greater benefit to taxpayers in terms of reduced payments for uninsured losses.

The RMS model suggests that, should a conventional attack occur, the odds that the losses will be greater than \$40 billion are less than 1 in 500. We are aware of no quantitative estimates of the likelihood of significant postattack government compensation. Since both probability estimates are deeply uncertain, we compare the expected cost of TRIA over a wide

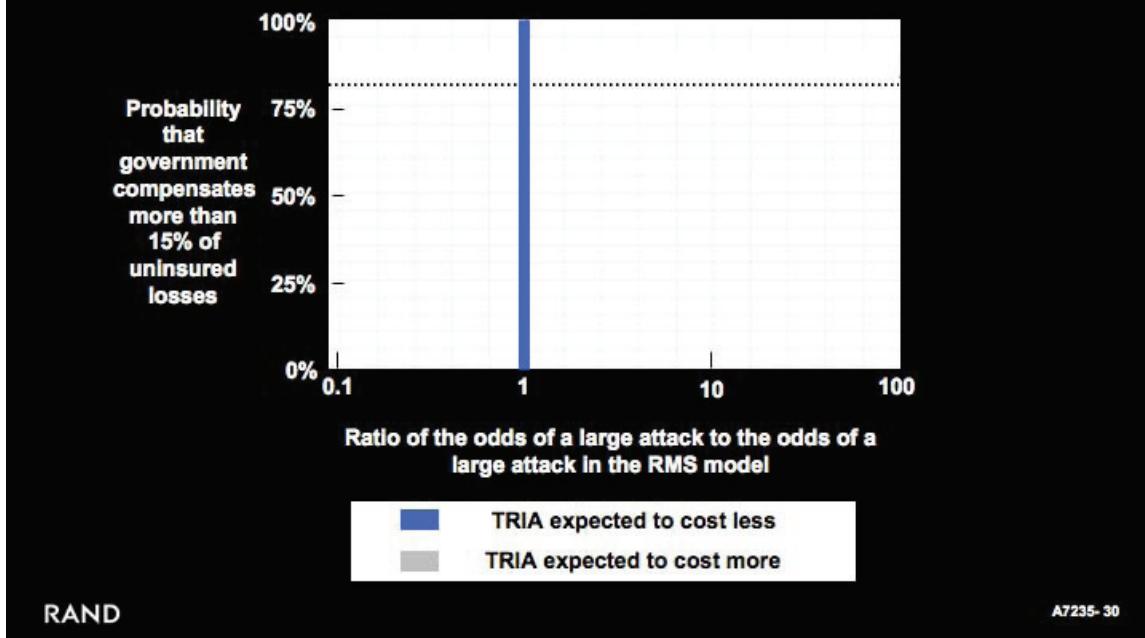
range of assumptions about the odds of a large attack and the probability of modest government compensation.

The chart shows the range of assumptions over which we compare expected taxpayer costs with and without TRIA should a conventional attack occur. The horizontal axis captures variation of the odds of a large attack. Points along the axis represent the ratio of the odds of a large attack relative to the baseline RMS model estimate. For instance, a value of 10 means that the odds of a large attack are 1 in 50 rather than 1 in 500. A value of 0.1 means that the odds of a large attack are 1 in 5,000 rather than 1 in 500. The base value of 1 (the odds of a large attack are the same as in the RMS model, or 1 in 500) is shown by the vertical dotted line on the chart.

The probability of substantial government compensation rises as one moves up the vertical axis of the chart. The axis shows the probability that government will compensate more than 15 percent of uninsured losses (up to a maximum of 75 percent of uninsured losses). The horizontal dotted line marks the value when any government compensation rate between 0 and 75 percent is equally likely.⁷ A value of 0 percent means that there is zero probability that the government will compensate more than 15 percent of uninsured losses.

⁷ If all government compensation rates between 0 and 75 percent are equally likely, then there is an 80-percent probability ($([75-15]/75)$) that government will compensate more than 15 percent of losses.

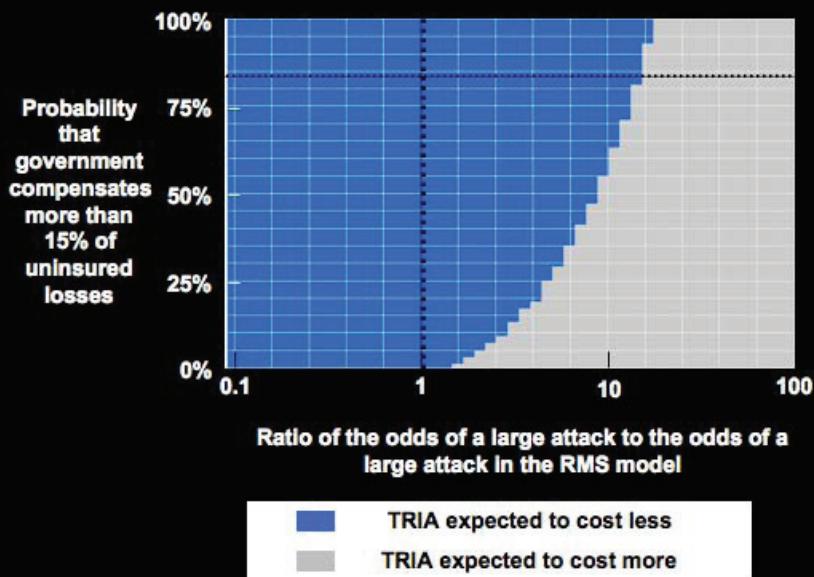
Expected Costs Under TRIA Are Less Regardless of Government Compensation Rate When Current Estimate of Large Attack Probability Used



Let us first compare the expected cost to taxpayers with and without TRIA should a conventional attack occur when the odds of a large attack are the same as the RMS model. As shown by the vertical line in the chart, the expected cost to taxpayers under TRIA is lower regardless of the probability that the government will provide substantial compensation for uninsured losses. Even when there is zero probability that the government will compensate more than 15 percent of uninsured losses, the expected cost to taxpayers is lower under TRIA than it is if TRIA were to expire.⁸

⁸ We assume equal probability for any level of government compensation between 0 and 15 percent.

***Expected Taxpayer Costs Under TRIA Are Less
If a Conventional Attack Occurs Over
a Wide Range of Assumptions***

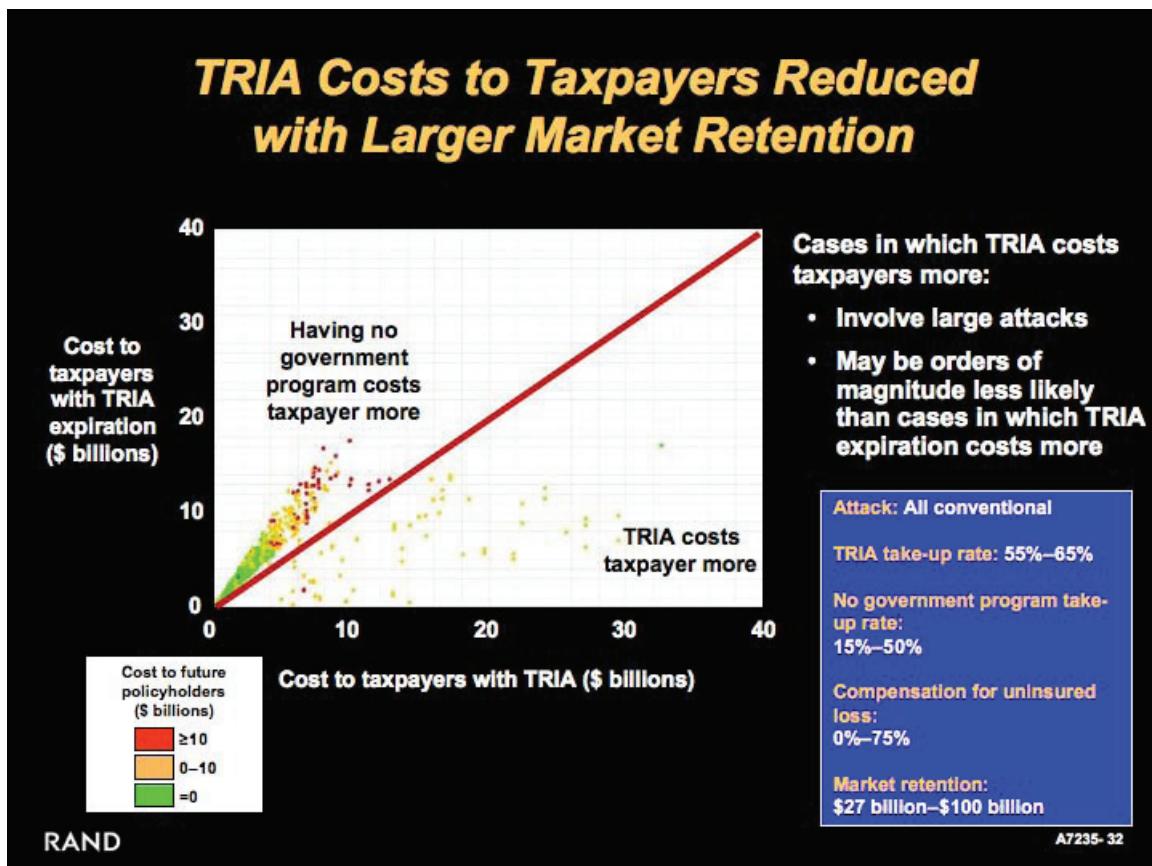


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TRIA is expected to cost taxpayers less than if it were to expire over a wide range of assumptions anchored around existing estimates of the relative probabilities of large and small conventional attacks. As shown here, TRIA is expected to cost less should a conventional attack occur no matter what is assumed about government compensation, as long as the odds of a large attack are lower than in the RMS model (area to the left of the vertical reference line).

TRIA also remains less expensive over a large region if the odds of large losses are greater than in the RMS model. For example, if the odds of a large attack are 10 times the odds given in the RMS model, the expected cost to taxpayers under TRIA remains lower as long as the probability of substantial government compensation exceeds about 55 percent.



The two preceding charts show the maximum cost to taxpayers under TRIA. TRIA requires the government to recoup some losses from future policyholders, but it allows the government the option of recouping more than the minimum. All the results shown to this point assume a minimum market retention of \$27.5 billion. This slide explores the implications of the government choosing a larger market retention. The chart compares the cost to taxpayers under TRIA with TRIA expiration for scenarios in which the market retention is allowed to vary between \$27.5 billion and \$100 billion. (See Table G.1 in Appendix G for discussion of the scenarios used to generate this chart.) The color of the dot indicates this future policyholder cost, as shown in the legend.

Comparing this chart with the previous scatter plot of taxpayer cost with and without TRIA shows that, when the government recoups more from taxpayers than the minimum required by law, TRIA's performance (relative to having no government program) improves from the taxpayers' perspective. The improvement comes at the cost of higher payments by future policyholders.

Uncertainty Remains About Resolution of Insured Losses Above \$100 Billion Cap

- A range of assumptions is made who will bear insured losses over cap
 - Insurers pay from 0% to 75% of insured losses over the cap
 - Government pays 0% to 75% of remaining insured losses

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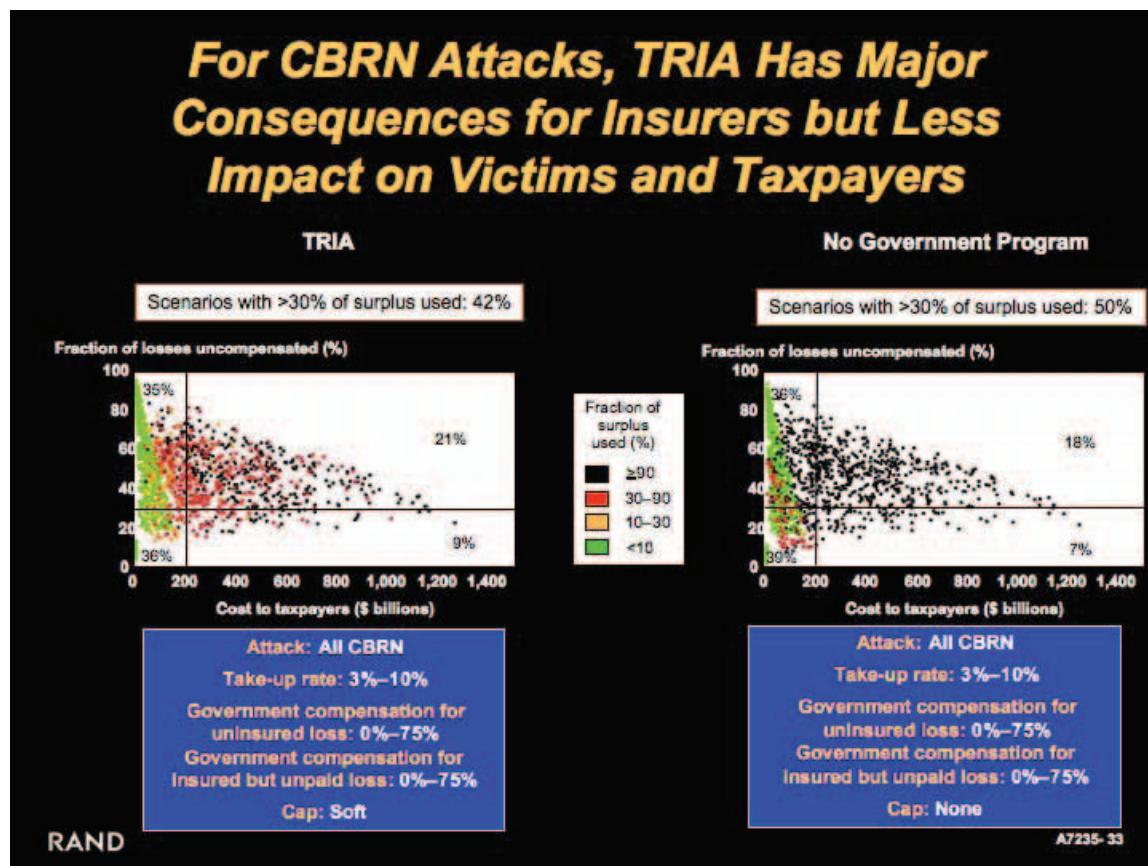
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So far, we have focused on what happens under the two interventions for conventional attacks. But does keeping TRIA in place or allowing it to expire make the same difference during CBRN attacks? Before we present our findings on this question, we need to address an issue that has not come directly into play so far because the losses caused by conventional attacks do not exceed the \$100 billion TRIA program cap: payment of insured losses more than \$100 billion.

As currently configured, TRIA sets a cap of \$100 billion on the amount that insurers are responsible for covering in the event of a terrorist attack. However, the current statutory scheme leaves largely unanswered the extent to which insured losses above the cap will be paid and how they will be financed. (See Appendix D for further discussion.)

In our analysis of TRIA, the expiration of TRIA, and TRIA with a mandatory CBRN offer, we predict the distribution of losses using a range of assumptions about the payment of insured losses more than \$100 billion. We examine scenarios in which postevent political or judicial decisions require insurers to pay from 0 to 75 percent of insured losses above the \$100 billion cap and in which the government decides to pay 0 to 75 percent of the remaining insured but unpaid losses. We refer to scenarios in which insurers may pay anywhere between 0 to 75 percent of insured losses above the cap as *TRIA with a soft cap*. To understand the implication of a soft cap, we also present results with a *hard cap*—that is, insurers have no responsibility for insured losses more than \$100 billion. However, even when the cap is hard,

the government is still assumed to pay between 0 and 75 percent of insured losses more than \$100 billion.



This pair of plots shows that, whether or not TRIA expires (and the cap is soft) makes less difference for CBRN attacks to victims and taxpayers than it does for conventional attacks.

The plot on the left shows TRIA's performance, and the plot on the right shows what happens with no government program in a wide range of scenarios with CBRN terrorist attacks. As shown previously, we considered four types of CBRN attacks, ranging from an indoor sarin attack with losses from \$2 billion to \$18 billion to a 5-kiloton nuclear detonation in a major U.S. city with losses ranging from \$200 billion to nearly \$2 trillion. These CBRN scenarios differ from the conventional scenarios in two important ways. First, the insurance industry is responsible for a smaller fraction of the losses, because take-up rates for CBRN property insurance are very low under TRIA and with no government program. But the insurance industry still remains liable for 100 percent of the WC losses. Second, the scale of the losses can be much larger, more than an order of magnitude, than the conventional attacks.

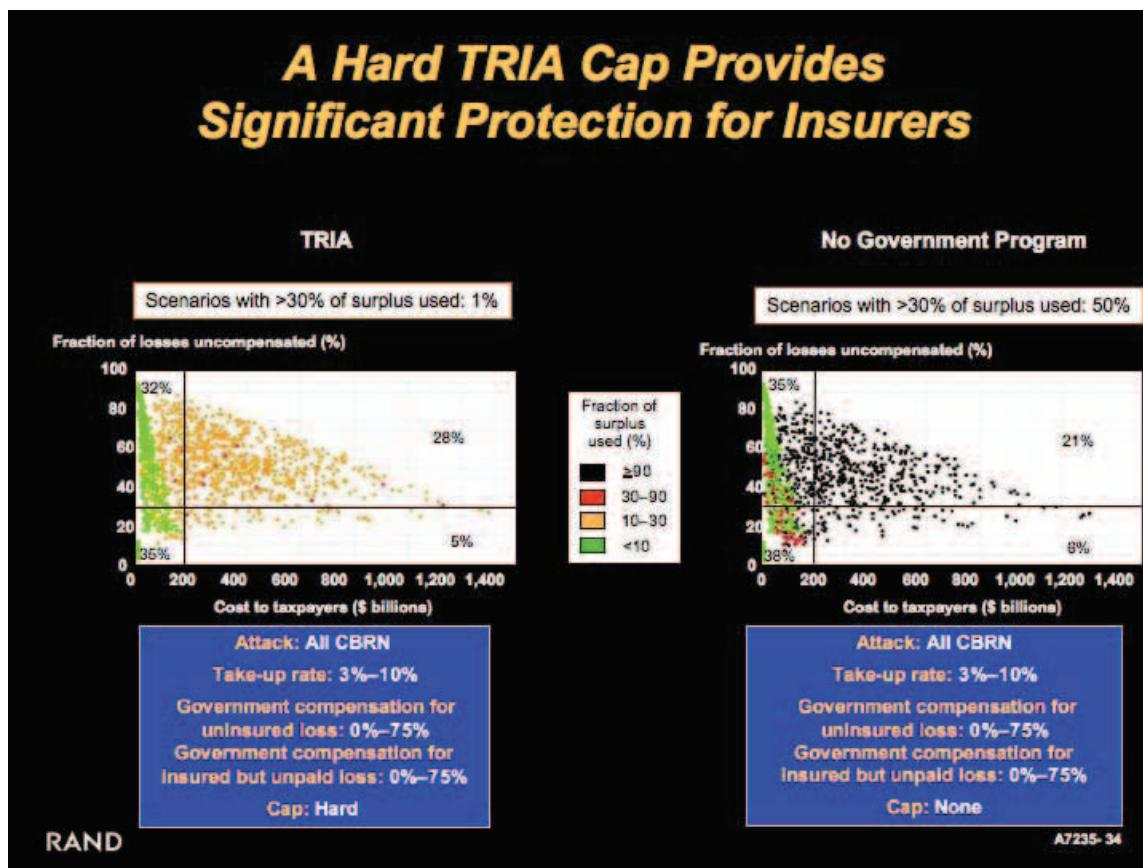
The scenarios in the central regions of both charts represent the 5-kiloton nuclear bomb and the outdoor anthrax attacks. In both cases, the fraction of uncompensated losses can approach 80 percent if the government compensation is small. If the government compensation is large, costs to taxpayers can rise into the trillions of dollars. Neither TRIA nor having no government program serves victims or taxpayers well in either of these nuclear or anthrax scenarios. Because of the WC liability, the fraction of industry surplus used under the TRIA intervention ranges from 30 percent to more than 90 percent. The situation is even worse with

no government program, where the fraction of industry surplus used is consistently more than 90 percent. TRIA does provide some relief for the insurance industry even in these very large attacks because of its \$100 billion cap.

The scenarios along the left side of each chart represent the radiological attack, losses from which range from \$20 billion to \$190 billion. Because these attacks result almost entirely in property losses and produce relatively little WC liability,⁹ the fraction of industry surplus used is less than 10 percent. However, because the fraction of insured losses is so small, the fraction of uncompensated losses can approach 100 percent unless the government provides compensation. Because the insurance industry has so little liability in this attack, there is little difference between the TRIA and no government program interventions.

Nearly 85 percent of the losses from indoor sarin attacks are WC and thus insured. These attacks are sufficiently small that the fraction of industry surplus used generally remains below 10 percent. The fraction of uncompensated losses remains small, as does the cost to taxpayers. Because these attacks are smaller than the TRIA deductible and WC take-up rates remain unchanged by the interventions we consider, there is little difference between TRIA and no government program interventions for these sarin attacks.

⁹ The RMS model does not capture the costs of latent injuries (such as radiation-induced cancer). These costs are difficult to project, and WC policies may not cover them in any case.



Under TRIA, a hard cap makes a significant difference for insurers in CBRN attacks. With a hard cap, the fraction of surplus used remains below 30 percent in the vast majority of cases. The decrease in industry losses is balanced by an increase in the fraction of uncompensated losses and an increase in the cost to taxpayers. Whether the cap is hard or soft, however, the fraction of uncompensated losses and the cost to taxpayers under TRIA for CBRN attacks does not look a great deal different from the way it would look if there were no government program for terrorism insurance.¹⁰

¹⁰ Note that the fraction of points in each of the quadrants for the no government program intervention is slightly different in this chart from that in the previous one. In principle, these charts should be identical, so this difference owes solely to random variations in the two experimental designs used to generate the scenarios for them.

Consequences of a Mandatory CBRN Offer Without Other Program Changes

Road Map

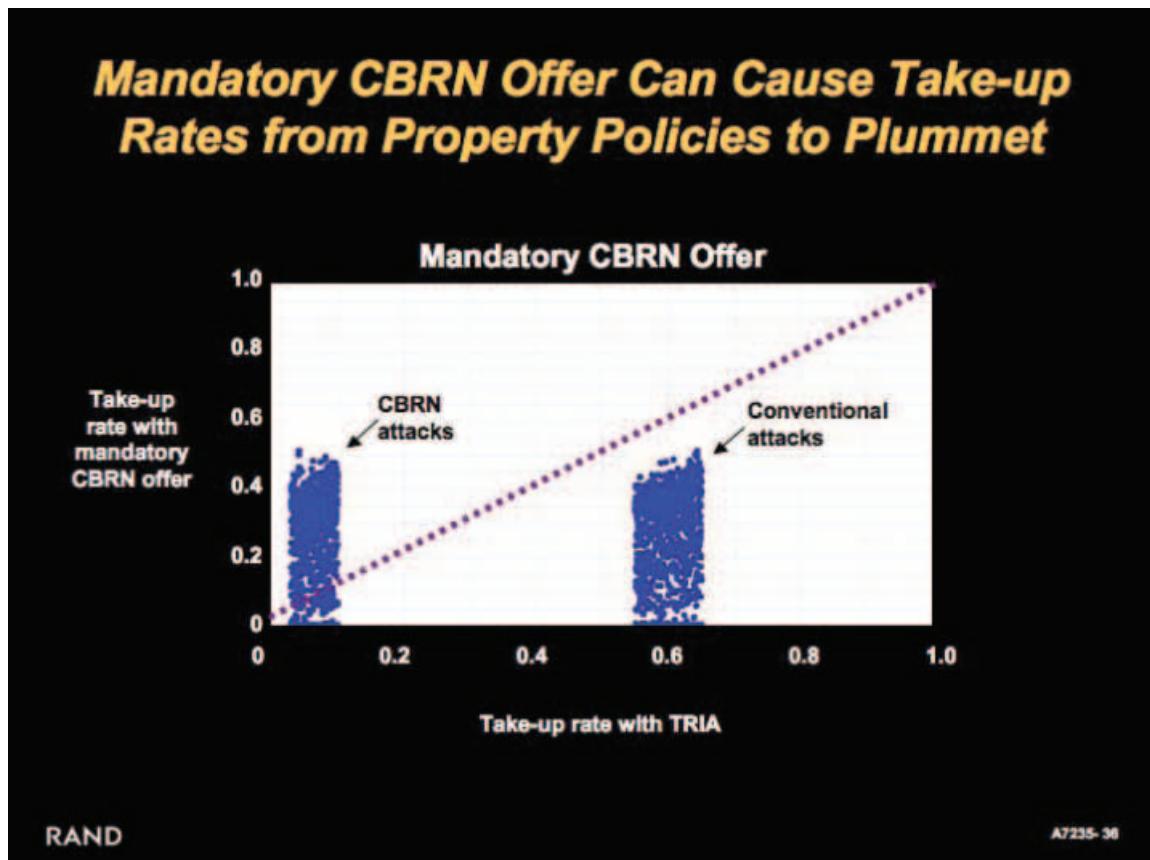
- **Consequences of allowing TRIA to expire**
 - Outcomes with TRIA
 - Outcomes if TRIA expires (no government program)
- **Consequences of mandatory CBRN offer without other program changes**
- **Conclusions and next steps**

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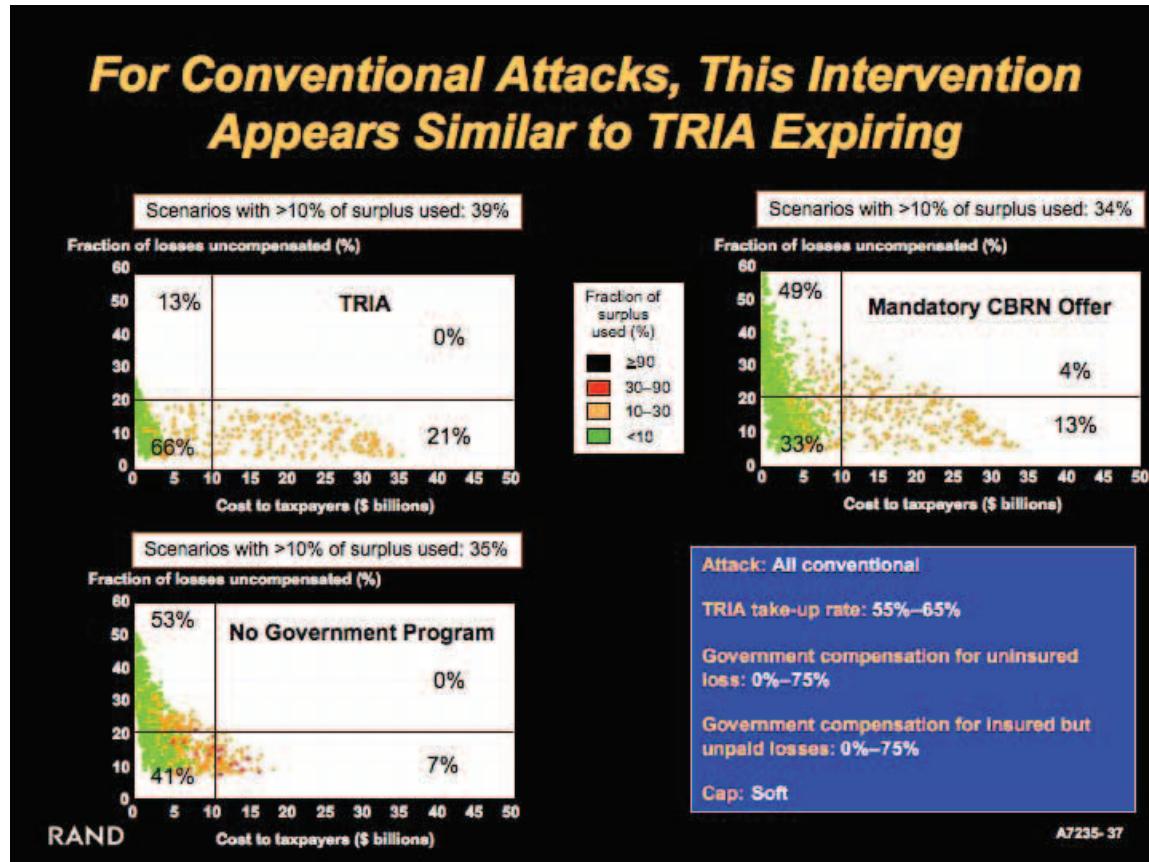
Both TRIA and the absence of any government program for terrorism insurance produce high taxpayer costs and a large share of uncompensated losses in many scenarios. Thus, we now consider a third government intervention that could plausibly address these shortcomings: a mandatory CBRN offer. As the reader will recall, this intervention requires insurers to offer coverage for both conventional and CBRN attacks (in the same policy), and the TRIA cap is

assumed to be soft. Other aspects of TRIA, such as the insurer deductible and the industry copayment for losses above the deductible, remain unchanged.



Returning to our chart that shows take-up rates, when we configure the take-up rate model to reflect this intervention, we find that a mandatory CBRN offer without other program changes can cause the take-up rate on property policies for conventional attacks to plummet. The take-up rate on property policies for CBRN attacks increases in most scenarios (the points in the left band of scenarios above the 45-degree line), but it can fall below its already low value with TRIA in some scenarios (the points in the left band of scenarios below the 45-degree line).

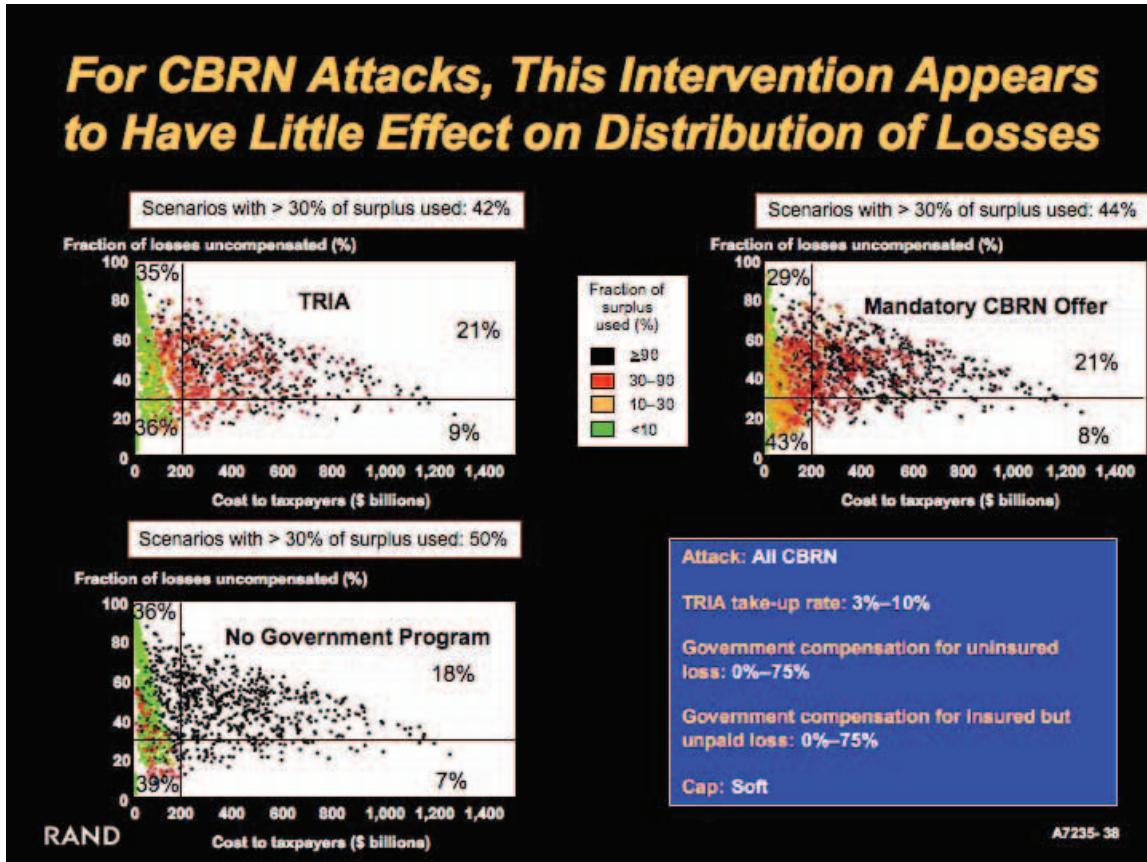
Requiring insurers to bundle coverage for conventional and CBRN attacks causes the cost and, consequently, the price of terrorism coverage for conventional attacks to rise, leading to a fall in the take-up rate from what we observed for conventional attack coverage under TRIA.



The decline in take-up rates means that outcomes for conventional attacks for TRIA with a mandatory CBRN offer are comparable to simply allowing TRIA to expire. Modifying TRIA in this simple way in an effort to improve outcomes for CBRN attacks can have the unintended consequence of degrading TRIA's performance in conventional attacks.

These three charts compare the performance of the three government interventions across the 1,404 conventional attack scenarios with minimum market retention. The two figures on the left replicate the side-by-side figures that we showed earlier for TRIA and no government program. The figure on the right shows the equivalent plot for a mandatory CBRN offer without other program changes.

The figure for no government program and the figure for a mandatory CBRN offer have similar distributions. The percentages in the four quadrants are comparable, and the fractions of the scenarios that use more than 10 percent of the industry surplus are very close. The mandatory CBRN offer intervention has a longer tail than the no government program intervention in the bottom right quadrant (which costs taxpayers more). In this sense, adding a mandatory CBRN offer to TRIA produces outcomes that are more costly for taxpayers than just letting TRIA expire.



When we make the same comparison for CBRN attacks, we find that a mandatory CBRN offer with a soft cap appears to have little effect on the distribution of losses compared with TRIA. These charts compare the performance of the three government interventions across the soft-cap CBRN scenarios. The take-up rate for CBRN coverage on property policies increases substantially relative to TRIA in some scenarios, but it remains low, and even declines, in others. The result is no significant change in the scenario point cloud.

The distribution of scenarios across the four quadrants is similar in all three interventions. The mandatory CBRN offer intervention does reduce the number of scenarios in which the fraction of industry surplus used is greater than 30 percent compared with that used with no government program, bringing it more in line with the TRIA intervention.

Conclusions and Next Steps

Road Map

- **Consequences of allowing TRIA to expire**
 - Outcomes with TRIA
 - Outcomes if TRIA expires (no government program)
- **Consequences of mandatory CBRN offer without other program changes**
- **Conclusions and next steps**

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Finally, we turn to our interim conclusions and our next steps.

TRIA Has Positive Effects in Many Dimensions for Conventional Attacks, but Performance for CBRN Attacks Is Mixed

- **For conventional attacks, expiration of TRIA**
 - causes take-up rates for terrorism coverage on property policies to decline significantly
 - increases uninsured losses substantially in many scenarios
 - increases expected costs to taxpayers should a conventional attack occur over a wide range of assumptions

- **For CBRN attacks, existence of TRIA**
 - reduces risk to industry but leaves large uncompensated losses and taxpayer payments

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Based on results to date, TRIA has important positive effects on the market for terrorism insurance, particularly for conventional attacks. TRIA causes the take-up rate for terrorism coverage for conventional attacks to be higher than it would be without the program, leading to lower costs borne by victims in a substantial number of the scenarios examined. While TRIA does increase the cost to taxpayers in scenarios involving the largest conventional attacks, the expected cost to taxpayers should a conventional attack occur is lower with TRIA than without TRIA over a wide range of assumptions anchored around existing estimates of the relative probabilities of large and small conventional attacks.

Transferring risk for the largest events to taxpayers provides benefits in terms of lower uncompensated losses and lower taxpayer costs in the most likely scenarios.

TRIA's performance for CBRN attacks is more mixed. The program cap does reduce risk to the insurance industry, even if insurers may still end up financing some of the losses above the program cap. However, the take-up rate for CBRN coverage on property policies is still very low under TRIA, leading to little change in either the fraction of losses compensated or the burden on taxpayers compared with no government program.

Care Must Be Taken in Designing Modifications to TRIA That Address CBRN Attacks

- A mandatory CBRN offer without modification of other program features may have unintended consequences for conventional attacks
 - Results for mandatory CBRN offer are similar to letting TRIA expire
- A mandatory CBRN offer without other changes in TRIA program makes little difference for CBRN attacks

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Given TRIA's mixed performance for CBRN attacks, we considered a simple enhancement of TRIA intended to better address CBRN attacks. Our findings illustrate that any expansion of TRIA to address CBRN attacks must be taken with significant care to achieve the desired goals and avoid unintended consequences.

More specifically, modifying TRIA to require insurers to offer policies that cover both CBRN and conventional coverage without changes in other program features, such as the insurer deductible or program cap, has little upside for conventional attacks and, in fact, may have major unintended disadvantages. In particular, the results for TRIA with a mandatory CBRN offer are very similar to those if TRIA expires for conventional attacks. And, when it comes to its effect on CBRN attacks, we find that TRIA with a mandatory CBRN offer does not improve outcomes much over TRIA alone.

Next Steps

- Continue analysis of modifications to TRIA that address
 - CBRN attacks
 - partial take-up rate of terrorism insurance even with TRIA
- Be a resource to Congress to evaluate program configurations of interest
 - Our modeling framework can be adopted to assess a wide range of policy options

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The results documented here are from work in progress. As such, we are continuing to analyze modifications to TRIA that may better address CBRN attacks and the partial take-up rate of terrorism insurance that occurs even with TRIA.

One of the products from the project is a modeling framework that can be adopted to assess a wide range of policy options. As Congress and other stakeholders debate the reauthorization of TRIA in the coming months, the modeling framework can be very useful in rapidly evaluating program configurations of interest.

Summary of the Appendixes

The appendixes describe the simulation model and analytic approach used in this study.

We use RDM and a computer simulation model to compare the performance of potential government interventions in the terrorism insurance market over a large ensemble of plausible futures. This simulation model projects how each federal intervention performs according to several outcome measures contingent on key uncertain input parameters to the model. As shown in Chapter One, the model begins with one of several alternative government interventions in private insurance markets. The take-up rate model projects take-up rates contingent on the government intervention. A terrorist attack described by one of our attack scenarios may occur. The loss distribution model then calculates the distribution of losses to different segments of society contingent on the take-up rates, as well as on any decisions the government makes about postattack compensation. Based on this distribution, the model calculates the value for each of the four outcome measures used to assess the government intervention's performance.

Using the RDM approach, we ran the model many times over a wide range of plausible assumptions for the values of its input parameters and used the resulting database to describe the key trade-offs among alternative federal government interventions in the terrorism insurance market.

The appendixes describe the following:

- RDM approach as used in this study (Appendix B)
- uncertainties, government interventions, and outcome measures (Appendix C)
- take-up rate model (Appendix D)
- RMS attack model (Appendix E)
- loss distribution model (Appendix F)
- RDM analyses using the simulation model (Appendix G).

Robust Decisionmaking

The traditional policy analytic approach for assessing alternative federal government interventions in terrorism insurance markets would rest on a probabilistic assessment of the likelihood of various types of terrorist attacks and other key uncertainties. The analysis would use some type of system model that describes outcomes of interest contingent on the choice of government intervention. The analysis would then recommend the government action with the optimal expected utility contingent on these distributions. In sophisticated applications, sensitivity analysis (Saltelli, Chan, and Scott, 2000) can then suggest how different assumptions about parameter values or probability distributions might affect this ranking of policies.

The traditional, optimum-expected-utility approach to risk management has proved extraordinarily useful for a wide range of decision challenges. (See Morgan and Henrion, 1990, for an excellent review.) However, it has significant shortcomings when applied to terrorism insurance, because the problem affects a large number of diverse interests and presents uncertainty so large that it is not possible to confidently define a system model or prior probability distributions on the inputs. We use the term *deep uncertainty* to describe such conditions, defined as the situation in which decisionmakers do not know or cannot agree on the system model that relates actions to consequences, prior probabilities on the inputs to the system model(s), or value functions that rank the desirability of the consequences (Lempert, Popper, and Bankes, 2003). If applied under such conditions of deep uncertainty, traditional, optimum-expected-utility methods can encourage analysts and decisionmakers to be overconfident in their estimates of uncertainty to make predictions more tractable; can make agreement on actions more difficult, as parties gravitate toward the differing expert pronouncements of probability distributions most compatible with their own individual values, policy priorities, or decision contexts; and can lead to strategies vulnerable to surprises that might have been countered had the available information been used differently (Groves and Lempert, 2007).

RDM provides a quantitative, decision-analytic approach to decisionmaking under conditions of deep uncertainty that attempts to address some of these problems by characterizing uncertainty with multiple representations of the future rather than a single set of probability distributions¹ and by using robustness, rather than optimality, as a decision criterion (Lempert

¹ Such multiple views of the future are used in a variety of policy areas, for example, those that consider monetary policies robust over competing economic models (Levin and Williams, 2003).

and Collins, forthcoming). RDM considers robust strategies as ones that perform relatively well, compared to alternative strategies, across a wide range of plausible future states.²

RDM is one of a variety of approaches that recognize the importance of robustness as a decision criterion appropriate under conditions of deep uncertainty (Ben-Haim, 2001; Rosenhead, 2001). It has been described extensively in the scholarly (Lempert, Groves, et al., 2006; Lempert and Popper, 2005; Lempert, Popper, and Bankes, 2003) and popular literature (Light, 2005; Popper, Lempert, and Bankes, 2005). The approach is consistent with traditional, optimum-expected-utility analysis, but it inverts its order. While expected utility decision analysis first characterizes the uncertainty as a prelude to ranking decisions, RDM is an iterative process that begins with decision options and then runs the expected utility machinery many times to identify potential vulnerabilities of these candidate strategies—that is, combinations of model formulations and input parameters in which the strategy performs poorly compared with the alternatives; to characterize the trade-offs involved in choosing among these decision alternatives; and to suggest new or modified strategies that might provide a more appealing set of trade-offs. In contrast to traditional sensitivity analysis, which often suggests how the ranking of strategies may change with differing assumptions, RDM seeks to identify strategies whose satisfactory performance compared with the other strategies is relatively insensitive to all or most of the most significant uncertainties.

This study is focusing on the RDM steps of identifying the vulnerabilities of alternative strategies and identifying the trade-offs among them.³ We thus emphasize exploratory modeling methods (Bankes, 1993), which use databases created from multiple runs of a computer simulation model to systematically explore the implications of a wide variety of assumptions and hypotheses. In particular, we use experimental designs over multiple uncertain input parameters to a computer simulation model to “stress test” alternative government interventions against a wide range of plausible future states. We then use these results to identify and assess the key trade-offs posed by a choice among these alternative government interventions.

This analysis does not offer any overall ranking of the alternative government interventions considered here. In part, our ability to do so is limited because we do not consider how any of the government interventions might affect the total societal losses in any terrorist attack, for instance, by influencing business decisions about location or security measures or by influencing terrorists’ attack plans. Rather, the analysis only considered how the losses from any given attack are distributed among different segments of society, such as property owners, the insurance industry, and taxpayers. We thus assess each intervention’s vulnerabilities by identifying the conditions under which losses to any of several stakeholders exceed some threshold value.⁴ For instance, we identify the key factors that could cause losses to the insurance industry to exceed 10 percent of surplus under each government intervention. As described in Appendix G, RDM uses statistical cluster-finding algorithms applied to a simulation-model-generated ensemble of plausible future states to identify such key factors.

² See Lempert and Collins (forthcoming) for a formal definition of robust strategies.

³ These steps represent a quantitative implementation of the qualitative, assumption-based planning method (Dewar, 2002).

⁴ This is a “satisficing” criterion as described by Simon (1959).

We then use these results to illuminate the key trade-offs that these alternative interventions offer policymakers. For instance, in Chapter Two, we compare the cost to taxpayers with and without TRIA for each of a wide range of plausible states. The statistical cluster-finding algorithms suggest that attack size is the key factor in determining whether the costs with TRIA exceed the costs if TRIA expires. This analysis suggests that the former costs will only exceed the latter for attacks with losses exceeding roughly \$40 billion.

This approach also allows us to appropriately include uncertain probabilistic information in the analysis. We use such information in two ways. First, as described in Appendix D, we use *ex ante* estimates of the probability distribution function of losses from terrorist attacks in the model of take-up rates for terrorism insurance. Second, we use probabilistic information as reference points when we compare the postattack (*ex post*) vulnerabilities of alternative interventions. For instance, we calculate the expected value of the cost to taxpayers under TRIA for a wide range of exceedance curves describing the probability of a large conventional terrorist attack. We note that the probability of such an attack may need to be roughly an order of magnitude larger than that estimated by the RMS model for the expected cost to taxpayers under TRIA to exceed that if TRIA expires.

Uncertainties, Government Interventions, and Outcome Measures

It is often useful to divide the factors contributing to an RDM analysis into four categories:¹ uncertainties outside of decisionmakers' control, policies under consideration by decisionmakers, measures that decisionmakers and other interested parties will use to rank the desirability of various scenarios, and the relationships that govern how policies and uncertainties affect those attributes of the system related to the measures.

This appendix describes the uncertainties, policies, and measures used in this analysis. The next three appendixes will describe the relationships that comprise the simulation model.

Uncertain Input Parameters

The behavior of each component of this simulation model depends on the values assigned to each of several uncertain input parameters. Table C.1 shows the entire set of uncertain model input parameters we vary to create the ensemble of plausible futures used for the RDM analysis and in which appendix the parameter is discussed.

We collect all the uncertain model inputs and their ranges here in a single table to facilitate subsequent discussion of the RDM analysis. In general, the results presented in the preceding chapters do not depend strongly on the choice of end points for these uncertain parameter ranges. Rather, the results depend on the parameter values that cause losses suffered by particular stakeholders to exceed certain values. Thus, the results depend on whether such threshold values are included within the uncertainty ranges we consider.

We focus on the parameters in Table C.1 because their uncertainty can have a large impact and because we judge them to be particularly important to the relative performance of the alternative strategies. These parameters fall into three groups, corresponding to the components of the model they address: preattack industry, those affecting take-up rates in response to particular government interventions; losses from attack, those affecting the losses generated in any future terrorist attack; and postattack government compensation, those relating to any government decision to compensate losses after any attack.

¹ Lempert, Popper, and Bankes (2003) describe these XLRM factors—uncertainties (X), policy levers (L), relationships (R), and measures (M)—in detail.

Table C.1
Input Parameters Varied to Create the Ensemble of Plausible Futures

Uncertain Input Parameter	Symbol	Range of Values	Described in Appendix
Preattack industry			
Take-up rate on commercial property policies for conventional attacks under TRIA	γ_{conv}	[55%, 65%]	D
Take-up rate on commercial property policies for CBRN attacks under TRIA	γ_{CBRN}	[3%, 10%]	D
Exceedance probability	p^e	1%, 0.1%, 0.01%, \$500 billion	D
Demand elasticity	ε_d	[-0.975, -0.325]	D
Expense factor	h	[1.43, 2.0]	D
Cost of capital	λ	[0.1, 0.25]	D
Expected industry copayment more than \$100 billion	c_2^e	[0%, 75%]	D
Initial surplus	Q	[\$120 billion, \$240 billion]	F
Losses from attack			
Attack type	—	Large nuclear, large anthrax, indoor sarin, large radiological bomb, 10-ton bomb, 1-ton bomb	F
Attack scaling	s	[0.33, 3.0]	F
Postattack government compensation			
Market retention	R	[\$27.5 billion, \$100 billion]	F
Actual industry copayment for losses more than \$100 billion	c_2	[0%, 75%]	F
Government compensation for unpaid claims	g_v	[0%, 75%]	F
Government compensation for uninsured	g_u	[0%, 75%]	F

Government Interventions Examined

In this briefing, we analyze three government interventions in the terrorism insurance market:

1. no government program
2. TRIA as configured in 2007
3. TRIA with a mandatory offer of CBRN coverage.

We briefly describe each in turn. Appendixes D and F describe in more detail how the simulation model treats each intervention.

No Government Program

As the name suggests, there is no federal government intervention in the market for terrorism insurance.

Terrorism Risk Insurance Act

Congress passed TRIA in November 2002 (Public Law 107-297) and extended it with the Terrorism Risk Insurance Extension Act in 2005 (Public Law 109-144). The law is scheduled to sunset on December 31, 2007. TRIA requires property and casualty insurers to make terrorism coverage available to their commercial policyholders. In return, the federal government agrees to reimburse insurers for payments to commercial policyholders for losses above certain thresholds from terrorism events. Insurers set insurance premiums (subject to state regulation), and policyholder purchase of the coverage is voluntary. The act applies to most commercial lines of property and casualty insurance, including WC insurance, but it does not apply to health or life insurance or to personal insurance lines such as home or auto insurance. TRIA applies only to losses from terrorist attacks committed on behalf of a foreign person or foreign interest and, in 2007, only when total insured losses exceed \$100 million. The U.S. Department of the Treasury administers the program established by the act.

After losses exceed an insurance company's deductible, the government covers 85 percent of payments until the combined insurer and public payments equal \$100 billion. The insurer's deductible is a fraction of its direct earned premium in the insurance lines subject to TRIA in the previous year—20 percent in 2007.² The U.S. Department of the Treasury estimated that the premiums in TRIA lines totaled \$182 billion in 2006, meaning that the industrywide deductible could amount to as much as \$36 billion in 2007 (assuming that losses affect all insurers in proportion to premiums earned).

The government charges no premium in advance for the coverage it provides but is required to recoup some or all of its outlays through subsequent surcharges on property and casualty premiums. In 2007, the government must recoup payments until the total amount of losses paid by insurers plus the policyholder surcharge equals \$27.5 billion. The government also retains discretion over whether to recoup a larger amount of government payments to insurers.

² In general, a *direct earned premium* is the portion of the gross premium collected from a policyholder, before the deduction for reinsurance premiums, for which all or part of the insurance policy term has expired. (Insurance premiums are payable in advance, but the insurance company “earns” them only as the policy period expires and in proportion to the expired period.) Under treasury department regulations issued to implement TRIA, the direct earned premium is the premium information that insurers report in column 2 of the NAIC Exhibit of Premiums and Losses of the Annual Statement (commonly known as Statutory Page 14). See 31 Code of Federal Regulations 50.5(d)(1).

TRIA stops government payments to insurers to cover claims once aggregate insured losses (whether paid by the government or by insurers) exceed \$100 billion.³ The act does not specify whether or how insured losses more than \$100 billion will be paid; rather, it states, “Congress shall determine the procedures for and the source of any payments for such excess insured losses” (Public Law 107-297, Section 103[e][3]).⁴

TRIA with Mandatory Offer of CBRN Coverage

TRIA requires that terrorism coverage offered under the act cover CBRN attacks only if the underlying insurance policy does. As discussed below, few commercial property policies provide CBRN coverage, so TRIA does little to expand coverage for property losses from CBRN attacks.

We are investigating numerous ways of extending TRIA to better address CBRN attacks; in Chapter Three, we examine the implications of a very simple enhancement. The enhancement we consider leaves the structure of TRIA unchanged but requires insurers to offer coverage for both CBRN and conventional attacks. Insurers continue to set the price of the terrorism coverage add-on, and purchase by policyholders remains voluntary. Policyholders, however, must purchase both CBRN and conventional coverage together or not at all.

Outcome Measures

We use four outcome measures to rank the desirability of different scenarios generated by the model. These measures are constructed from the outputs generated in each model run.

Ideally, our simulation model would allow us to assess the alternative government interventions according to their effects on social welfare, broadly defined, before and after any terrorist attack. Before an attack, government interventions ought to be assessed according to the extent to which they encourage firms to reduce their vulnerability to terrorist attacks, the extent to which terrorists were deterred from conducting attacks, and the extent to which expenditures on resources and capital for responding to terrorism were minimized. After any attack, government interventions ought to be assessed according to the extent to which they facilitate recovery, maintain a well-functioning insurance marketplace, and minimize the cost of response, as well as according to the resulting distribution of losses across various segments of society.

³ To give an idea of how large government claims payments might be under TRIA, consider an attack that produced \$100 billion in insured losses (the TRIA cap). If losses were evenly distributed across insurers and the combined deductible paid by all insurers totaled \$36 billion, the federal government would pay approximately \$54 billion ($0.85 \times [100 - 36]$). Some or all of these payments could be recouped from policyholders. The potential government exposure is large relative to current estimates of the reinsurance capacity for terrorism risks. Estimates of capacity for conventional attacks run from \$6 billion to \$8 billion and from \$0.9 billion to \$1.6 billion for CBRN attacks (President’s Working Group on Financial Markets, 2006, p. 26).

⁴ For more information on TRIA, see the U.S. Department of the Treasury’s Terrorism Risk Insurance Program Web site (U.S. Department of the Treasury, 2006).

Rather than address this full range of societal impacts, our model focuses on how a particular government intervention affects the allocation of losses from any given terrorist attack among various segments of society. The model allocates losses to the following:

- the insurance industry, which pays them from its surplus⁵
- taxpayers, who are assumed ultimately responsible for any costs borne by the federal government
- future holders of commercial property insurance policies, who may be assessed a surcharge to compensate past losses or fund a pool to compensate future losses
- uninsured property owners, who pay any losses they suffer directly
- unpaid claimants, who have insured losses that remain uncompensated by outside parties because overall losses exceed the cap or because of insurance company bankruptcies.

We combine these model outputs into four outcome measures for alternative government interventions. Each serves as a direct measure of the government intervention's performance and as a proxy for a broader social welfare concern. The first two measures broadly represent social outcome measures, while the second two represent outcome measures more focused on the postattack health of the insurance marketplace.

The first measure is the *fraction of losses that remain uncompensated after any attack*. We calculate this measure as the sum of the uninsured losses and unpaid claims divided by total losses in the attack. This measure represents the burden that a terrorist attack on the United States places on individual property owners and is related to ability of businesses to recover effectively in the aftermath of any terrorist attack.⁶ We consider the ratio of uncompensated to total losses, rather than the magnitude of uncompensated losses, because the former seems more closely related to both the equity and economic recovery issues that this measure aims to represent. For instance, \$1 billion in uncompensated losses would seem to present a larger barrier to the recovery of affected firms in the aftermath of a relatively localized terrorist attack that causes \$2 billion in total losses than \$1 billion in uncompensated losses in a more extensive attack that causes \$20 billion in losses.

The second measure is the *cost to taxpayers*. This measure reflects an issue of direct concern to the federal government, because it compares alternative interventions. We consider the direct costs to the government, because this seems to be the measure of most concern to these policymakers. However, in our ongoing work, we are also considering the costs to the government as a fraction of the total size of the attack.

The third measure is the *fraction of industry surplus used to compensate losses following an attack*.⁷ This measure reflects the postattack health of insurance markets. The fraction of sur-

⁵ An insurer's *surplus* (also called *policyholder surplus*) is the difference between its assets and its liabilities. It is the financial cushion that protects policyholders in the case of unexpectedly large claims.

⁶ Firms may also be able to access funds to finance recovery from other sources, such as the bond market, so one might argue that the insurance is not critical to recovery. Some research has shown, however, that adequate insurance coverage is important for a company's long-term success following a natural disaster (Alesch et al., 2001).

⁷ As discussed below, we base the fraction of surplus used on estimates of the surplus allocated to the insurance lines covered by TRIA (not the entire surplus of the property and casualty insurance industry).

plus used, as opposed to the magnitude, seems appropriate because credit rating agencies (such as A. M. Best or Standard and Poor's) consider this ratio as a measure of industry health. These rating agencies begin to downgrade firms if losses exceed roughly 10 percent of their surplus. If a terrorist attack consumed too large a fraction of industry surplus, the economy might be affected as insurance became more expensive, not only for terrorism, but for auto, property, and a variety of other insurance lines.

The final measure is the *cost to future policyholders*. This measure reflects the increased cost of insurance policies, in the form of a surcharge placed on commercial property and casualty insurance premiums. Increasing the postattack cost of insurance could adversely affect the postattack economy and lead to cross-subsidies between lower-risk and higher-risk areas. We report this measure as the percentage of surcharge on premiums needed to repay the loss over 10 years.

Take-Up Rate Model

Introduction

This appendix describes the approach used to predict how take-up rates for terrorism insurance will change if TRIA were to expire and if TRIA were enhanced by requiring insurers to offer coverage for CBRN attacks and conventional attacks. First, a model of the cost of writing terrorism coverage is developed. The cost model is developed in several steps. It starts with a probability distribution for the total commercial property and WC losses (insured and uninsured) caused by terrorist attacks. A baseline estimate of the take-up rate for terrorism coverage is then used to determine insured losses industrywide, and assumptions are made about the claims that an individual insurer would expect. The cost of writing terrorism coverage is subsequently based on the insurer's expected claim payments and the cost of the capital needed to cover claims should they exceed their expected levels. The next part of this appendix describes how this cost model is used to project changes in take-up rates from changes in policy regime. Changes in the cost of writing terrorism insurance coverage when the policy regime changes (for example, from TRIA—the baseline—to no government program) are translated into changes in the price of insurance, which then drives the change in take-up rate for terrorism coverage on property policies.

Insurer Cost Model

Total Losses Caused by Attacks

The RMS model was used to develop a probability distribution of the losses from foreign-sponsored acts of terrorism in the United States.¹ The RMS model produces an exceedance probability curve of the form

$$\text{Prob}(L > L_j^e) = p_j^e,$$

where

¹ The vast majority of the attacks in the RMS model are in high-risk areas. Thus, we interpret the output of the RMS model as characterizing terrorism risk in high-risk areas.

- L = the total WC and property losses at commercial locations, regardless of whether there is terrorism coverage for property losses (\$ billions),
 L_j^e = loss j reported in the RMS exceedance probability analysis,
 j = the losses reported in the RMS exceedance probability analysis, $j = 1, 2, \dots, 5,100$, and
 p_j^e = the probability that the loss will exceed L_j^e .

We took the difference between successive values of p_j^e and averaged successive values of L_j^e to create a discrete probability distribution (p_j, L_j) , which specifies the probability of an event of size L_j occurring for $j = 1, 2, \dots, 5,099$.

Insured plus uninsured losses were then decomposed into WC and property losses based on analysis of the different types of terrorist attacks represented in the RMS model.² The fraction of loss L that is from CBRN attacks was found to be a function of the size of the loss:

$$\eta_{CBRN} = \begin{cases} 0.09 & L < 12.5 \\ 0.0164L - 0.115 & 12.5 \leq L < 37.5 \\ 0.00192L + 0.428 & 37.5 \leq L < 100 \\ 0.62 & 100 \leq L \end{cases}.$$

Similarly, the fraction of loss that is a property loss (as opposed to a WC loss) was also found to be related to the size of the loss:

$$\eta_{prop} = \begin{cases} 0.8 & L < 1.0 \\ 0.75 & 1.0 \leq L < 10. \\ 0.55 & 10 \leq L \end{cases}$$

Based on these relationships, the overall loss thus breaks down as follows:

$$\begin{aligned} L_{we} &= (1 - \eta_{prop})L \\ L_{p,conv} &= \eta_{prop}(1 - \eta_{CBRN})L \\ L_{p,CBRN} &= \eta_{prop}\eta_{CBRN}L, \end{aligned}$$

where

- L_{wc} = WC loss when total loss is L ,
 $L_{p,conv}$ = property losses from conventional attacks when total loss is L , and

² The various attacks that RMS modeled were sorted into bins by size of overall loss (insured plus uninsured). The proportion of losses in each bin (1) from CBRN attacks and (2) that were property losses was then calculated. Linear interpolations were constructed between the values determined for each bin.

$L_{p,CBRN}$ = property losses from CBRN attacks when total loss is L .

WC losses are not decomposed by type of attack, because WC policies cover loss regardless of cause.

Industrywide Insured Losses Generated by Attacks

Assumptions on take-up rates for terrorism insurance are used to determine the insured property losses that will result from the total losses. In certain states, property losses that result from fire are covered, regardless of the underlying cause of the fire (as long as a property policy is in place). Thus, even if a property policy excludes losses from terrorist attacks, property losses from a fire caused by an attack would be covered. Based on analysis of the losses from a fire for the attacks represented in the RMS model, we developed the following relationships for the fraction of property losses from fire following for a terrorist event with losses of size L :

$$f_{conv} = 0.094 \quad \text{for all } L \text{ and}$$

$$f_{CBRN} = \begin{cases} 0.0002 & \eta_{CBRN} L < 10 \\ 0.0025 & 10 \leq \eta_{CBRN} L < 25 \\ 0.0096 & 25 \leq \eta_{CBRN} L < 100 \\ 0.023 & 100 \leq \eta_{CBRN} L \end{cases}.$$

The take-up rate for terrorism insurance and the fire-following factors are used to project the insured losses for industry as a whole:

$$I_{wc} = L_{wc}$$

$$I_{p,conv} = (\gamma_{conv} + (1 - \gamma_{conv}) f_{conv}) L_{p,conv}$$

$$I_{p,CBRN} = (\gamma_{CBRN} + (1 - \gamma_{CBRN}) f_{CBRN}) L_{p,CBRN},$$

where

- I_{wc} = WC losses for loss of size L ,
- $I_{p,conv}$ = insured property losses from conventional attacks for loss of size L ,
- $I_{p,CBRN}$ = insured property losses from CBRN attacks for loss of size L ,
- γ_{conv} = the terrorism insurance take-up rate for property policies when losses are from conventional attacks, and
- γ_{CBRN} = the terrorism insurance take-up rate for property policies when losses are from CBRN attacks.

These equations reflect the fact that WC insurance policies cover the loss regardless of the cause and our assumption that property losses not covered by a terrorism policy are covered in part from the fire-following regulations.

Total insured loss produced by an attack with loss L is then

$$I = I_{wc} + I_{p,conv} + I_{p,CBRN}.$$

An Individual Insurer's Share of Industrywide Insured Losses

Not all insurers in the industry will have policyholders affected by a terrorist attack. Assumptions on the percentage of insurers affected by an attack and on the distribution of insured losses across those affected are used to project the insured losses expected by an individual insurer for an attack with losses of size L . Insurance Services Office (ISO), a leading firm that gathers data and analyzes claims and prices in the insurance industry, developed estimates of percentage of the premium base that would be affected by terrorist attacks of different sizes (ISO, 2002, p. 20). We interpolated between these estimates to derive

$$\beta^I = \begin{cases} 0.1I + 0.05 & I < 1 \\ 0.05I + 0.1 & 1 \leq I < 10 \\ 0.00111I + 0.589 & 10 \leq I < 100 \\ 0.7 & 100 \leq I \end{cases},$$

where

β^I = the proportion of industry premiums accounted for by insurers with policyholders affected by an attack with losses of size L .

An individual insurer is assumed to have pessimistic expectations about the incidence of claims across insurers. In particular, we assume that an insurer expects that its policies will be hit first and that other insurers will be brought in only as the size of the attack grows sufficiently large.

$$\beta^i = \begin{cases} 1 & \beta^I < \beta_m^i \\ \frac{\beta_m^i}{\beta^I} & \beta^I \geq \beta_m^i \end{cases},$$

where

β^i = the share of total insured losses born by insurer i and

β_m^i = the market share of insurer i as measured by its share of total industry premiums in TRIA lines.

Insurer Claim Payments for an Attack of a Given Size

The overall amount of insured losses generated by an attack, the share of insured losses borne by the individual insurer, and the characteristics of the government program for terrorism insurance determine an insurer's expected claim payments:

$$P^i = \begin{cases} \beta^i I & \beta^i I < D^i \text{ and } I < K \\ D^i + c_1(\beta^i I - D^i) & \beta^i I \geq D^i \text{ and } I < K, \\ P_K^i + c_2(\beta^i I - P_K^i) & I \geq K \end{cases}$$

where

- P^i = the claim payment by insurer i for a loss of size L ,
- D^i = insurer i 's deductible under the government terrorism program,
- K = the cap on annual liability for insured losses established by the government terrorism program,
- c_1 = the insurer's copayment for insured losses above its deductible (D^i) until total insured losses industrywide reach K ,
- c_2 = the expected insurer copayment for insured losses when insured losses exceed K ,
- P_K^i = the amount that insurer i pays when industry-insured losses equal K ,
- β_K^i = the percentage of insured losses borne by insurer i when industry-insured losses equal K , and

$$P_K^i = \begin{cases} \beta_K^i K & \text{for } \beta_K^i K < D^i \\ D^i + c_1(\beta_K^i K - D^i) & \text{for } \beta_K^i K \geq D^i \end{cases}.$$

The ratio of P^i to the total insured losses faced by the insurer, $\beta^i I$, represents the fraction of insured losses for the insurer that the insurer will pay, given the government terrorism program. We assume that both WC claims and property claims against the insurer are reduced by this ratio. Thus,

$$\begin{aligned} P_{wc}^i &= \frac{P^i}{\beta^i I} \beta^i I_{wc} = \frac{P^i}{I} I_{wc} \\ P_p^i &= \frac{P^i}{\beta^i I} \beta^i (I_{p,CBRN} + I_{p,conv}) = \frac{P^i}{I} (I_{p,CBRN} + I_{p,conv}), \end{aligned}$$

where

- P_{wc}^i = payments on WC claims by insurer i for a loss of size L and
- P_p^i = payments on property claims by insurer i for a loss of size L .

Cost of Writing Terrorism Coverage

An insurer's cost of writing terrorism coverage includes the expected payments multiplied by an expense factor that reflects the cost of writing policies and adjusting claims. The cost also

includes the cost of the capital needed to ensure, with a given probability, that the insurer has enough resources to finance claim payments should payments exceed expected payments.³ The insurer selects this planning probability, with a lower probability implying that the insurer must obtain more capital:

$$\begin{aligned} C_{wc}^i(D^i, c_1, c_2^e, K, p^e) &= hE_{wc}^i + \lambda(P_{wc, p^e}^i - E_{wc}^i) \\ C_p^i(D^i, c_1, c_2^e, K, p^e, \gamma_{conv}, \gamma_{CBRN}) &= hE_p^i + \lambda(P_{p, p^e}^i - E_p^i), \end{aligned}$$

where

- C_{wc}^i = the cost to insurer i to support terrorism coverage on its WC policies,
- C_p^i = the cost to insurer i to support terrorism coverage on its property policies given the specified take-up rates for terrorism coverage on property policies for conventional and CBRN attacks,
- h = the expense factor ($h \geq 1$),
- λ = the cost of capital ($\lambda > 0$),
- P_{wc, p^e}^i = WC payments by insurer i when the exceedance probability is p^e ,
- P_{p, p^e}^i = property claim payments by insurer i when the exceedance probability is p^e ,
- E_{wc}^i = expected WC payments by insurer i from terrorist attacks,
- E_p^i = expected property payments by insurer i from terrorist attacks,

$$E_{wc}^i = \sum_{j=1}^{5,099} p_j P_{wc, j}^i, \text{ and}$$

$$E_p^i = \sum_{j=1}^{5,099} p_j P_{p, j}^i.$$

The reader will note that the amount of government payments under TRIA that is recouped from policyholders does not enter the insurer cost function. Such reimbursements are financed by policyholder surcharges (surcharges on commercial property and casualty policyholders, not just those having purchased terrorism coverage), and we ignore the effect of such surcharges on the demand for insurance.⁴ Thus, insurer costs for terrorism coverage are not affected by government decisions on what portion of its outlays to recoup from policyholders.

The fire-following regulations in some states mean that insurers will be subject to some claims on property policies for losses due to terrorist attacks, whether or not policyholders

³ For literature motivating this approach, see Harrington and Niehaus (2004, pp. 82–89 and 146–147), who discuss the value of holding capital to reduce the probability of insolvency from claim costs exceeding insurer assets; Dong, Shah, and Wong (1996, p. 213), who present capacity-based pricing formulae that are a linear function of expected loss and the standard deviation or variance of losses; and Cummins (1991, pp. 267–272), who discusses situations in which an insurer will charge expected loss plus a premium to establish a buffer fund needed to mitigate the risk of ruin.

⁴ We are also ignoring any management costs incurred by insurers in collecting the surcharge that might be passed on to policyholders through higher rates.

purchase terrorism coverage. (WC policies, in contrast, always cover terrorism losses.) Consequently, some costs of terrorism coverage should be attributed to property policies regardless of whether additional terrorism coverage has been purchased, and other costs should be attributed to the costs of additionally purchased terrorism coverage. To determine the cost attributable to the separate terrorism coverage, we first determine the cost of terrorism risk for property policies assuming that the take-up rate for terrorism coverage is zero. Then, we calculate the cost when the take-up rate for explicit terrorism coverage is set at the value assumed for the insurer. The difference between the two costs is the cost attributable to the terrorism policies.

Effect of Change in Government Program on Take-Up Rates

We now use the cost model to estimate the impact of a change in government intervention (with the 2007 version of TRIA as the base case) on take-up rates. We first describe the method for calculating the change in take-up rate from the change in costs. We then detail the parameter ranges used to construct the scenarios for the take-up rate analysis, followed by the methods used to parameterize the three government interventions. We move on to describe how the existing literature on take-up rates with and without TRIA is used to calibrate the model and, finally, how the model is used to project take-up rates with a mandatory CBRN offer.

Calculating Change in Take-Up Rate from Change in Costs

Insurers are assumed to set the premium required equal to the cost projected from the cost model, and an elasticity of demand is used to translate the percentage change in cost for property policies to the percentage change in the take-up rate on property policies.⁵ In the case of allowing TRIA to expire, the change in take-up rate is derived using the following:

$$\frac{\gamma_{conv}^{NoProg} - \gamma_{conv}^{TRIA}}{\gamma_{conv}^{TRIA}} = \varepsilon_d \frac{C_p^{NoProg} - C_p^{TRIA}}{C_p^{TRIA}},$$

where

- C_p^{NoProg} = the premium required by insurers when parameter values are set to reflect the absence of any government intervention in the terrorism insurance market,
- C_p^{TRIA} = the premium required by insurers for property policies when parameter values are set to reflect the 2007 TRIA program, and
- ε_d = the elasticity of demand for the inclusion of terrorism coverage on property policies.

⁵ The costs used to calculate the percentage change in costs are those that represent the cost of explicit terrorism coverage. Changes in costs that are spread across all property policies from fire-following regulations have been netted out. Setting the premium required equal to the cost of providing the coverage is equivalent to average cost pricing.

The change in the cost of providing terrorism insurance from a change in government intervention (and, consequently, the implied change in take-up rate) is calculated at the take-up rate observed under TRIA. Figure D.1 helps to explain the implications of this approach in the case of allowing TRIA to expire. The demand for terrorism insurance on property policies from insurer i is represented by the downward-sloping demand curve. The supply curve under TRIA is represented by the line S_{TRIA} . The firm supply curve in this model would be flat (average cost would be constant) were it not for the TRIA deductible and the industry cap. Simulation of the cost model over a range of parameter values suggests that the average cost curve slopes slightly downward. By fixing the take-up rate at the values observed for TRIA in calculating the change in cost, we are estimating the change in price (and the implied change in take-up rate), using the distance AB in the figure. If the supply curve is downward sloping, the change in price would be larger (CD) according to this model, and, thus, the change in take-up rate would be larger than predicted. Our analysis, however, suggests that, because the supply curve slopes downward only gradually, CD is not likely too much larger than AB and that our approach provides a good first-order approximation of the change in take-up rate from a cost increase from C to D.

Parameter Ranges Used to Construct Scenarios for Take-Up Rate Analysis

The change in take-up rate is calculated for a large number of plausible futures. Each of these futures is characterized by a particular set of values for the parameter listed in Table D.1. The ranges considered for each of the parameters are included in the table (also reproduced in Table

Figure D.1
Approach Used to Calculate Change in Take-Up Rate

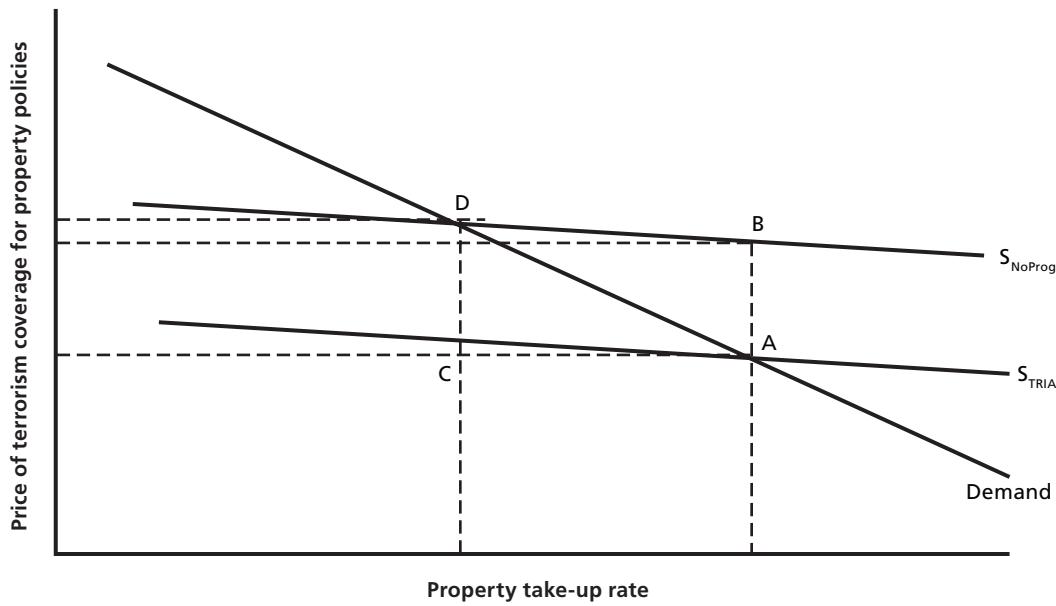


Table D.1**Parameter Values Varied in Experimental Design That Determine Change in Take-Up Rate**

Parameter Name	Symbol	Range	Basis for Range
Property take-up rate under TRIA for conventional attacks	γ_{conv}	[0.55, 0.65]	Surveys by U.S. Department of the Treasury and public reports by insurance brokers
Property take-up rate under TRIA for CBRN attacks	γ_{CBRN}	[0.03, 0.10]	Surveys by U.S. Department of the Treasury and the Risk Insurance Management Society
Exceedance probability used in insurer planning	p^e	1%, 0.1%, 0.01%, \$500 billion event	Wide range of plausible values
Elasticity of demand	ε_d	[-0.975, -0.325]	Study by the Wharton School
Expense factor	h	[1.43, 2.0]	Typical expense factors observed in insurance
Cost of capital	λ	[0.05, 0.25]	Range of plausible values
Insurer copayment above program cap	C_2^e	[0, 0.75]	Range of plausible values
Insurer's market share	β_m^i	0.05	Not allowed to vary; varying value makes little difference

C.1 in Appendix C) and discussed below. Appendix G discusses the methods for selecting the scenarios.

Take-Up Rate on Property Policies Under TRIA for Conventional Attacks. The range for the conventional take-up rate for property policies, 55 percent to 65 percent, is based on a variety of estimates in the literature. The insurance broker Marsh reported a 58-percent take-up rate for its clients (which are predominantly large companies) for policy renewals and purchases in 2005 and a 64-percent take-up rate in the fourth quarter of 2005 (Marsh, 2006, p. 7). Aon Corporation, an insurance broker that also serves large clients, put the take-up rate at 59 percent during the first two quarters of 2005 (Aon Corporation, 2005, p. 26). Based on a nationwide survey of policyholders, the U.S. Department of the Treasury found that 58 percent of policyholders purchased some amount of terrorism coverage in 2004 (U.S. Department of the Treasury, 2005, p. 84).

Our analysis of the effects of TRIA expiring takes the 2007 version of TRIA as the base case, but the take-up rates discussed here apply to 2005 and 2003. The insurer deductible and copayment increased between 2005 and 2007, tending to push terrorism costs up. However, the insurer deductible declined between 2005 and 2007 because the 2005 extension of TRIA

narrowed the insured lines covered by TRIA.⁶ We used the cost model to analyze the effect of these changes on insurer costs and found that the opposing factors roughly cancelled each other out.⁷ Thus, it seems reasonable to set the take-up rates in 2007 to those observed in 2005.

Take-Up Rate Under TRIA for CBRN Attacks. The range of CBRN take-up rates, 3 percent to 10 percent, is also based on empirical data. Based on policyholder surveys, the treasury department found that less than 3 percent of policyholders reported CBRN coverage in lines other than WC in 2003, 2004, and 2005 (U.S. Department of the Treasury, 2005, p. 106). A survey of corporate risk managers in 2006 done by the Risk and Insurance Management Society found that less than 10 percent of companies had CBRN coverage on property policies (President's Working Group on Financial Markets, 2006, p. 78).

The treasury department survey includes insurance coverage provided by captive insurers and, thus, should, in principle, capture CBRN coverage from all insurance sources (U.S. Department of the Treasury, 2005, p. 88).⁸ Growth in the number of captives since 2005, however, may mean that 2005 estimates of the CBRN take-up rate may understate the take-up rate in 2007. Aon notes that access to CBRN coverage is *the* driving force behind the use of onshore captives (Aon Corporation, 2006, p. 24), and the U.S. Department of the Treasury (2005, p. 88) found that the use of captives for terrorism risk insurance rose from about 3 percent of all policyholders in 2004 to almost 8 percent in 2005. We are not aware of data on how the use of captives has grown since 2005 and, thus, have used the 2005 estimates of the CBRN take-up rate in our analysis.

Exceedance Probability. We selected a range of values that reflects a wide range of insurer behavior. An exceedance probability of 1 percent (1 in 100 chance) usually results in little or no predicted change in take-up rate when TRIA expires, so there was not much point in selecting a higher value. Exceedance probabilities lower by one and two orders of magnitude are also considered. In addition, we project terrorism policy costs when insurers are planning for a \$500 billion event, because some of the insurers we interviewed said that they were concerned about a \$500 billion event. There is, of course, great uncertainty in the exceedance probabilities out in the tail of the loss distribution. Assigning more weight to the very large losses in the RMS model would be equivalent to increasing the exceedance probabilities used in this analysis.

Demand Elasticity. Based on data from Aon, a study by the Wharton School of the University of Pennsylvania estimates that the elasticity of demand for terrorism insurance (percentage change in the amount of terrorism coverage purchased divided by the percentage change in price) is -0.65 (Kunreuther and Michel-Kerjan, 2005, p. 178). While Wharton reports that its estimate is statistically different from zero, it gives inadequate information to calculate a statistical confidence interval. Absent better information, we allow the demand elasticity to rise

⁶ Commercial automobile insurance, burglary and theft insurance, surety insurance, professional liability insurance, and farm owners' multiple peril insurance were dropped from TRIA by the Terrorism Risk Insurance Extension Act (President's Working Group on Financial Markets, 2006, p. 12).

⁷ Specifically, we found that the cost of providing terrorism coverage predicted by the cost model described here was very similar for the 2005 and 2007 versions of TRIA.

⁸ A *captive insurer* is an entity formed primarily to insure or reinsurance the risk of one or a small number of policyholders.

and fall 50 percent from this point estimate. The resulting range for this parameter is -0.975 to -0.325 .

Expense Factor. The expense loading for underwriting and loss adjustment expenses ranges from about 30 percent to 50 percent of premiums across a wide range of insurance lines (Harrington and Niehaus, 2004, p. 146). Because of the long tail of the exceedance probability curve for terrorism risk, we apply this factor to the expected loss as opposed to the sum of expected loss and the cost of the capital needed to protect against the possibility that actual losses exceed expected losses. Converting from a proportion of premium (which includes expense) to a multiple of the expected loss results in an expense factor that ranges from 1.43 to 2.0.⁹

Cost of Capital. The long-term return on a diversified portfolio of stocks is generally thought to be around 10 percent, and there is research that suggests that insurers' cost of capital could be in the range of 5 to 10 percent (Michel-Kerjan, 2007). We thus chose 5 percent as the lower bound for the cost of capital that insurers secure to protect themselves against the possibility that actual losses exceed insured losses. Hedge funds often aim for returns of 20 to 30 percent and are already active in providing capital for terrorism insurance markets. It is thus plausible that the cost of capital could go as high as 30 percent. Our analysis assumes that insurers need to reserve capital specifically for terrorism risk. However, if they have risks in their portfolio that are less than perfectly correlated with terrorism risk (which seems likely), they would presumably be able to cover different types of risk with the same capital. Thus, even if insurers have to pay high rates for capital, the effective rate may be considerably lower (moving toward the low end of our range) if the capital supports multiple risks. Given the likelihood that capital can cover different risks to some extent, we set the upper bound on the cost of capital at 25 percent.

Insurer Copayment over TRIA Program Cap. There was considerable disagreement among the insurers we contacted during this study about whether insurers face any liability for insured losses over the \$100 billion TRIA cap. Some thought that the statute establishing the program very clearly stated that insurers would have no liability. Others believed that, despite the cap, insurers will be required to pay some fraction of the insured losses over \$100 billion. They pointed out that the statute states, "Congress shall determine the procedures for and the source of any payments for such excess insured losses" (Public Law 107-297, Section 103[e][3]) and that Congress could conceivably impose taxes on insurers to cover the loss. They also questioned whether the statute fully preempts claims that might be made in state court against insurers that do not pay all insured loss from an attack. In particular, they pointed to the U.S. Department of the Treasury's comment (the department administers the TRIA program) during the rulemaking process that the preemption language in the statute does not apply to WC claims (U.S. Department of the Treasury, 2004).

In our analysis, we vary the proportion of insured losses over the cap that insurers will pay from 0 to 0.75. The lower end of the range reflects views that the cap is truly hard and that insurers have no responsibility for losses over the cap. It seems unlikely that insurers would end

⁹ If the expense loading as a fraction of combined expenses and expected losses is x ($0 < x < 1$), then expenses are $1/(1-x)$ of expected losses.

up paying all insured losses over the cap, but possible legal responsibility for all WC claims and the imposition of taxes or a court ruling in favor of policyholders for property claims means that the percentage could be substantial. If insured losses were divided equally between WC and property claims (which is the case for some of the attacks examined in this study) and insurers end up paying all WC claims and half the property claims over the cap, the insurance industry could end up paying our assumed maximum 75 percent of insured losses over the cap.

Parameterization of Different Government Interventions

Parameters that characterize government intervention in the terrorism insurance market are varied to project the change in take-up rate in each plausible future. Table D.2 shows the parameters that characterize each of three interventions examined. The parameters for TRIA reflect the 2007 version of TRIA, as described in Appendix C. Expiration of TRIA eliminates the deductible, government copayment for losses, and the program cap. The take-up rate on property policies for CBRN attacks is not tied to the take-up rate for conventional attacks.

Enhancement of TRIA to include a mandatory offer of CBRN coverage leaves the remaining structure of TRIA unchanged. Thus, all the program parameters remain at their TRIA values except the take-up rate for CBRN coverage. The take-up rate for CBRN attacks is set equal to the take-up rate for conventional attacks.

Calibration of the Model

The chart in Chapter Two titled “Model Estimates a Wide Range of Take-Up Rates on Property Policies If TRIA Expires” shows the projections of take-up rate for property coverage with and without TRIA across the 2,000 futures examined for each attack. Note that, for some futures, the take-up rate does not decline at all (the points on the 45-degree line), but, in others, it declines substantially. The points on the chart represent all the futures examined. We also examined performance using only those 866 futures that produce the changes in take-up rate suggested by previous empirical studies on the effect of TRIA expiring. (See the subsequent chart, titled “We Focus on the Range of Take-Up Rates Consistent with Estimates in

Table D.2
Parameters Affected by the Government Intervention

Parameter Name	Symbol	2007 TRIA	No Government Program	Mandatory CBRN Offer
Insurer deductible	D^i	20% of 2006 direct earned premium in TRIA lines	0	20% of 2006 direct earned premium in TRIA lines
Insurer copayment below program cap	c_i	0.15	1	0.15
Program cap	K	\$100 billion	Infinity	\$100 billion
CBRN take-up rate	γ_{CBRN}	Not tied to conventional take-up rate	Not tied to conventional take-up rate	Set equal to conventional take-up rate

the Literature.") Doing so is a way of calibrating the model. It restricts attention to those sets of parameter values (e.g., the exceedance probability that insurers use to determine the amount of capital they must hold to cover losses) that produce the change in take-up rate estimated by empirical studies.

Four studies provide some empirical evidence on how take-up rates might fall if TRIA were to expire. We summarize the results of each study and then draw on the results to set the range used in our analysis for the decline in take-up rate should TRIA expire.

In 2005, Aon analyzed insurance policies with terms that extended beyond TRIA's original December 31, 2005, expiration date. Aon found that absolute or substantial coverage sub-limits for terrorism coverage were being imposed on 70 percent or more of available capacity for insurance with terms beyond December 31 (or that 30 percent of capacity would include terrorism coverage even if TRIA expired) (Aon Corporation, 2005, pp. 21–22). As discussed, Aon estimated that take-up rates under TRIA were roughly 60 percent, so a decline to 30 percent represents a 50-percent decline in take-up rates.

In the last wave of their survey of insurers, the treasury department asked whether policies written or renewed in the first two months of 2005 incorporated coverage for international terrorism in 2006 that was roughly similar to the coverage they provided in 2005. (Insurers were requested to restrict their attention to policies that did include terrorism coverage in 2005.) Given that policies typically run for one year, the responses provide insight into insurers' willingness to write terrorism coverage in TRIA's absence. The survey results suggest that take-up rates for terrorism coverage would fall from 38 percent to 50 percent (U.S. Department of the Treasury, 2005, p. 76).

David Cummins, a leading author on insurance issues, inferred how TRIA's expiration would affect take-up rates by comparing take-up rates for foreign acts of terrorism (covered by TRIA) with take-up rates for domestic, or so-called *noncertified*, acts of terrorism (not covered by TRIA). He noted that approximately 90 percent of insurers wrote coverage for foreign acts of terrorism in 2002 through 2004, while 40 percent wrote coverage for domestic attacks. Given that domestic terrorism events are generally viewed as less risky than foreign attacks, he concluded that, if TRIA expired, no more than 40 percent of insurers would offer coverage for foreign attacks (Cummins, 2006, p. 370). If this decline applies evenly across insurers of all sizes, take-up rates would be expected to fall by 56 percent.

A Mortgage Bankers Association survey of commercial and multifamily mortgage lenders provides a final piece of evidence about how take-up rates would decline if TRIA were to expire. Based on survey responses, the association projected that the proportion of loan balances covered by terrorism coverage would fall by 76 percent if TRIA were to expire (Mortgage Bankers Association, 2004).

Estimates of the percentage decline in take-up rate that would result if TRIA expired range from 38 to 76 percent in the four studies reviewed.¹⁰ The spread in the estimates reflects both the different methods used and the many uncertainties underlying the issue. Substantial

¹⁰ Studies on the impact of TRIA's expiration on take-up rates are all based on the expiration of the 2005 version of TRIA. However, as discussed above, we expect the take-up rate under the 2005 and 2007 versions of TRIA to be comparable. Thus, the findings of these studies should apply to the expiration of the 2007 version of TRIA.

uncertainty remains over how TRIA's expiration would affect take-up rates; to balance out the estimate (from the Mortgage Bankers Association) that is substantially higher than the other three, we set the range over which the take-up rates fall from 25 to 75 percent.

Projecting Change in Take-Up Rates for TRIA with a Mandatory CBRN Offer

We predict changes in take-up rate when TRIA is extended to require the mandatory offer to include CBRN coverage for the entire ensemble of 2000 futures examined for each attack, as well as only those that produced the 866 changes suggested by empirical studies if TRIA were to expire. The latter set of futures allows one to project the impact of requiring a mandatory CBRN offer if one believes that allowing TRIA to expire would cause the take-up rate for property policies for conventional attacks to fall by 25 to 75 percent.

The change in take-up rate if TRIA is modified to require a mandatory CBRN offer is calculated by comparing the cost of terrorism coverage on property policies at the observed take-up rates for conventional and CBRN coverage (0.55–0.65 for conventional and 0.03–0.10 for CBRN), with the cost if the CBRN take-up rate rises to the same level as the take-up rate for conventional coverage under TRIA (0.55–0.65). As illustrated in Figure D.1, this approach for calculating the change in take-up rate ignores the possibility of a downward-sloping curve. Consequently, our estimates will tend to underestimate the decline in take-up rate. Our assumption that the demand curve does not shift when CBRN coverage is added, however, will tend to cause our estimates to overstate the decline in take-up rate. The demand curve in Figure D.1 depicts demand for terrorism coverage for conventional attacks. It is reasonable to expect that policyholders would be willing to pay more for an insurance policy that covers both conventional and CBRN attacks and, thus, for the addition of CBRN coverage to shift the demand curve upward. While such a shift would mute the effect of increased prices on take-up rate, the question is by how much.

We think it plausible that the upward shift in the demand curve will not be large relative to the change in cost and, thus, that ignoring it will not have a substantial impact on our findings. First, previous work suggests that the demand for CBRN coverage is not great. A 2004 survey of policyholders by the U.S. Department of the Treasury found that only 3 percent of policyholders purchased coverage for CBRN attacks and that the primary reason policyholders gave for not purchasing CBRN coverage was that they believed that they were not at risk.¹¹ The widespread perception among policyholders that they are not at risk suggests that the inclusion of CBRN coverage would not lead to a substantial upward shift in the demand curve.

Second, the low take-up rate for CBRN coverage suggests that, for a large number of policyholders, the price of CBRN coverage is high relative to the perceived value of the coverage. Thus, it seems reasonable to expect the increase in price caused by adding CBRN coverage to conventional coverage would be large relative to the upward shift in demand caused by augmenting the coverage. Again, the implication is that ignoring the shift in demand is not likely to have a major impact on our findings.

¹¹ Among those policyholders responding to the question, 62 percent reported that a major reason for not purchasing terrorism coverage was that they were not at risk (U.S. Department of the Treasury, 2005, pp. 106–107).

Risk Management Solutions Attack Model

We use RMS' Probabilistic Terrorism Model to provide the data for the terrorist attack scenarios in Chapter One. The RMS model was developed primarily for use in the insurance industry to assist property and casualty insurers manage their exposure to catastrophic terrorism loss. The model estimates the risk from a wide range of potential terrorist attack scenarios and can be applied at any scale, ranging from an individual building to the entire country. The model computes the terrorism risk from the overall probability of an attack occurring, the relative likelihood of thousands of individual attack scenarios, and the consequences of each scenario.

The RMS model estimates the consequences, in terms of property damage and casualties, of various potential terrorist attacks based on the modeling of weapon effects and geocoded databases of structural characteristics of targets, population densities, human activity patterns, business activities, and the values of buildings and their contents. RMS estimates the overall probability of attack and the relative likelihoods of different types of attacks at different targets using expert judgment about capabilities and objectives of terrorist groups, terrorist target selection, capability requirements for different attack modes, and propensity to stage multiple coordinated attacks. This appendix provides an overview of the RMS model. Additional information can be obtained from the RMS Web site (RMS, undated) or by contacting RMS directly.

Model Scope

The loss estimates in the RMS model focus on those losses that are normally eligible for insurance. Thus, the baseline estimates used in this study exclude losses that are not normally covered by insurance but may nonetheless be of interest to government policymakers, such as indirect economic losses (e.g., business losses resulting from decreased sales) and losses to entities that are typically self-insured (government property and employees). In addition, the losses modeled by RMS are restricted to those covered by commercial property and WC policies; the RMS model does not consider losses to noncommercial property (e.g., single-family homes and automobiles owned by individuals), nonemployee casualties (e.g., business patrons in stadiums, hotels, transportation systems, shops, or restaurants; visitors; passers-by; people at home; people at school), psychological damage, or liability losses.

Estimating Attack Consequences

RMS estimates loss for a wide variety of terrorist attack modes against a wide variety of target types. The loss estimate in each of these terrorist attack scenarios represents the total monetary loss from terrorist attacks, independent of the fraction of the total loss that insurance actually covers. Total terrorism losses estimated by the model include the sum of the replacement value of the property lost or damaged, the replacement value of the building contents lost, business interruption losses that would normally be eligible for insurance coverage, and WC insurance payments for employee death or injury. Property, contents, and business interruption losses are based on values estimated on an individual-property and individual-business basis and are collectively referred to as *property losses* in our analysis. WC losses are based on the distribution of casualties across six severity categories and average WC insurance payments for each category in the state in which the attack occurs.

The consequences of each of these terrorist attack scenarios are estimated from three components: weapon effects, target characteristics, and exposure characteristics. Weapon effects comprise the type of weapon, delivery mechanism, the hazards to people and property, and the spatial and temporal footprint of those hazards. A 600-pound bomb, for example, is detonated in a car, and damage occurs from blast pressure waves and debris impact that extends for tens of meters around the blast site.

The RMS model considers 37 attack modes. Table E.1 provides a brief description of some general attack mode categories. For each attack mode in the model, RMS has developed physical event models that generate a hazard footprint that specifies a hazard-level estimate as a function of location around the attack site. The size of the hazard footprint can vary from less than 100 meters (e.g., for a small bomb) to several hundred square kilometers (e.g., for a nuclear or outdoor biological attack).

The RMS model also includes 35 target types that are divided into eight groups representing distinct levels of threat. Table E.2 lists the target types included in each group.

Target characteristics include a number of building characteristics, such as height, number of stories, year built, and construction type, that influence the attack consequences. Characteristics may also include other factors specific to a particular target type. These target characteristics help define the vulnerability of people and structures to the hazard imposed by the weapon. For example, newer steel buildings will suffer less damage from a bomb than will older masonry buildings. Building characteristics are compiled from multiple sources, including data from the Sanborn Map Company.¹

Attack exposure refers to the population and additional structures that an attack impacts. The exposure includes the number and spatial distribution of people within the hazard footprint, as well as (for insurance loss calculation purposes) their occupational status and age distribution. The exposure also accounts for the characteristics and density of structures within the hazard footprint. Along with those of the target itself, the exposure's characteristics determine the losses from an attack in terms of the casualty distribution and property damage.

¹ The Sanborn Map Company maintains spatial coordinates and numerous attributes for buildings in major metropolitan areas in more than 21 cities across the United States.

Table E.1
Modes of Attack Modeled in the RMS Terrorism Risk Model

Attack Mode Category	Description of Attack Scenarios in Model
Surface-to-air missile	Commercial 747 airliner shot down
Bomb	600 lb, 1 ton, 2 ton, 5 ton, and 10 ton
Aircraft impact	Hijacked 747 commercial airliner flown into a target
Conflagration	9,000-gallon gasoline tanker hijacked and set on fire
Sabotage: industrial, explosion	5-, 50-, and 150-ton TNT equivalent
Sabotage: industrial, toxic release	5%, 40%, and 100% of Bhopal accident
Sabotage: industrial, explosion + release	5 ton + 5% Bhopal; 50 ton + 40% Bhopal; and 150 ton + 100% Bhopal
Sabotage: nuclear plant, radiation release	0.5%; 5%; and 20% of inventory
Dirty bomb: cesium 137	1,500 Curies and 15,000 Curies
Chemical: sarin gas	Indoors: 10 kg; outdoors: 10 kg, 300 kg, and 1,000 kg
2% anthrax slurry released outdoors	1 kg, 10 kg, and 75 kg of slurry
Weaponized anthrax released indoors	40 g of weaponized anthrax
Smallpox	10, 100, and 1,000 initially infected
Genetically engineered smallpox	100 and 1,000 initially infected
Nuclear bomb	1 kiloton and 5 kiloton

Table E.2
RMS Target-Type Groups

Target-Type Group	Target Types
1	Government buildings
2	Business districts, skyscrapers, stock exchanges, hotels and casinos, airports, and nuclear power plants
3	Military, train and subway stations, stadiums, and bridges and tunnels
4	Industrial facilities, oil and gas refineries, tourist attractions, shopping malls, restaurants, and ports and ships
5	Media headquarters, Fortune 100 companies' headquarters, theaters, major entertainment centers, and gas stations
6	Cruise ships, apartment buildings, foreign consulates, and the United Nations
7	Water reservoirs and distribution systems, passenger trains, and airspace zones
8	Power plants other than nuclear, dams, and railway networks

Estimates of the number and demographics of building occupants are derived from local census data, journey-to-work data, building-use type, and building size. The number of occupants is

also adjusted to account for the time of day. We examined the effects of midafternoon, weekday attacks. Most types of buildings would be most fully occupied at this time; therefore, our estimates reflect the worst case in the sense of the number of people exposed to the attack.

The model converts damage from an attack into losses in the form of casualties and property damage. The model provides estimates of the number of victims in each of six casualty categories: medical only, temporary total disability, permanent partial minor disability, permanent partial major disability, permanent total disability, and fatality. These categories correspond to the standard WC injury categories and are defined in the same way.

Property damage in the RMS model includes replacement value of damage to buildings and building contents and business interruption losses. Building and building content losses represent the replacement value of damage to structures. Business interruption losses represent losses resulting from a civil authority exclusion zone around the incident site; this includes only losses from business closure and does not include indirect losses such as decreased sales.

Estimating Attack Probability

In addition to estimates of each attack scenario's consequences, RMS also provides estimates of its likelihood. Given the deep uncertainty in these likelihood estimates, we use them in this study primarily for two purposes. First, we use them to inform the take-up rate model's representation of industry's expectations about future losses.² Second, we use these likelihood estimates to inform judgments about the trade-offs among the three government interventions. For instance, our analysis suggests that the cost to taxpayers under TRIA may be larger than the cost if TRIA expires only for attacks with total losses greater than approximately \$40 billion. The RMS likelihood estimates suggest that the odds of such an attack are very small.

The RMS model bases its likelihood estimates on subjective judgments by experts (Morgan and Henrion, 1990). This is necessary because, fortunately, terrorist events have occurred infrequently compared to accidents and natural disasters. Given this sparse record, as well as the complex and dynamic social origins of terrorism, terrorism threat lacks a phenomenological basis from which to model attack probabilities quantitatively. This makes it difficult to use the historical patterns of terrorism to estimate future attack likelihoods.

The RMS model uses expert judgment to assess both the relative likelihoods of various attack scenarios and the overall attack probability. Values for both the absolute attack probability and the relative likelihoods of individual scenarios are derived through a structured expert elicitation process that is informed by terrorist attack histories and contextual trends such as mentions of particular cities and targets in terrorist groups' media. Expert elicitation conferences are held twice each year to ensure that probability profiles are consistent with the most current information and analysis. Details of how this process is carried out can be obtained from RMS.

² Much of the industry, in fact, uses the RMS model to help inform its decisions about what terrorism coverage to offer.

Overall Probability of Attack

RMS develops the overall annual probability of a terrorist attack occurring from several components:

- the probability that a terrorist attack of any kind will occur in the next year
- the probability that, if an attack occurs, it will be a single attack or a set of coordinated attacks
- the probability that, if an attack occurs, there will be other attacks within the year
- the probability that an attempted attack will be successful.

RMS develops three probability estimates for different assumptions about the terrorist threat level. These estimates reflect differing interpretations of available intelligence and consider terrorist group capabilities and objectives, access to particular weapon types, and effectiveness of counterterrorism efforts. The three threat outlooks are summarized below (RMS, 2003).

- **Reduced Threat Outlook:** Optimistic interpretations of the available intelligence that imply a low risk of terrorism loss in the United States. Al Qaeda attack probability is assumed reduced from its long-term, historical average. Less destructive attack modes are more likely, and the chance of an al Qaeda CBRN attack is negligible. Other foreign threat groups will not be active.
- **Standard Threat Outlook:** Best assessment of the risk of large-scale terrorism loss in the United States throughout the year, resulting from all known terrorism threat groups. Probability of attack from al Qaeda is below its long-term, historical, worldwide average. Medium-scale attack modes predominate, and the chance of a CBRN attack is small. There is the additional possibility of attacks from other foreign threat groups.
- **Increased Threat Outlook:** Pessimistic interpretations of the available intelligence that imply a heightened risk from terrorist loss in the United States during the year. Probability of an al Qaeda attack is assumed similar to its long-term, historical average. Destructive attack modes are likely, and the chance of an al Qaeda CBRN attack is significant. There is the additional possibility of attacks from other foreign threat groups.

Relative Likelihoods of Attack Scenarios

Several factors influence the relative likelihoods of terrorist attacks in the RMS model. These factors can be classified into four components:

- the relative likelihood that any particular city will be attacked
- the relative likelihood that any particular target type will be attacked
- the relative likelihood that any specific target will be attacked because of its inherent iconic value or security
- the relative likelihood that any particular mode will be used in an attack.

Relative likelihoods define the probability that, if an attack happens, it will be in a particular place, of a particular type, on a particular target type, and, in some cases, on a particular target.

City Tier Likelihood. The RMS model groups cities into eight tiers according to relative likelihood of attack. The terrorist attack risk in the RMS model is heavily concentrated in a small number of cities, illustrated by the fact that the likelihood of attack in a city not ranked in the top 10 is estimated to be less than 11 percent.

Target Type and Individual Target Likelihoods. As with cities, RMS bins target types into separate groups according to the relative likelihood of attack using the target types shown in Table E.2. The RMS model also provides the ability to incorporate attack likelihoods for specific individual targets based on their iconic value and security status. The iconic value parameter allows the attack likelihood for individual, high-profile targets, such as iconic buildings, to be increased. Conversely, the security parameter allows the attack likelihood for individual targets with particularly high security, such as the White House, to be decreased. In general, however, this feature is largely unutilized in the RMS model because the specific information needed to assess these parameters for individual buildings is not available. That is, nearly all targets of a given target type are assigned the same iconic value and security levels.

Attack Mode Likelihood. The RMS model also assigns each attack mode, such as those shown in Table E.1, a relative likelihood based, in part, on each mode's logistics burden. The *logistics burden* is a cost assigned to each mode that reflects skill, labor, time, and financial resource requirements. More resource-intensive modes have a higher logistics burden, which decreases their relative likelihood.

The relative likelihood of a terrorist attack depends strongly on the type of attack being considered. The variation in relative likelihood by attack mode spans several orders of magnitude. This large range in attack mode likelihoods is broadly consistent with the variation in attack mode likelihoods seen in the historical terrorism record (LaTourrette et al., 2006).

Loss Distribution Model

This appendix describes how losses from terrorist attacks are distributed among various parties under the different government interventions examined in this study.

Terrorism Losses Considered

Our loss estimates are based on estimates from the RMS model described in Appendix E. For our purposes, the key characteristics of a terrorist attack include the total insurable losses (hereafter referred to as total loss, L), the distribution of losses between property (L_p) and WC (L_{wc}), and whether the property losses are covered by insurance policies that cover both CBRN and conventional attacks as opposed to just conventional attacks.

To efficiently sample a wide variety of plausible terrorist attacks, we begin with six terrorist attack scenarios from the RMS model (a 1-ton truck bomb, a 10-ton truck bomb, an indoor chemical [sarin] attack, an attack using a radiological device [a dirty bomb], outdoor anthrax attack, and a 5-kiloton nuclear bomb). These six attack scenarios present a wide range of total losses, extending from \$6 billion to \$625 billion (the largest single event in the RMS model); a wide range of property loss as a fraction of the total loss, from 30 percent to 80 percent; and two conventional and four CBRN attacks.

We then scale the losses for each attack over an order of magnitude, so that

$$L_p = s L_p^{RMS}$$

and

$$L_{wc} = s L_{wc}^{RMS},$$

where

$$(1/3) \leq s \leq 3,$$

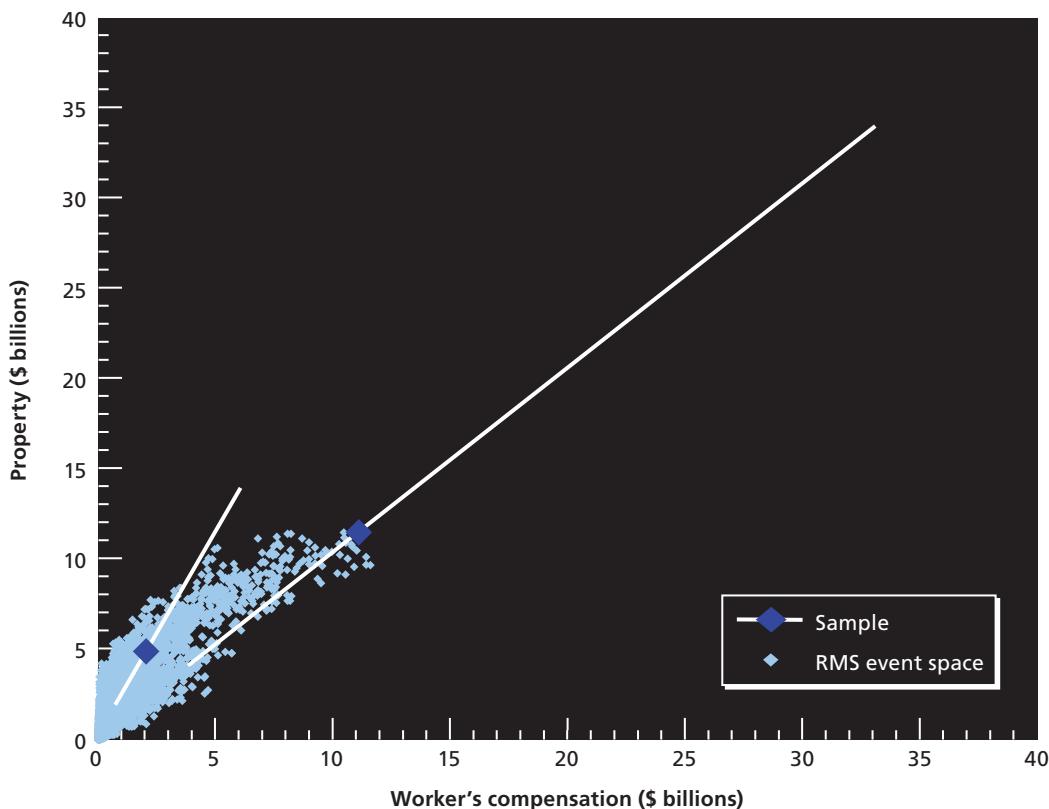
L_p^{RMS} = the total property loss for that attack in the RMS model, and

L_{wc}^{RMS} = the total WC loss for that attack in the RMS model.

The RMS model's estimates of the property and WC losses for each attack represent the mean values of upward-skewed distributions with standard deviations at least as large as their means. Our order-of-magnitude scaling is intended to capture both the uncertainty in the loss estimates for a single attack and, for the larger values, the potential for multiple attacks.

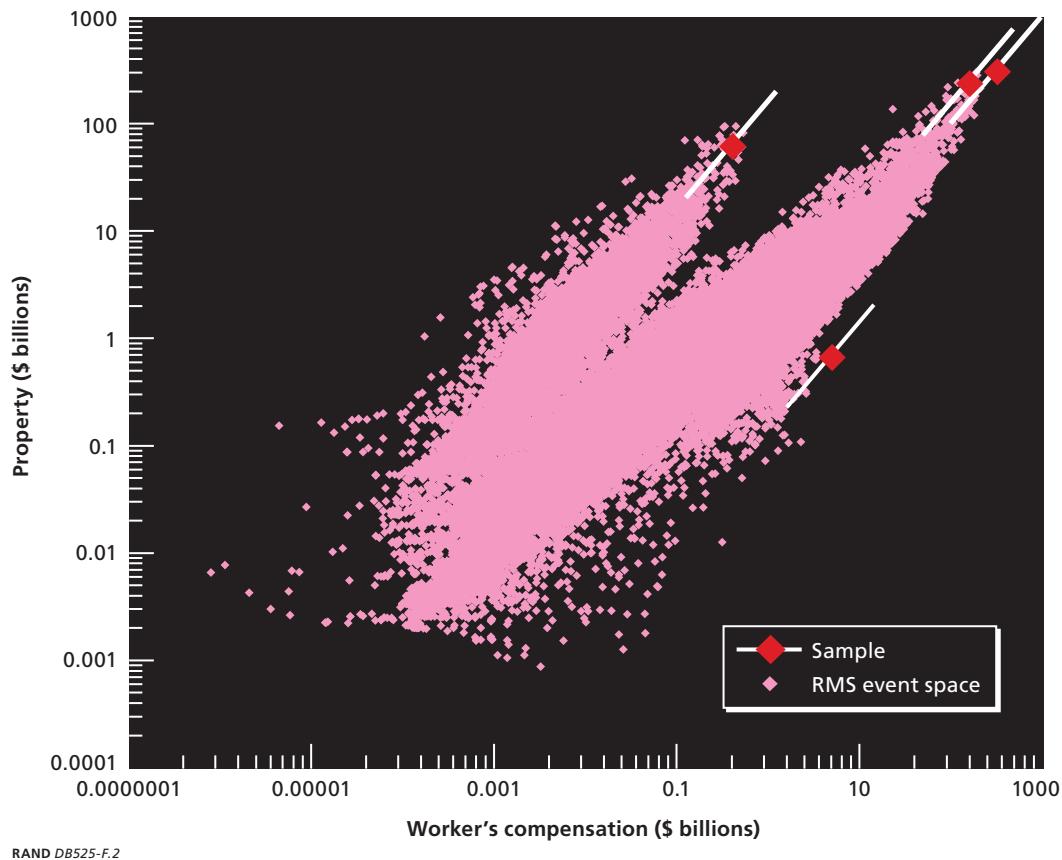
Figures F.1 and F.2 show scatter plots of all the conventional and CBRN attacks in the RMS model. The lines show the range of losses considered in our experimental design as we scale our six cases over the order-of-magnitude range. The range of attacks considered here, with total losses ranging from \$2 billion to \$1,900 billion, seems to adequately cover the ranges of plausible attacks one can infer from the RMS model.

Figure F.1
Range of Conventional Attacks Considered



RAND DB525-F.1

Figure F.2
Range of CBRN Attacks Considered



Insured Losses and Paying Parties

Insured loss is determined from the fraction of losses covered by insurance, known as the *insurance take-up rate*. Generally, insurance take-up rates vary by insurance line and by peril. Our analysis addresses terrorism coverage for WC and commercial property insurance lines. WC insurance coverage is mandatory and does not allow exclusions for specific perils, so the WC take-up rate for all losses, including those resulting from terrorism, is 100 percent. Commercial property insurance coverage may exclude specific perils, and the fraction of commercial property insurance that includes terrorism coverage (γ) is a critical variable in our analysis. This take-up rate γ varies with the intervention being modeled and is determined by the supply-demand equilibrium described in Appendix D.¹

¹ In this appendix, we do use a subscript on take-up rate to denote whether the take-up rate applies to conventional or CBRN attacks. The loss distribution model sets take-up rate according to the mode of the particular attack modeled.

Following the discussion of insured loss in Appendix D and taking account of losses covered by fire-following regulations, total insured loss is

$$I = L_{wc} + (\gamma + (1 - \gamma)f)L_p.$$

The RMS model provides estimates of the fire losses for each type of attack. The fraction of losses resulting from fire for the six attacks considered in this study is listed in Table F.1.

We consider distribution of losses among five parties: (1) private commercial property and WC insurers (insurance industry); (2) owners of uninsured commercial property and uninsured businesses in those properties (uninsured losses); (3) all private commercial property and WC insurance policyholders nationwide (future policyholders); (4) insured commercial property owners, businesses, and employees not receiving insurance payments, either because of insurance company failures or because total insured losses exceed a program threshold (unpaid claims); and (5) taxpayers.

To simplify our analysis, we do not estimate policyholder premiums, policyholder deductibles, or policyholder coverage limits. The effect of this simplification is to effectively lump premiums, deductibles, and losses exceeding coverage limits together with the insurance industry share rather than to separately account for them as an insured's share. As discussed by Carroll et al. (2005), the sum of these loss components is expected to be small compared to the total insurance industry share; therefore, our simplification has little effect on the overall loss distribution.

Below, we describe how losses are distributed among the stakeholders under the different government interventions considered in this study. Note that our model includes the possibility for postevent government compensation of both uninsured losses and unpaid claims under all government interventions considered.

No Government Program

This intervention represents the case in which TRIA is allowed to expire and no new program takes its place. Thus, there is no a priori government involvement or commitment, though the government may end up making postevent compensation. In addition, some fraction of

Table F.1
Fraction of Loss Resulting from Fire

Attack Type	Fraction of Loss Resulting from Fire, f
Nuclear bomb	0.18
Outdoor anthrax	0
Indoor chemical	0
Radiological bomb	0
10-ton car bomb	0.1
1-ton car bomb	0.1

insured losses may go unpaid in large events, because the amount that the insurance industry can pay is limited by the amount of surplus available for paying terrorism claims. Losses are therefore distributed among uninsured, commercial insurers, unpaid claims, and taxpayers. The resulting distribution of losses is summarized below.

Insurance Industry Loss. The insurance industry loss is the insured loss less any unpaid claims. In a large disaster in which the insured loss exceeded the insurance industry surplus, some fraction of insurance claims would not be paid to insureds, because the maximum amount that the insurance industry can pay is limited by the amount of available surplus, Q . In fact, many insurers would go bankrupt and be unable to pay claims long before the insured loss reached the industry surplus (e.g., Cummins, Doherty, and Lo, 2002), but we assume that the insurance industry would nonetheless pay these losses through guaranty funds.² The loss paid by the insurance industry, B , is then given by

$$B = \begin{cases} I & \text{for } I < Q \\ Q & \text{for } I \geq Q \end{cases}.$$

The surplus Q is one of the parameters whose value is varied to create the ensemble of plausible futures used in the RDM analysis. As shown in Table C.1 in Appendix C, our analysis considers a range of values for the available surplus, \$120 billion to \$240 billion, which is 33 percent above and below the current estimate of a \$180 billion surplus for TRIA-relevant lines.³

Uninsured Loss. Uninsured loss is all loss not insured by commercial insurers less any ex post government compensation. Uninsured loss, U , is given by

$$U = (L - I)(1 - g_U),$$

where

g_U = the fraction of the original uninsured loss compensated by the government.

There is a great deal of uncertainty about what fraction of uninsured business property losses (which can include certain business interruption costs) the government would compen-

² In developing the take-up rate model, we used data from ISO to determine the percentage of insurers affected by an attack. This proportion is not relevant here, because guaranty funds can levy assessments on all insurers, not just those that the attack affected. Thus, in our analysis, neither the number of insurers that go bankrupt nor the percentage of insurers affected by an attack influences the insured loss paid by the insurance industry.

³ In 2006, the President's Working Group estimated that the direct earned premium in TRIA lines for 2006 would be \$182 billion (President's Working Group on Financial Markets, 2006, p. 35). Net earned premium (which nets out insurer purchases of reinsurance) was \$436 billion in 2006, suggesting that the TRIA lines accounted for approximately 42 percent of premiums in the property and casualty industry. The property and casualty industry finished 2006 with \$487 billion in surplus (Hartwig, 2007). The surplus attributable to the TRIA lines thus would be on the order of \$180 billion ($0.42 \times \486 billion).

sate. There are numerous examples of federally funded disaster-victim assistance programs that provide compensation specifically for uninsured losses. For example, the World Trade Center Business Recovery Grant Program in Lower Manhattan after the 9/11 attacks provided the equivalent of business interruption and property damage insurance to small businesses that did not carry insurance at the time of the attacks (Dixon and Stern, 2004, p. 115). The Lower Manhattan Development Corporation administered a federally funded program after September 11, 2001, that covered the costs of restoring the private utility infrastructure not covered by insurance or other federal reimbursement (Dixon and Stern, 2004, p. 117). The Small Business Administration makes loans to businesses (of any size) to repair or replace disaster damage to property owned by the business (U.S. Small Business Administration, 2002). Presumably, a business would not take out such a loan for damage that insurance covered. Even though businesses are required to repay these loans, the loans are subsidized, and it is estimated to cost taxpayers \$0.27 per dollar loaned (Dixon and Stern, 2004, p. 109).⁴

There are also numerous examples of postdisaster business assistance that are not tied directly to uninsured loss. These programs are often targeted at economic recovery after an attack. For example, the World Trade Center Job Retention and Creation Program (funded by the U.S. Department of Housing and Urban Development) provided payments to large businesses that created new jobs in Lower Manhattan after the 9/11 attacks (Dixon and Stern, 2004, p. 119). Such programs may not provide direct compensation for uninsured losses, but they may still be linked to uninsured losses: The government may be more likely to adopt such programs and in greater amounts when there are higher uninsured losses.⁵

This discussion shows the existence of a link between uninsured losses and government compensation, but substantial uncertainty exists over the strength of the link. To account for this uncertainty, we allow g_U to vary between 0 percent and 75 percent, as shown in Table C.1 in Appendix C.⁶

Unpaid Claims. Insured victims are responsible for all insured loss not paid by commercial insurers less any ex post government compensation. The value of unpaid claims, V , is given by

$$V = \begin{cases} 0 & \text{for } I < Q \\ (I - Q)(1 - g_V) & \text{for } I \geq Q, \end{cases}$$

⁴ Studies in other settings have not found a strong inverse relationship between insurance and federal disaster assistance. For example, Dixon, Clancy, et al. (2006, p. 71) found some empirical evidence that a higher take-up rate of flood insurance by homeowners was associated with less disaster assistance but that the relationship was not large and was statistically significant only for the relatively small amount of disaster assistance that overlaps with the insurance coverage available from the National Flood Insurance Program.

⁵ Government disaster outlays that are completely independent of uninsured losses (for example, driven only by attack size) would presumably be independent of the particular government intervention in terrorism risk insurance markets and thus provide no basis for distinguishing among the interventions considered in this analysis.

⁶ It seems plausible that the percentage of uninsured losses compensated would rise with attack size. Data are not available to confirm or reject this hypothesis, however, and we do not vary by attack size the proportion of uninsured losses compensated.

where

g_V = the fraction of the unpaid claims compensated by the government.

The fraction of the unpaid claims compensated by the government is one of the parameters varied for our RDM analysis. Although there is little precedent for postevent government compensation of unpaid claims, this is primarily because unpaid claims, even after disasters, are relatively rare. The government might feel strongly compelled to help compensate victims whose claims for insurance that they purchased went unpaid. As shown in Table C.1 in Appendix C, we allow g_V to vary between 0 percent and 75 percent.

Taxpayer Costs. With no government intervention, taxpayers are responsible only for any ex post government compensation for uninsured losses and unpaid claims. Taxpayer cost, T , is given by

$$T = \begin{cases} g_U(L - I) & \text{for } I < Q \\ g_U(L - I) + g_V(I - Q) & \text{for } I \geq Q. \end{cases}$$

TRIA

Under TRIA, the insured loss is shared among insurers, future policyholders, and taxpayers, up to a program cap of \$100 billion. The law does not specify who is responsible for paying insured losses above the \$100 billion cap; in our analysis, these losses are shared among insurers, taxpayers, and unpaid claims. The total losses are thus distributed among uninsured, the insurance industry, future policyholders, unpaid claims, and taxpayers.

Insurance Industry Loss. Under TRIA, the insurance industry pays a portion of the insured loss determined by an insurer deductible and a copayment. Each insurer has a fixed deductible (a fraction of its annual direct earned premium for the previous year in specified commercial property and casualty insurance lines). The aggregate industry payment under TRIA therefore depends on the number and size of insurers suffering losses and on the distribution of losses among those insurers. In general, the more widely spread the losses are among insurers, the greater the industry share.

Modeling the insurance industry share is complicated by the fact that there is no obvious way to predict the distribution of annual terrorism losses among insurers.⁷ The relationship developed in Appendix D is used to project the percentage of the premium base (β^I) affected by the attack. The applicable annual industrywide TRIA deductible, D , for any size insured loss can then be computed by multiplying the total aggregate industry deductible, D_A (20 per-

⁷ The industry share is bracketed by two end members. If a single small insurer incurred all the insured losses from an attack, the deductible would be very small and the industry share would essentially consist of the copayment. If the insured losses were distributed among many large insurers, each insurer's loss could be less than its deductible, in which case the industry would pay the entire insured loss until the insured loss exceeded the aggregate industry deductible (the sum of individual deductibles for all terrorism risk insurers in the nation). The industry share will fall somewhere between these two extremes.

cent of direct earned premium from the prior year in specified TRIA lines, which gives a 2007 aggregate deductible of \$36 billion), by the market share, β^I :

$$D = D_A \beta^I.$$

Before using this deductible to calculate insurer payments following a terrorist attack, it is useful to compare our method for approximating the insurer deductible with the approach used in a recent study by Kunreuther and Michel-Kerjan (2006).

Kunreuther and Michel-Kerjan (2006) use a micro approach for WC coverage that is based on the characteristics of the WC market in the state in which the attack occurs. They distribute property losses across insurers according to the nationwide market share. Our approach is equivalent to distributing losses across insurers in proportion to combined WC and property premiums for policies nationwide.

The two approaches produce somewhat different estimates of the insurer payments following a terrorist attack. For example, Kunreuther and Michel-Kerjan (2006) used WC market-share data by state for the nation's 451 largest insurers to compare insurance industry losses for a \$25 billion bomb attack that occurred in New York City, Los Angeles, or Houston. They found that the industry payments under TRIA following the same attack in each of the three cities varied by about 10 percent, from \$13.1 billion to \$14.5 billion. Our estimate of the industry payments using a single, national market-share model (for WC and property lines subject to TRIA combined) for the equivalent attack and same TRIA parameters and take-up rate is \$17.5 billion (or about 25 percent larger than the midpoint of the Kunreuther–Michel-Kerjan estimate). The Kunreuther–Michel-Kerjan estimate may be lower than ours because the WC markets in the states they examined are dominated by companies that write exclusively WC coverage. Because the TRIA deductible is based on premiums in WC and commercial property lines, companies writing only WC policies will have lower TRIA deductibles for a given WC loss than will companies writing a mix of WC and commercial property policies.

The differences between the two estimates for this attack will likely decline as the approach of Kunreuther and Michel-Kerjan (2006) is extended to more cities. Also, the difference between the two estimates will decline and ultimately reverse as the attack size grows because of the relationship we assume between market share of insurers incurring losses and loss size. We use the ISO model, in which market share initially increases rapidly with loss size and then tapers off and is capped at 70 percent. Kunreuther and Michel-Kerjan assume that all loss is shared among all insurers in the market in proportion to their TRIA direct earned premium (the relevant market is the state for WC losses and the nation for property losses). For a \$40 billion loss, our estimate of insurer losses is between Kunreuther and Michel-Kerjan's estimates for the three cities, and, for a \$100 billion loss, our estimate is 20 percent to 35 percent lower.

There is no way to predict exactly how losses will be distributed among insurers and, therefore, no way to know which relationship (the ISO model or a proportionate distribution of losses across insurers based on the proportion of premiums written in the relevant market) would better model reality. We note, however, that, if the market includes some insurers whose

coverage is concentrated in low-risk properties, then the market share affected by an attack may never reach 100 percent, and the ISO relationship may be more plausible than a proportionate allocation.

All things considered, it is not obvious which of the two approaches yields better estimates for expected insurer payments across all high-risk cities in the United States. Comparison of the two approaches warrants further examination.

Returning to our model of insurer payments, the amount the insurance industry pays toward the deductible, B_D , is then the lesser of the insured loss or D :

$$B_D = \begin{cases} I & \text{for } I < D \\ D & \text{for } I \geq D \end{cases}$$

The industry copayment, I_C , is a fixed fraction of the insured loss above the deductible, with the maximum amount limited by the TRIA cap, K (\$100 billion). B_C is thus expressed as

$$B_C = \begin{cases} c_1(I - B_D) & \text{for } I < K \\ c_1(K - B_D) & \text{for } I \geq K \end{cases}$$

where

c_1 = the industry portion of the shared compensation feature of TRIA (15 percent in 2007).

The nominal total industry share under TRIA, B_T , is the sum of the deductible and copayment:

$$B_T = B_D + B_C.$$

For a total aggregate industry deductible of \$36 billion, B_T is equal to the insured loss for insured losses up to about \$22 billion. Therefore, under TRIA, the insurance industry is responsible for all losses up to \$22 billion.

In our analysis, we allow for the possibility that the insurance industry will be responsible for some fraction of the losses above the program cap. This amount, B_K , is given by

$$B_K = \begin{cases} 0 & \text{for } I \leq K \\ c_2(I - K) & \text{for } I > K \end{cases}$$

where

c_2 = the fraction of insured losses above the program cap that the industry is called on to pay.

The industry copayment for losses above the cap is one of the parameters we vary to create the ensemble of plausible futures used in the RDM analysis. TRIA has never been invoked, so there is no precedent for what action, if any, would be taken to settle claims for insured losses above the cap. In our analysis, we allow for both government and industry to compensate for these losses. The government contribution is included in g_V . As shown in Table C.1 in Appendix C, we allow the industry copayment for losses above the cap to vary from 0 percent to 75 percent.

The nominal insurance industry loss, B_N , is thus given by the sum

$$B_N = B_D + B_C + B_K.$$

Finally, as with no government program, some fraction of the insurance industry loss may not be paid because the industry surplus will be exhausted. The total industry loss is therefore given by

$$B = \begin{cases} B_N & \text{for } B_N < Q \\ Q & \text{for } B_N \geq Q \end{cases}.$$

Uninsured Losses. The uninsured share is all loss not insured by commercial insurers less any ex post government compensation. Uninsured losses are given by

$$U = (L - I)(1 - g_U).$$

Future Policyholder Losses. Under TRIA, the government reimburses each insurer for its loss above its deductible and copayment; then, it recoups all or part of that reimbursement through a surcharge levied on all commercial property and casualty insurers in the country, whether or not they had purchased terrorism insurance. The amount recouped is governed by the “insurance marketplace aggregate retention amount,” R (\$27.5 billion in 2007). The future policyholder surcharge amount, S , is given by

$$S = \begin{cases} I - B_T & \text{for } I \leq R \\ R - B_T & \text{for } I > R \text{ and } B_T \leq R \\ 0 & \text{for } B_T > R \end{cases}$$

For $I \leq R$, S equals the federal reimbursement, and, therefore, the entire federal payout is recouped. When $I > R$ and $B_T \leq R$, the federal payout is only partially recouped, and, if $B_T > R$, none of the federal payout is recouped.

The government recoupment is one of the parameters whose value we vary for our RDM analysis. The government has never had occasion to recoup payments under TRIA, so there is no precedent to guide our choice for this parameter. As shown in Table C.1 in Appendix C, we

thus assume that it can range from \$27.5 billion to \$100 billion, its minimum to its maximum values under the law.

Unpaid Claims. Under TRIA, unpaid claims could arise from (a) insurance industry responsibilities not paid because of surplus limitations and (b) insured loss above the program cap that is not compensated by ex post industry or government compensation. Any industry payments for losses above the cap are included in B . Therefore, the unpaid claims are given by

$$V = \begin{cases} (B_T - B)(1 - g_V) & \text{for } I \leq K \\ (B_T - B + I - K)(1 - g_V) & \text{for } I > K \end{cases}$$

Taxpayer Costs. Under TRIA, taxpayers are responsible for all federal outlays not recouped through the commercial policyholder surcharge, plus any ex post compensation for uninsured losses and unpaid claims. Taxpayer costs are given by

$$T = \begin{cases} I - B_T - S + g_U(L - I) + g_V(B_T - B) & \text{for } I \leq K \\ K - B_T - S + g_U(L - I) + g_V(B_T - B + I - K) & \text{for } I > K \end{cases}$$

TRIA with a Mandatory CBRN Offer

Losses are distributed across the different stakeholders using same methods as described for TRIA. The only difference is the value of the take-up rate.

Robust Decisionmaking Analysis

We conduct an RDM analysis on the model described in the previous sections. The model is constructed in Microsoft® Excel® and exercised using the CARs™ exploratory modeling software.¹

Experimental Design

To conduct the RDM analysis, we use the simulation model to create an ensemble of plausible futures. We choose the ensemble to provide a comprehensive sample of the plausible results from our simulation model, within the constraints of reasonable run times and analysis. We thus seek to constrain the total analysis to roughly 100,000 runs of the simulation model, which consumes about eight hours of CPU time on the Sony® Vaio® computer used for this analysis.

The ensemble of plausible futures consists of two experimental designs, one for conventional and one for CBRN attacks, over the uncertain input parameters in Table C.1 in Appendix C. In addition to exploring different terrorist attacks, the designs differ because in the conventional attack scenarios we compare cases with minimum market retention to those in which market retention can vary and because in the CBRN attack scenarios we compare cases with hard and soft TRIA caps.

For the conventional attacks, the design combines an eight-point, full-factorial sample over the two uncertain integer parameters (attack type with two values and exceedance probability with four values) and two 500-point Latin hypercube (LHC) samples over the real-valued inputs. The first LHC sample varies over all the real-valued inputs. The second LHC sample holds the market retention at its minimum value of \$27.5 billion and varies over the remaining real-valued inputs. The resulting experimental designs have a total of 8,000 points. The LHC sample used in this study provides one of the most efficient means of comprehensively sampling a multidimensional space.

For the CBRN attacks, the design combines a 16-point, full-factorial sample over the two uncertain integer parameters (attack type with four values and exceedance probability with four values) and two 500-point LHC samples over the real-valued inputs. The first LHC sample

¹ We thank Evolving Logic for making this CARs software available for this project.

varies over all the real-valued inputs and represents the soft cap. The second LHC sample holds the expected industry copayment over \$100 billion and the actual industry copayment over \$100 billion to 0 percent and varies over the remaining real-valued inputs. This sample represents the hard cap. The resulting experimental design has 16,000 points.

We next divide the conventional and CBRN experimental designs each into two sets of cases: those in which the preattack industry parameters are consistent with estimates in the literature of take-up rates for commercial property insurance for conventional terrorist attacks if TRIA is allowed to expire, and those that include no government program take-up rates that may fall outside the literature's estimates. We calculate the conventional property take-up rates with *no government program* for each point in each of the designs. We identify the records that have *no government program* take-up rates within the range predicted in the literature—that is, within 25 percent to 75 percent of the conventional property take-up rates under TRIA—and consider separately the designs that include records with *no government program* take-up rates outside this range. Table G.1 shows the numbers of points in the resulting designs.

We calculate the performance of each of the three government interventions according to each of the four outcome measures for each case in each of the experimental designs, for a total of 72,000 runs of the simulation model. We report results for the cases consistent with the *no government program* take-up rates in the literature (a total of 21,900 runs). We also conduct runs for all 72,000 cases. These latter results, not reported here, are qualitatively similar to those in the preceding chapters.

Cluster Finding

Following Lempert, Groves, et. al. (2006) and Groves and Lempert (2007), we identify the key factors leading to vulnerabilities for each of the strategies and other outcomes of interest by applying Friedman and Fisher's (1999) patient rule induction method (PRIM) to the model-generated database representing the ensemble of plausible futures. PRIM is a data-mining algorithm designed to generate a set of low-dimensional "boxes" in high-dimensional data containing regions in which a particular function's value is large (or small) compared to its value

Table G.1
Numbers of Points in Experimental Designs

Design	No Government Take-Up Rates Consistent with Literature	All Take-Up Rates
Conventional attacks		
Minimum retention	1,404	4,000
All retentions	1,436	4,000
CBRN attacks		
Soft cap	2,788	8,000
Hard cap	1,672	8,000

outside these boxes. PRIM is particularly useful for identifying the key factors leading to the vulnerabilities of alternative interventions, because it aims to optimize both the classification accuracy of the boxes (the percentage of large or small function values they contain) and the interpretability of the boxes (the simplicity of the rules needed to define them).

We implement PRIM using publicly available software² that inputs a data set (which can be the output of a model run over many combinations of input values) and a criterion for interesting cases. The algorithm outputs descriptions of several alternative low-dimensional regions, or boxes, that contain a high density and span a high proportion of the interesting cases. We define the record of interest in the ensemble of plausible futures as one in which one of the outcome measures for a government intervention exceeds some threshold value. We also consider cases of interest in which the outcome measure for one intervention (e.g., cost to taxpayers under TRIA) exceeds a measure for another intervention (e.g., cost to taxpayers if TRIA expires). With such definitions, PRIM naturally generates two useful quantitative outcome measures for the resulting clusters—the coverage and density of total states of interest captured.

PRIM is inherently interactive in the sense that each run suggests several alternative clusters from which the user is asked to choose. In particular, the coverage and density measures are generally inversely correlated, since a larger cluster may include a lower density of high-value data. The PRIM implementation software we used, SuperGEM, thus presents the user with trade-off curves that display clusters with different combinations of coverage and density. These clusters often differ in the number and identity of the driving forces that define them. Users then choose the cluster with the desired density and coverage trade-off and interpretability—that is, the one with the particular set of defining driving forces that makes it meaningful to the user. After choosing a cluster, the records within it are removed from the database and PRIM can be run again on the remaining records to produce additional clusters.

Figure G.1 suggests the trade-offs typically offered by the PRIM algorithm. Imagine a data set with six records of interest (shown by solid dots) and a total of 25 records. The smaller box contains only points of interest (100-percent density) but captures only four of the six such points (67-percent coverage). The larger box captures all six points of interest (100-percent coverage) but contains three additional unwanted points (67-percent density). In this example, the same two factors, represented by the axes of Figure G.1, describe both boxes. In general, this need not be the case for the clusters suggested by PRIM.

Table G.2 shows two clusters that explain the results shown on the chart in Chapter Two titled “Large Costs to Taxpayers Under TRIA from Conventional Attacks Result Entirely from Very Large Attacks” and that are generated by applying PRIM to the 1,404-case data set representing the performance of TRIA in conventional terrorist attacks. Both these clusters aim to identify the key factors that cause costs to taxpayers under TRIA to exceed \$10 billion. The cluster on the left suggests that attacks with total losses larger than \$40 billion explain all the cases with high taxpayer costs under TRIA, and all but 11 percent of such cases occur when losses exceed \$40 billion. The cluster on the right suggests that high taxpayer costs under TRIA occur in all the cases with attacks larger than \$45 billion, but 12 percent of cases in

² SuperGEM™ is an implementation of PRIM offered by Jerome Friedman at Stanford University.

Figure G.1
Coverage and Density Trade-Offs Offered by PRIM

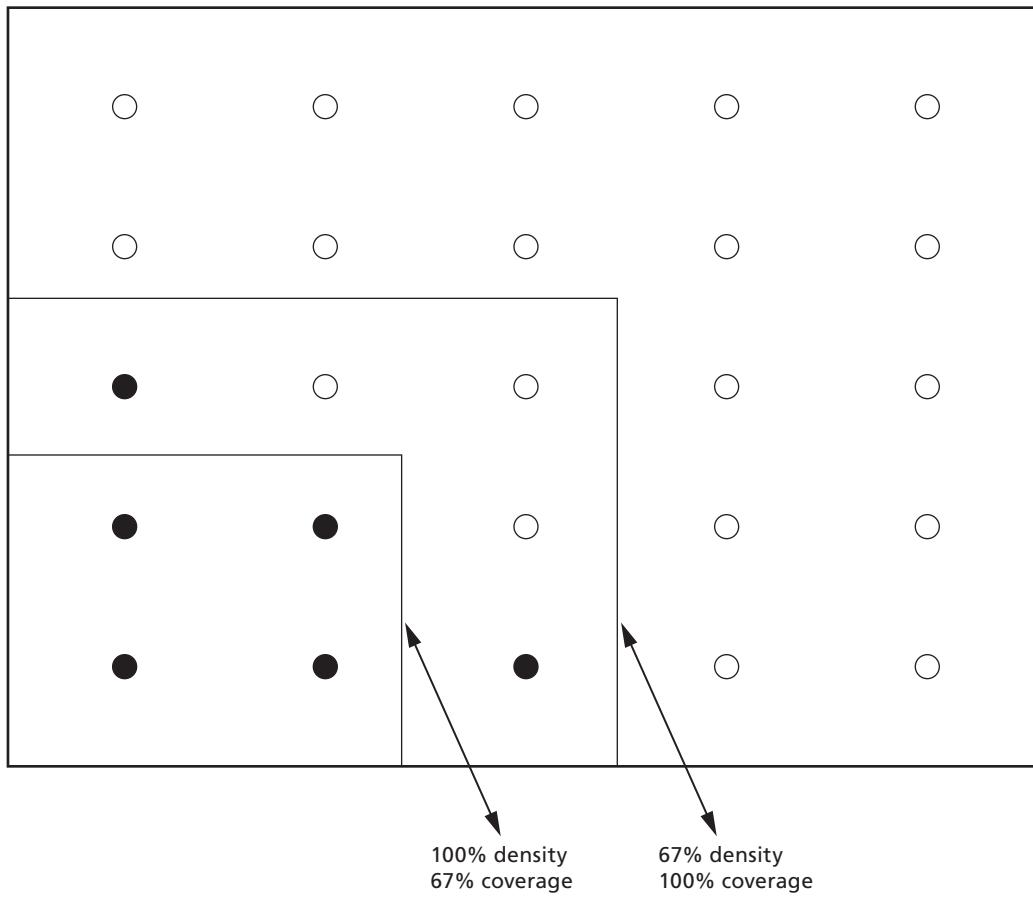


Table G.2
PRIM-Generated Clusters Explaining the $289/1,404 = 21$ Percent of Cases in Which TRIA Imposes High Costs ($>\$10$ billion) on Taxpayers

Range	Attack Size $> \$40$ Billion (%)	Attack Size $> \$45$ Billion (%)
Coverage	100	88
Density	89	100

which TRIA imposes high costs have smaller attacks. The relatively narrow range of attack sizes between these two clusters suggests that the attack size totally dominates the effect of all the other uncertain parameters in Table C.1 in Appendix C in explaining the causes of high taxpayer costs under TRIA.

Table G.3 shows two PRIM clusters that explain the results on the chart in Chapter Two titled “High Unpaid Losses Without TRIA Due Entirely to Low Government Postattack

Table G.3
PRIM-Generated Clusters Explaining the $740/1,404 = 53$ Percent of Cases with a High Fraction (>20 percent) of Unpaid Claims If TRIA Expires

Range	Government Compensation to Uninsured < 54% (%)	Government Compensation to Uninsured < 18% (%)
Coverage	100	49
Density	72	100

Compensation of Uninsured.” Both these clusters aim to identify the key factors that cause the fraction of unpaid claims if TRIA expires to exceed 20 percent. The cluster on the left suggests that a postattack government decision to compensate less than 54 percent of uninsured losses explains all the cases with a high fraction of unpaid claims, though only 72 percent of such cases have such high unpaid claims. The cluster on the right suggests that a high fraction of unpaid claims occurs in all the cases with postattack government compensation less than 18 percent, but 51 percent of such cases have more government compensation. The relatively wide range of government compensation between these two clusters suggests that many of the other uncertain parameters in Table C.1 in Appendix C can, in some cases, be important in causing a high fraction of unpaid claims if TRIA expires.

Table G.4 shows two PRIM clusters that explain the results on the chart in Chapter Two titled “TRIA Expiration Costs Taxpayers More Than TRIA for Majority of Conventional Attack Scenarios.” Both these clusters aim to identify the key factors that cause costs to taxpayers under TRIA to exceed the cost to the taxpayer if TRIA expires. The cluster on the left suggests that attacks with total losses larger than \$33 billion explain all the cases with higher taxpayer costs under TRIA, and all but 10 percent of such cases occur when losses exceed \$33 billion. The cluster on the right suggests that TRIA costs the taxpayer more in all the cases with attacks larger than \$36 billion and government compensation over uninsured losses less than 51 percent, and only 2 percent of cases in which TRIA imposes high costs have smaller attacks or more compensation. The relatively narrow range of attack sizes between these two clusters suggest that the attack size largely dominates the effect of all the other uncertain parameters in Table C.1 in Appendix C in explaining the cases in which TRIA costs the taxpayer more than letting TRIA expire.

Table G.4
PRIM-Generated Clusters Explaining the $369/1,404 = 26$ Percent of Cases with Taxpayer Costs Under TRIA Higher Than Those If TRIA Expires

Range	Attack Size > \$33 Billion (%)	Attack Size > \$36 Billion and Government Compensation to Uninsured < 51% (%)
Coverage	100	98
Density	90	100

References

- Alesch, Daniel J., James N. Holly, Elliott Mittler, and Robert Nagy, *Organizations at Risk: What Happens When Small Businesses and Not-for-Profits Encounter Natural Disasters*, Green Bay, Wisc.: Public Entity Risk Institute, 2001.
- Aon Corporation, *Property Terrorism Update: TRIA in the Balance*, October 2005. As of May 9, 2007: http://www.aon.com/about/publications/issues/property_terrorism_update-oct2005.jsp
- , *Response to U.S. Treasury and President's Working Group: Terrorism Insurance*, April 21, 2006.
- Bankes, Steve, "Exploratory Modeling for Policy Analysis," *Operations Research*, Vol. 41, No. 3, May 1993, pp. 435–449.
- Ben-Haim, Yacov, *Information-Gap Decision Theory: Decisions Under Severe Uncertainty*, San Diego, Calif.: Academic Press, 2001.
- Carroll, Stephen J., Tom LaTourrette, Brian G. Chow, Gregory S. Jones, and Craig Martin, *Distribution of Losses from Large Terrorist Attacks Under the Terrorism Risk Insurance Act*, Santa Monica, Calif.: RAND Corporation, MG-427-CTRMP, 2005. As of May 9, 2007: <http://www.rand.org/pubs/monographs/MG427/>
- Code of Federal Regulations, Title 31, Part 50.5, Paragraph (d)(1), State Licensed or Admitted Insurers, May 11, 2006. As of May 9, 2007: <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=9879602659fca70573946d51b7ecdf9e&rgn=div8&xiv=w=text&node=31:1.1.1.28.1.21.4&idno=31>
- Cummins, J. David, "Statistical and Financial Models of Insurance Pricing and the Insurance Firm," *The Journal of Risk and Insurance*, Vol. 58, No. 2, June 1991, pp. 261–302.
- , "Should the Government Provide Insurance for Catastrophes?" *Review (Federal Reserve Bank of St. Louis)*, Vol. 88, No. 4, July–August 2006, pp. 337–385.
- Cummins, J. David, Neil Doherty, and Anita Lo, "Can Insurers Pay for the 'Big One'? Measuring the Capacity of the Insurance Market to Respond to Catastrophic Losses," *Journal of Banking and Finance*, Vol. 26, Nos. 2–3, March 2002, pp. 557–583.
- Dewar, James A., *Assumption-Based Planning: A Tool for Reducing Avoidable Surprises*, Cambridge and New York: Cambridge University Press, 2002.
- Dixon, Lloyd, Noreen Clancy, Seth A. Seabury, and Adrian Overton, *The National Flood Insurance Program's Market Penetration Rate: Estimates and Policy Implications*, Santa Monica, Calif.: RAND Corporation, TR-300-FEMA, 2006. As of May 9, 2007: http://www.rand.org/pubs/technical_reports/TR300/
- Dixon, Lloyd, and Rachel Kaganoff Stern, *Compensation for Losses from the 9/11 Attacks*, Santa Monica, Calif.: RAND Corporation, MG-264-ICJ, 2004. As of May 9, 2007: <http://www.rand.org/pubs/monographs/MG264/>

- Dong, Weimin, Haresh Shah, and Felix Wong, "A Rational Approach to Pricing of Catastrophe Insurance," *Journal of Risk and Uncertainty*, Vol. 12, Nos. 2–3, May 1996, pp. 201–218.
- Friedman, Jerome H., and Nicholas I. Fisher, "Bump Hunting in High-Dimensional Data," *Statistics and Computing*, Vol. 9, No. 2, April 1999, pp. 123–143.
- Groves, David G., and Robert J. Lempert, "A New Analytic Method for Finding Policy-Relevant Scenarios," *Global Environmental Change*, Vol. 17, No. 1, February 2007, pp. 73–85.
- Harrington, Scott E., and Greg Niehaus, *Risk Management and Insurance*, 2nd ed., Boston, Mass.: McGraw-Hill, 2004.
- Hartwig, Robert P., "2006: Year End Results," Insurance Information Institute, New York, April 18, 2007. As of May 10, 2007:
<http://www.iii.org/media/industry/financials/2006yearend/>
- Insurance Services Office, "Terrorism Loss Costs and Complementary Rating Rules Being Filed for Commercial Property in Response to the Terrorism Risk Insurance Act of 2002; Rule Updated for Other Property Lines," *ISO Circular*, Jersey City, N.J.: Insurance Services Office, December 23, 2002.
- ISO—see Insurance Services Office.
- Knight, Frank Hyneman, *Risk, Uncertainty and Profit*, Boston and New York: Houghton Mifflin Company, 1921.
- Kunreuther, Howard, and Erwann Michel-Kerjan, *TRIA and Beyond: Terrorism Risk Financing in the U.S.*, Philadelphia, Pa.: Insurance and Risk Management Department, Wharton School, University of Pennsylvania, August 1, 2005. As of May 9, 2007:
<http://knowledge.wharton.upenn.edu/paper.cfm?paperid=1310>
- , *Looking Beyond TRIA: A Clinical Examination of Potential Terrorism Loss Sharing*, Cambridge, Mass.: National Bureau of Economic Research, NBER working paper 12069, March 2006. As of May 9, 2007:
<http://www.nber.org/papers/W12069>
- LaTourrette, Tom, David R. Howell, David E. Mosher, and John MacDonald, *Reducing Terrorism Risk at Shopping Centers: An Analysis of Potential Security Options*, Santa Monica, Calif.: RAND Corporation, TR-401, 2006. As of May 9, 2007:
http://www.rand.org/pubs/technical_reports/TR401/
- Lempert, Robert J., and Myles Collins, "Managing the Risk of Uncertain Threshold Response: Comparison of Robust, Optimum, and Precautionary Approaches," *Risk Analysis*, forthcoming.
- Lempert, Robert J., David G. Groves, Steven W. Popper, and Steve C. Bankes, "A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios," *Management Science*, Vol. 52, No. 4, April 2006, pp. 514–528.
- Lempert, Robert J., and Steven W. Popper, "High-Performance Government in an Uncertain World," in Robert Klitgaard and Paul C. Light, eds., *High-Performance Government: Structure, Leadership, Incentives*, Santa Monica, Calif.: RAND Corporation, MG-256-PRGS, 2005, pp. 113–138. As of May 8, 2007:
<http://www.rand.org/pubs/monographs/MG256/>
- Lempert, Robert J., Steven W. Popper, and Steven C. Bankes, *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis*, Santa Monica, Calif.: RAND Corporation, MR-1626-RPC, 2003. As of May 8, 2007:
http://www.rand.org/pubs/monograph_reports/MR1626/
- Levin, Andrew T., and John C. Williams, "Robust Monetary Policy with Competing Reference Models," *Journal of Monetary Economics*, Vol. 50, No. 5, July 2003, pp. 945–975.
- Light, Paul Charles, *The Four Pillars of High Performance: How Robust Organizations Achieve Extraordinary Results*, New York: McGraw-Hill, 2005.
- Marsh, "Marketwatch: Terrorism Insurance," 2006.

- Michel-Kerjan, Erwann, managing director, Center for Risk Management and Decision Processes, The Wharton School, University of Pennsylvania, comment on *Trade-Offs Among Alternative Government Interventions in the Market for Terrorism Insurance*, emailed to Lloyd Dixon, Robert Reville, and Tom LaTourrette, April 7, 2007.
- Morgan, M. Granger, and Max Henrion, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, Cambridge and New York: Cambridge University Press, 1990.
- Mortgage Bankers Association, *Study of Terrorism Insurance, TRIA and the “Make-Available” Provision*, Washington D.C., 2004.
- Popper, Steven W., Robert J. Lempert, and Steven C. Banks, “Shaping the Future—Given the Unavoidable Uncertainty of the Long-Term Future, a New Analytical Approach to Setting Policy May Help with Problems Such as Global Warming,” *Scientific American*, Vol. 292, No. 4, April 2005, pp. 66–71.
- President’s Working Group on Financial Markets, *Terrorism Risk Insurance: Report of the President’s Working Group on Financial Markets*, September 2006. As of May 9, 2007:
<http://www.treas.gov/offices/domestic-finance/financial-institution/terrorism-insurance/pdf/report.pdf>
- Public Law 107-297, Terrorism Risk Insurance Act of 2002, November 26, 2002. As of May 9, 2007:
http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=107_cong_public_laws&docid=f:publ297.107.pdf
- Public Law 109-144, Terrorism Risk Insurance Extension Act of 2005, December 22, 2005. As of May 9, 2007:
http://www.treas.gov/offices/domestic-finance/financial-institution/terrorism-insurance/pdf/tria_pl-109-144.pdf
- Risk Management Solutions, “RMS Home,” undated homepage. As of May 8, 2007:
<http://www.rms.com>
- _____, *Managing Terrorism Risk*, Newark, Calif.: Risk Management Solutions, 2003. As of December 20, 2006:
http://www.rms.com/publications/terrorism_risk_modeling.pdf
- RMS—*see* Risk Management Solutions.
- Rosenhead, Jonathan, “Robustness Analysis: Keeping Your Options Open,” in John Mingers and Jonathan Rosenhead, eds., *Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict*, 2nd ed., Chichester and New York: Wiley, 2001, pp. 181–208.
- Saltelli, A., K. Chan, and E. Marian Scott, *Sensitivity Analysis*, Chichester and New York: Wiley, 2000.
- Simon, Herbert A., “Theories of Decision-Making in Economics and Behavioral Science,” *The American Economic Review*, Vol. 49, No. 3, June 1959, pp. 253–283.
- SuperGEM™ 1.0 with S/Splus, software. As of May 9, 2007:
<http://stat.stanford.edu/~jhf/SuperGEM.html>
- U.S. Department of the Treasury, “Terrorism Risk Insurance Program; Litigation Management,” proposed rule, *Federal Register*, Vol. 69, No. 88, May 6, 2004.
- _____, Office of Economic Policy, *Assessment: The Terrorism Risk Insurance Act of 2002*, Washington, D.C.: U.S. Department of the Treasury, Office of Economic Policy, 2005. As of May 9, 2007:
<http://www.treasury.gov/press/releases/reports/063005%20tria%20study.pdf>
- _____, Office of Domestic Finance, “Terrorism Risk Insurance Program,” Web page, last modified March 23, 2006. As of May 9, 2007:
<http://www.ustreas.gov/offices/domestic-finance/financial-institution/terrorism-insurance/>
- U.S. Small Business Administration, *Fact Sheet About U.S. Small Business Administration Disaster Loans*, Disaster Area 1 Office, Niagara Falls, N.Y., 2002.