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# More than a Wing and a Prayer: Government Indemnification of the Commercial Space Launch Industry

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RESOURCES FOR THE FUTURE

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## Abstract

Using rockets to launch communications satellites and other spacecraft poses risks to the uninvolved public, including persons and property under the flight path of the launch vehicle. The federal government plays a pivotal technical role during the actual launch by carrying out certain risk-related procedures, thus causing third-party risk to be jointly produced by the company and the government. In addition, under the Commercial Space Launch Act, the government partially indemnifies commercial launch companies for third-party damages. We compare the indemnification policy to optimal liability rules under public-private co-production of risk. Under modest assumptions, shared liability created by the indemnification rules decreases the incentive of both parties to take care relative to the optimum. If care were observable, it would be preferable for the government to fully indemnify companies that take due care. The role of the government as an agent for third parties may qualify these findings.

**Key Words:** government indemnification, liability, insurance, space transportation

**JEL Classification Numbers:** L51, L98

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## 1. Introduction

The federal government indemnifies many risks, including nuclear power accidents, terrorism attacks, and flood events.[1] One justification for indemnification is the potential for catastrophic losses that would threaten insurers' solvency and lead to premiums insureds would be unwilling or unable to pay (e.g., Grossman 1958). Another justification for limiting liability is as an implicit subsidy in recognition of the positive externalities associated with the activity receiving (or prompted by) the indemnification (e.g., Lakdawalla and Zanjani 2005; 42 U.S.C. §2012(i) 1970[2]).

Both situations introduce moral hazard by creating a wedge between those taking the risk and those paying for it. We examine a case where indemnification may be economically justified for a different reason—because the government establishing the indemnification rule is also co-producing the risk along with the private sector. The specific setting we examine is commercial space launch. Commercial companies launch satellites for TV, telephony, navigation, environmental monitoring, and many other services.[3] The launch vehicle passes over

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We thank Rene Ray and his colleagues at the Federal Aviation Administration (FAA) for assistance in locating material and in their patience in helping us understand the FAA's maximum probable loss calculation. Background sections of our paper draw from Macauley's participation in two FAA-sponsored studies (FAA 2002; Vedda 2006). Responsibility for errors and opinions rests with the authors.

[1] Many flood insurance policies are subsidized, leading to federal indemnification. Moreover, the program is not priced to cover catastrophic events, such as Hurricane Katrina, for which claims will likely be covered by public tax dollars (as supported by the Obama administration).

[2] The Price-Anderson Act limited the liability of the nuclear industry in the event of an accident. The stated goal of the act was to "protect the public and to encourage the development of the atomic energy industry." The social benefits of nuclear power were thought to justify the indemnification.

[3] Commercial space launches generally involve putting objects into orbit around the earth, rather than either flights beyond the earth's orbit, such as to the moon or other planets, or suborbital "up and down" launches. Proposed "space tourism" is very likely to begin with suborbital launches.

populated land for a period of time, during which its breakup or explosion could cause damage to private property and injury or death to the population below. Production and ownership of the launch vehicle are private, but industry has little control over the actual launch, which is conducted by the Air Force. In particular, the Air Force has final authority for terminating the launch if needed to protect third parties. Thus, both the company and the Air Force contribute to the risk of third-party harm from a launch.

The U.S. Commercial Space Launch Act (CSLA) of 1984 directed the Federal Aviation Administration (FAA) to regulate commercial launch safety and establish a policy for sharing liability between the government and private sectors, including protecting the uninvolved public during launch. The FAA fashioned a three-layer approach to covering third-party claims from private launches.[4] In the first layer, the launch company is responsible for third-party claims—the lesser of either $500 million or the maximum private insurance available at a reasonable cost. In the second layer, the government indemnifies the launch provider and covers losses between $500 million and $1.5 billion. Finally, claims above $1.5 billion revert to the company.

Although the co-production of the risk suggests that government should bear some of the costs, partial indemnification of the launch company could still lead to moral hazard. The launch company may take too little care before the launch in the production of the launch vehicle, since the government will be bearing some of the costs of an accident. On the other hand, failure to indemnify the company could lead to moral hazard in the reverse direction, where the government takes too little care during the launch or in setting safety regulations. Splitting the costs, as is currently done, also poses problems, in that the government may take too little care to avoid losses below the level at which it becomes liable. The government may also be too quick to abort launches, since it is not responsible for the private costs to the company of loss of a satellite from an abort.

To develop recommendations for liability and safety regulations in these situations, we model private sector care levels in response to various levels of government indemnification. We find that the current risk-sharing arrangement likely reduces both parties' incentives to take due care. Full government indemnification of the company for third-party damages, conditional on undertaking due care, would be preferable. However, treating the government as a unified

[4] P.L. 98-575 and extended in P.L. 108-428. The FAA guidelines creating the tiered approach are codified in 14 CFR 440.

decisionmaker may not be appropriate, since the Air Force may not feel responsible for federal tax dollars used to cover third-party losses. Finally, the government may not act as a private party facing financial liability would, since it is not a principal but an agent subject to political influences from the launch industry, the public at risk of harm from errant launches, and taxpayers, who ultimately fund any payments made to victims of launch accidents.

Determining optimal regulation and liability rules in this case of co-production of risk between private companies and the government is timely. Congress will soon be revising the indemnification provisions of the CSLA, whose liability structure expires in 2009. Our analysis will also be applicable to the development of regulations regarding commercial space transportation, where entrepreneurial efforts to provide public space rides are ongoing. Our findings have implications for other cases of co-production of risk levels, as well. One example is terrorism, where government policies, as well as private sector security measures, determine the risks of attacks on particular installations. A second is federal flood insurance, where individuals choose where to locate, but the federal government may be able to change the likelihood and severity of harm through structural flood control measures.

Following this introduction, the next section of the paper provides background on the launch industry, the CSLA provisions, and the critical role of the Air Force in terminating launches. We then turn in Section III to our model of indemnification, extending familiar models of negligence to the case of commercial space launch. We discuss the role of the government as "last actor" in aborting a space launch and examine the complexities of government as agent, not principal. Section IV concludes.

## 2. Background

### *2.1 The Market*

Commercial space transportation companies now operate in almost every spacefaring nation, including the United States, Russia, Japan, China, India, Israel, and Europe. The companies serve a global market and offer a range of sizes of launch vehicles to accommodate differences in the sizes of payloads. Small vehicles launch navigation and small environmental monitoring satellites into low-altitude orbits, and launchers with three or four times more powerful thrust are used for larger satellites destined for higher-altitude orbits. These satellites supply telephony, cable and direct broadcast satellite television, data transmission, weather monitoring, banking transactions, and other services.

Table 1 illustrates the size of the market based on the number of launches and the amount of revenue received for launch services for the United States and the rest of the world during the past decade. The number of launches varies widely each year as satellites die and are replaced and as new satellites are added in response to increasing demand, but has averaged around 22 annually. The prices of launches range from about $10 million for a very small payload destined for a low orbit to $140 million or more for large, high-altitude payloads. Revenue also varies but has averaged about $1.6 billion yearly over the past decade.

**Table 1. Commercial Launches and Launch Revenue, 1999–2009**

| | Launches | | Revenue (current year $, millions) | |
|---|---|---|---|---|
| Year | Supplied by U.S (adjustment for partial U.S. ownership) | Rest of World (adjustment for partial U.S. ownership) | U.S. | Rest of World |
| 1999 | 14 (15) | 22 (21) | $763 (806) | $1,454 (1412) |
| 2000 | 10 (12) | 24 (22) | 708 (836) | 2,067 (1940) |
| 2001 | 5 (6) | 11 (10) | 341 (426) | 1,128 (1043) |
| 2002 | 6 (7) | 18 (17) | 418 (456) | 1,546 (1509) |
| 2003 | 8 (9) | 8 (7) | 529 (642) | 663 (551) |
| 2004 | 9 (11) | 6 (4) | 600 (713) | 450 (338) |
| 2005 | 1 (3) | 17 (15) | 70 (210) | 1,117 (977) |
| 2006 | 7 (9) | 13 (11) | 490 (665) | 926 (751) |
| 2007 | 4 (5) | 18 (17) | 220 (255) | 1,317 (1282) |
| 2008 | 11 (14) | 14 (11) | 674 (912) | 1,124 (887) |
| 2009[a] | 9 (12) | 8 (5) | 504 (664) | 462 (302) |

Source: Federal Aviation Administration, *Annual Launch Reports*, various years
Notes: [a]projected as of 12/2008

## *2.2 The Hand of Government*

U.S. government involvement in commercial space transportation is extensive, reflecting the industry's military heritage and the national security applications of the technology.

Government is sometimes a customer in the space transportation market, although the liability rules we study here do not pertain in these cases, since government self-insures for launches of government satellites. Government funds most industry R&D,[5] serves as "gatekeeper" in operating the launch ranges, sets and enforces safety regulations, and controls munitions-related technology exports.

In the United States, ownership of launch vehicle manufacturing and production is private. Vehicles are supplied under contract to government and commercial customers (with the exception of the space shuttle, which is wholly government owned and operated). In other countries, facilities are owned and operated exclusively by government or involve a mix of public and private arrangements, often subsidized. Governments self-insure in those cases of government ownership. In mixed public and private arrangements, some governments provide partial indemnification in a variety of ways (FAA 2002; Vedda 2006). These arrangements in other countries have led U.S. industry to argue for government subsidies in the form of indemnification to "level the playing field," given the state ownership or co-ownership of launch vehicles in other countries and their self-insurance and partial indemnification by the public sector.

### *2.3 The Liability Requirements*

The focus of this paper is on the optimal liability rules for third-party losses from commercial space launches.[6] Third-party risks arise mainly when the vehicle passes over occupied land. Explosion or breakup of the vehicle could cause property damage or injury or fatalities to those within the flight path or the range of jettisoned boosters, casings, and other debris. In addition, aircraft and ships are given advanced notification and are restricted from travel within the launch vicinity, typically for several hours before the launch.[7]

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[5] However, some of the newest rockets now being designed and tested for space tourism are privately financed. *SpaceShipOne* was developed by the British industrialist Richard Branson and other private investors in pursuit of the Ansari X-Prize, *SpaceShipTwo* is now under development, and *Falcon* is under development by Paypal founder Elon Musk.

[6] Risks to government property and to personnel on the launch range are separately addressed by the FAA (see note 9, below). Satellite owners obtain additional insurance for successful operation of their satellites once the spacecraft are in orbit. This insurance is not regulated and, because it does not involve harms to third parties, is not our focus here. Government-owned satellite operations, once the satellites are in orbit, are self-insured by taxpayers.

[7] The duration of the restrictions varies based on the launch "window." Launches are notoriously delayed and postponed, leading to a large social cost of time lost by ships and aircraft. Analysis of this aspect of space launches is a worthy topic for additional study.

Table 2 describes the liability requirements outlined in the CSLA, which take the form of a three-tiered allocation of potential financial losses between the company and the government. The first tier deals with losses below a limit intended to represent those losses with greatest likelihood of occurrence. This is the maximum probable loss (MPL), established by the FAA for each launch based on the vehicle's past performance ("failure probability") and the proximity of the launch flight trajectory to population and other property ("expected loss").[8] The MPL assessment is generally agreed to give significant weight to public safety.[9] To date, there have been no third-party claims in the United States due to space launch accidents. Third parties in other countries have not fared as well. For example, news reports document large numbers of citizens killed when rockets veered off course in China during the 1990s, although the Chinese government disputes the number of fatalities.

In practice, the MPL is calculated under two settings.[10] For both, the regulator, here the FAA, first determines a threshold probability below which losses are deemed to be negligible. For third-party losses, that likelihood has been set at 1 in 10 million. The regulator then identifies accident scenarios. In the first setting, where none of the scenarios have a likelihood of exceeding the threshold probability, the regulator ranks scenarios in order of loss that would

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[8] The government's "probabilistic hazard analysis" estimates risks based on probabilities as a function of elapsed time into the mission, characteristics of the vehicle, local weather conditions, and the surrounding population distribution (see Research Triangle Institute, 1995). The values are expressed as a "casualty expectation," defined as $E_c = \Sigma P_i(A_{Hi}/A_i)N_i$ . The casualty expectation, $E_c$ , is the sum over the number of people, $N$, in hazard area $A_{Hi}$ (where "lethal" debris impacts can occur). The area $A$ is partitioned into $I$ subsets of with areas $A_i$, $i = 1, \ldots I$; $N = \Sigma N_i$, where $N_i$ is the number of people in area $i$. The "fragment impact probability density," $P_i$ , is determined by characteristics and previous performance of the launch vehicle, weather, and the planned launch trajectory. The casualty expectation is not to exceed 30 x $10^{-6}$. The statistical value of life is used to convert this risk into monetary values, based on estimates established by the US Department of Transportation for its safety regulation of other transport modes.

[9]See Federal Aviation Administration (2000); also, in reviewing the possibility of third-party accidents involving space launch, the investigating board for the accident involving the space shuttle *Columbia* pointed out the "flawless" public safety record of US space flight, noting that hundreds of US space launches have taken place without injury to the public (Columbia Accident Investigation Board 2003, 214). The report noted that falling debris from aviation killed about eight people per year during 1964 and 1999; the probability of a US resident's being killed by aircraft debris—a category known as "groundling" fatalities—is less than one in a million over a 70-year lifetime (214).The report states further that although comparisons with aviation accidents are difficult given the small number of space flights compared with aircraft flights and *government space flight safety standards* (emphasis added), "it is unlikely that US space flights will produce many, if any, public injuries in the coming years," given the procedures of US space launch range commanders and other government range personnel (214).

[10] The characterizations here are our understandings based on conversations with FAA staff, but responsibility for their accuracy remains ours.

occur, and then sets the MPL as that for the scenario for which the probability of larger losses is, in the aggregate, less than 1 in 10 million. In the second setting, where some of the scenarios have a likelihood of exceeding the threshold probability, the regulator sets the MPL as the largest loss among the set of those scenarios, reflecting an assumption that the probability of a loss is inversely related to its magnitude. The chance that a loss will exceed the MPL is no greater than but could be as large as the multiple of the threshold probability times the number of scenarios where the chance of a loss is less than the threshold probability. However, the number of excluded scenarios in the current methods used to assess launch risk is small.

Under the indemnification rules, the FAA limits third-party liability to the lesser of the MPL and "the maximum amount of insurance available on the world market at reasonable cost."[11] The FAA has set an effective ceiling on liability under these rules at $500 million, effectively implying an expectation that the MPL for any given launch will be less than that.[12] Under Tier I, as described in Table 2, the launch company is responsible for losses below the MPL, through either insurance or some other demonstration of financial responsibility (this demonstration is enforced as a licensing requirement). At this juncture, we can only speculate as to why this insurance may not be available. The current MPL appears to be set so high that the probability of damages' falling into the government's layer of liability is almost negligible. When the probability that losses will exceed the MPL is, at most, 1 in 10 million, the expected value of indemnification up to $1.5 billion is only $150. In cases where there are multiple scenarios above the MPL, the exposure of the launch company could be multiples of $150, but conversations with the FAA have indicated that there are very few such scenarios for any given launch.

Consequently, the expected value of the indemnification appears minimal compared with the costs of the launch, making the (political) demand by the launch industry for indemnification puzzling. Explanations include either extreme risk aversion against catastrophic outcomes on the part of the companies or their belief that the risks are orders of magnitude larger than

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[11] In addition, an MPL is estimated for damages to government property on the launch range. The company's liability is limited to the MPL provided it does not exceed the lesser of $100 million or the maximum amount of insurance available on the world market at reasonable cost. Since our focus is on third-party harms, we ignore this here, although we note that safety investments induced by these liability rules are likely to affect the magnitude of the risks faced by third parties.

[12] The largest MPL calculated so far by the FAA for a commercial launch is $264 million; see http://www.faa.gov/about/office_org/headquarters_offices/ast/licenses_permits/media/mplsum.pdf.

government estimates imply. There may be good reason for the latter. Between 1999 and 2009, the years for which we have data, there have only been 84 commercial launches in the United States, none causing third-party damage. Even if one includes government launches, there would still be far too little empirical evidence to estimate accident probabilities as small as 1 in 10 million.

The alleged unavailability of insurance is also puzzling. At the time of the original legislation, global insurance markets were in a downturn (more on this below), but this would not explain why the concern continues. One possibility is that the lack of data on accidents and their correlates makes insurers unable to hedge the risk, and thus makes them no less risk averse than the launch companies themselves. For losses whose probability or magnitude is unknown, insurers have been found to charge an "ambiguity premium" that could make premiums higher, again, than insureds will pay (Kunreuther and Hogarth 1992). This may explain the lack of affordable terrorism insurance after 9/11 (Kunreuther 2022). A second possibility is that the price may not be "reasonable" because companies may choose a small likelihood of bankruptcy over paying the cost of insurance against these high losses. In focusing on the effects of the indemnification rule itself, we do not address the theoretical or empirical veracity of these claims.

**Table 2. U.S. Liability-Sharing Regime for Commercial Space Transportation (49 USC Subtitle IX, Chapter 701)**

| *Structure* | | *Liability* |
|---|---|---|
| **Tier I: Maximum Probable Loss (MPL)-Based Financial Responsibility Requirements**<br><br>FAA-determined MPL, not to exceed lesser of $0.5 billion for third-party liablity, or maximum available on world market at reasonable cost | → | Licensee (commercial space transportation supplier) |
| **Tier II: Indemnification (Government Payment of Claims)**<br><br>Successful third-party claims between MPL (or $0.5 billion) and $1.5 billion (1988 dollars; to be adjusted for inflation at time of claim) | → | Government, subject to congressional appropriations; claims waived for government property damage |
| **Tier III: Above MPL-Based Insurance plus Indemnification**<br><br>Greater than $1.5 billion (1988 dollars; to be adjusted for inflation at time of claim) | → | Licensee (commercial space transportation supplier) |

In Tier II, known as the indemnification provision, the government is liable for claims that exceed the MPL. The Tier II government liability is capped at $1.5 billion ($1988) for third parties (if there is a claim, the amount is to be adjusted for inflation since 1988.13 The government will waive claims exceeding the Tier I amount for government property damage. In Tier III, financial responsibility for third-party liability above the inflation-adjusted $1.5 billion reverts to the licensee. Because the likelihood of harms in this tier is small, and including it only complicates the analysis without providing significant additional insights into the design of optimal liability rules in this context, we do not include Tier III in the models below.

### *2.4 Legislative Background*

Before turning to analysis of the liability regime, we first examine the legislative record for clues as to why the choice was made for government intervention in the launch industry in general, and for risk sharing through indemnification in particular. We then provide details about the unique role of the U.S. Air Force in actual implementation of safety procedures associated with a launch. It is through this role that the government influences the risk of third-party damages from launches, thus co-producing the risk with the launch company.

Prior to 1986, all launches, including commercial payloads, were carried out by government, which self-insured against third-party damages. Government would contract with the launch company on behalf of the payload owner and, under the Space Act of 1958, assume all third-party launch liability risk of its contractors (i.e., the launch companies). Owners of the satellites typically insured the payload itself in the event of its failure to operate once in orbit.

During 1987 and 1988, Congress sought to transform the industry into a commercial business. Hearings addressed how best to assist U.S. launch companies in competing with Europe, China, and the Soviet Union, whose space launch programs were by then well developed. Because U.S. companies had launched very few commercial payloads, the hearings characterized the sector as a new industry requiring government support to develop. Proposals

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[13] Any government payments are subject to congressional appropriation; presumably, the launch company would be liable if Congress does not appropriate funds. We expect, however, that congressional appropriation would probably be forthcoming, for reasons similar to that of Litan (2006). In a study of government's role in insurance after events such as Hurricane Katrina, he points out that "history has demonstrated time after time that when disaster strikes, especially mega-disasters, governments will not sit idly by and let injured, but privately uninsured or underinsured people suffer. Government has provided disaster aid to these individuals in the past and always will do so in the future."

advanced during the hearings ranged from direct subsidies to U.S. launch companies to implicit subsidies by way of government launch indemnification.[14]

The executive branch and some members of Congress opposed direct subsidies but were open to alternatives. Industry was asking for help in light of international competition, and the indemnification option appeared to be a compromise. Assistance was further motivated by testimony of the insurance industry. The industry had insured several commercial payloads that had been destroyed in rocket launch failures during 1983–1985 as well as in the space shuttle *Challenger* accident (the *Challenger* was carrying a large commercial satellite). It was the practice of insurers to write satellite policies under regular property-casualty lines of business, and payouts of satellite losses were unexpectedly high. Insurers further testified that as a result of these losses, some underwriters had exited the satellite market; others declared that they lacked adequate capacity for any kind of insurance and that additional demands from the launch industry could be difficult to supply at “reasonable rates” (U.S. Congress 1988b).

At the same time, those seeking insurance faced an overall worldwide slump in the insurance industry (see testimony by insurers at hearings reported in U.S. Congress 1988a, 1988b). A congressional report summarized these concerns by noting that “the liability insurance industry went through the worst cyclical downturn in the industry’s history in the mid 1980s as evidenced by huge rate increases, mass cancellation of coverage, and entire lines of insurance virtually unavailable at any price.”[15] In a subsequent analysis, a report for the U.S. Department of Transportation depicted an insurance industry in malaise, stating that a “widespread crisis affected the entire property/casualty market and was manifested in an increase in liability insurance rates, lack of cover in some areas, and the potential for large jury verdicts” (U.S. Department of Transportation 2002).

In light of these findings, Congress became concerned that unless the government agreed to become more directly involved in resolving insurance issues, including limiting the industry’s

[14] Launch companies also sought subsidies as a means of redressing pre-emption of their business in the early years of the space shuttle program, during which government required all commercial satellites to use the shuttle fleet as a means of keeping the shuttle in business (see Toman and Macauley 1989).

[15] Dionne and Harrington (1992) discuss this mid-1980s liability insurance “crisis” in the context of related research on insurance price volatility and underwriting cycles. This period was also during the heyday of proposed tort reform. The report noted that “industry critics have charged that these losses largely resulted from self-destructive insurer management actions involving the long-term pricing of risk below cost. Insurers say the losses resulted primarily from claims arising from a liberalized tort law system” (5).

potential liability, a U.S. launch services industry would fail to develop (U.S. Congress 1988a, 1). Previous legislation, the Commercial Space Launch Act in 1984, had already called for some type of shared government and industry insurance, and in 1988 Congress passed the Commercial Space Launch Amendments, setting forth the three-tiered regime. In recognition of the cyclical nature of insurance markets and the desire to establish a commercially viable launch industry, the provision was to expire in five years. At that time, Congress and the administration were to "revisit the need for an extension based upon launch and insurance industry developments and related market conditions." Congress has subsequently extended the provisions in 1999, 2000, and 2004; they come up for reauthorization again in 2009.[16]

Such extensions are not unusual. Once involved in subsidizing or indemnifying a risk, government has found it very difficult to withdraw that support. The Price-Anderson Act, passed in 1957, provides partial indemnification of the nuclear industry in the event of an accident. It was set to expire in 10 years, after which time it was thought private insurance could take over. The program has now been renewed five times and is currently set to expire in 2025. Similarly, the Terrorism Risk Insurance Act, a federal backstop on terrorism claims, was passed in 2002 and intended to be temporary while the private market for terrorism insurance was reestablished. It has since been extended in 2005 and 2007 and is currently set to expire in 2014. This raises the question of whether it is simply that subsidies are difficult to take away after political support for them is created, or whether it was a mistake to think that private insurance could ever develop for risks where losses can be truly catastrophic.

### *2.5 The Air Force on the Trigger*

The legislative record does not mention another, and in our view, more justifiable role for government risk sharing. Once a launch vehicle is manufactured and shipped to the launch range, industry has very little control over the launch itself. With few exceptions, launch ranges are owned by the government and operated by the U.S. Air Force. Most commercial launches take place at two Air Force–operated ranges, in Florida and California. For several minutes during launch, the vehicle passes at some time over occupied land. Launches from the east coast facility pass not only over the Florida coast but also over Africa; vehicles launched from the west coast

[16] The extensions were contained in the 1999 Department of Veterans Affairs and Housing and Urban Development and Independent Agencies Appropriations Act, the 2000 Commercial Space Transportation Competitiveness Act, and the 2004 Commercial Space Launch Amendments Act.

facility pass over portions of the southwestern US, southern Argentina, and Chile. As stated earlier, third-party risks are to property and populated areas within the flight path and within range of jettisoned boosters, casings, and other debris, as well as within a larger area in which accidental explosions and breakups of the vehicle could occur; aircraft and ships are given advance notification restricting them from swaths of area within the launch vicinity.

The most-often discussed element of managing a launch to avoid third-party damages is the flight termination system (FTS), which consists of explosive or other disabling equipment installed in the rocket and remotely operated on command by the launch managers. By enabling destruction of an errant vehicle before its debris can be dispersed off-range, the system is the principal means of controlling most risks associated with the launch. Flight termination, as well as control of other public risks from jettisoned stages and hardware prior to orbital insertion, are a “range responsibility” and thus controlled by Air Force range safety personnel rather than the launch vehicle supplier.

The guidance for range operation defines as the principal mission “the protection of life and property both off and on-site at the launch facility” (FAA 1995, 2-6) Yet, “in keeping with that objective, the range must not be negligent, nor impose undue restrictions on launch conditions, that could result in a high probability of a good vehicle being destroyed.” Hence, each launch is a decision that balances “minimization of the probability of terminating a ‘good’ flight, and simultaneous minimization of the potential risk due to a malfunctioning vehicle” (FAA 1995, 2-6). A variety of technical characteristics and operational actions can reduce the risk to third parties; an example is the width of the “abort lines,” the geographic swath within which the launch vehicle travels before it becomes “errant” and a candidate for termination. The FAA points out that narrower swaths “decrease the overall launch risk but increase the probability of aborting a good vehicle. Considering the very high value of many of the launch vehicles and their payloads, tight abort lines put additional pressure on the range safety officials who must decide on an active destruct command” (FAA 1995, 2-9).

## 3. A Model of Indemnification

As noted above, the maximum probable loss (MPL) cutoff point for damages below which the government does not indemnify the launch company can be thought of as akin to a deductible in an insurance plan offered by the government to the launch company. The theoretical and practical rationale for deductibles is well known: to mitigate *ex post* moral hazard (Raviv 1992; Pauly 1968). In addition, under some conditions, deductibles can mitigate the effects of adverse selection by creating the potential for separating clients with *ex ante* high risk from those with low risk (Raviv 1992).

However, that analogy has limited utility here. With the extensive regulatory structure surrounding launches, it is not clear that there is asymmetric information, i.e., that the government knows less about the risk of a launch than the launch company. Because the launch company is not actually purchasing insurance from the government, the potential for separating high-risk from low-risk launches is not translated into a menu of insurance options with high deductibles and low premiums, appealing to low-risk launch companies, and low-deductible, high-premium policies that high-risk launch companies would prefer. In addition, the launch vehicle companies are themselves required to obtain private insurance, thus undercutting any potential gains from countering moral hazard (assuming premiums cannot be varied in response to care levels) and separating high-risk from low-risk launches.

Of more central interest here is that the nominal insurer or indemnifier, the government, also plays a role in determining the risk. As already described above, it may do this by taking care prior to the launch and taking actions to limit the likelihood and scope of an accident. Consequently, in evaluating the structure of the government's indemnification policy, we determine how it affects the level of care that both the launch company and the government would take. We do so first by building on familiar models of negligence (Brown 1973; Cooter and Ulen 2000) to identify optimal rules and then show how the current indemnification policy leads at least one party and perhaps both to underprovide care.

We then discuss how the model might be affected by recognizing two special aspects of the government's role. First, because the government is the last actor, in that as the entity that oversees the launch, it makes the final determination whether to abort a launch or to destroy a rocket taking an errant flight path, we discuss how choosing care levels sequentially instead of simultaneously would alter our results. A second is recognizing that the government is not a principal. As a government entity, any payments it might make as the indemnifier, were an accident to exceed the MPL, come from the taxpayers, not from itself. Thus the government here—a complex combination of entities including the Air Force, FAA, NASA, and Congress—is an agent that acts on behalf of the launch company, which wants missions to be successful, third parties at risk, who want to be protected, and taxpayers, who could be on the hook for payments above the MPL. These factors could affect the prediction from the model below—that because they are not liable for losses below the MPL, the government would take too little care.[17]

### *3.1 The Model*

With that as backdrop, consider the following model of choice of care by the government ($c_G$) and by the launch company ($c_L$). The levels of care are assumed to be chosen simultaneously (before observing the other's) and one-dimensional (neglecting how different types of care affect different aspects of accident risk). These levels of care affect the probability distribution *f* over sizes of third-party damages *x*, such that the distribution is $f(x, c_L, c_G)$, where it satisfies the general definition of a frequency distribution:

$$\int_0^\infty f(x, c_L, c_G)dx = 1.$$[18]

The costs of care are characterized in money terms at a dollar per unit, so the marginal cost of care is a dollar; the differential effects of care on risk are built into the function *f*. The expected harm, given levels of care, is thus

$$\int_0^\infty xf(x, c_L, c_G)dx. \tag{1}$$

Ignoring risk aversion for simplicity,[19] the social optimum is to minimize the sum of the expected harm and the costs of care,

$$\int_0^\infty xf(x, c_L, c_G)dx + c_L + c_G. \tag{2}$$

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[17] Brennan and Boyd (2006) discuss how these factors affect regulatory decision making, in the context of justifications for compensation for regulatory takings.

[18] In practice, this distribution could be discontinuous with a point mass at 0, where more care could increase the chance that there would be an accident with no damage or, equivalent for our purposes, no accident at all. Since that outcome can be approximated arbitrarily closely by a continuous distribution with high values at very low levels of harm, we can apply this definition without appreciable loss of generality.

[19] One cannot ignore risk aversion in examining the indemnification structure as an insurance policy, since the motivation for purchasing insurance is for those with relatively high risk aversion to pay those with less or no risk aversion to take the risk. Here, however, we are modeling incentives to take care, and assuming risk neutrality most cleanly allows us to illustrate the effects of the indemnification policy on those incentives.

The first-order conditions for a minimum sum of expected harm and care costs are

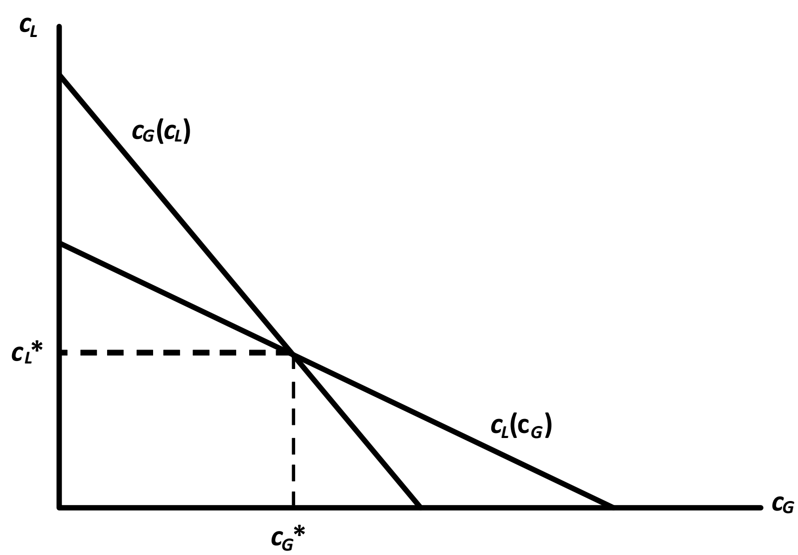
$$\int_0^\infty x f_L(x, c_L, c_G)dx + 1 = 0, \tag{3}$$

$$\int_0^\infty x f_G(x, c_L, c_G)dx + 1 = 0, \tag{4}$$

where $f_I$ is the derivative of the marginal probability with respect to changes in care level $c_I$. We assume that increasing care reduces expected harm, i.e., that both integrals in the above expressions are negative.[20] Let $c_L$* and $c_G$* be the optimal levels of care defined by (3) and (4).

A number of assumptions, which may not precisely hold in practice, are useful. The first is that $f_{GL} < 0$. In this sense, $c_L$ and $c_G$ are substitutes; the more care one party practices, the less will the other party's care reduce the chance of an accident. This implies that the reaction functions $c_L(c_Q)$ defined by (3) and $c_G(c_L)$ defined by (4) are decreasing in their arguments. To ensure an equilibrium, we assume they look as shown in Figure 1.

**Figure 1. Care "Reaction Curves"**




[20] We also assume second-order conditions necessary to ensure a unique maximum for a launch, i.e., that the marginal effect of added care on reducing risk is positive, or in other words, that the change in expected harm becomes less negative the more care one takes.

These optimal levels of care can be achieved through negligence rules incorporating an efficient due care standard. Here, for example, a rule would say that if the launch company exercises care level $c_L$*, it is not liable for any damages, even those below the MPL; if it does not take due care, it is fully liable. The government would then choose $c_G$* in response, as it now bears the residual harm and thus would act as if it is minimizing total expected harm and care costs as given in (4), taking $c_L$* as given (Brown 1973). In this context, an appropriate policy at least in theory would be for the government to fully indemnify launch vehicle companies that exercise due care, and hold them liable if it is discovered that they fail to meet that standard. This policy would be feasible only if the government could accurately observe care levels of the launch company. If an *ex post* review led to an erroneous conclusion that the launch company had failed to exercise due care, this policy would fail to be optimal. It is worth noting that if care levels are observable, allowing this type of policy, then presumably private insurance companies could also observe care levels of the launch company and adjust premiums accordingly, thus making possible the use of Tier I as a deterrent to moral hazard.

We can now examine how the current indemnification policy changes the care choices, by seeing how it would affect the location of these reaction curves. Let $M$ be the maximum probable loss (MPL) as described above, below which the launch company is liable (although insured) and above which the government bears the cost. As stated earlier, for ease of exposition, because relevant likelihoods are advertised to be insignificant, and recognizing the possibility that launch companies might be judgment proof for damages above the upper limit because of bankruptcy regulations, we ignore here the upper bound of damages that the government will indemnify, and restrict our attention to the effect of $M$.

With $M$ in place, the launch vehicle company and the government, respectively, want to minimize the sum of their expected damages and costs of care:

$$\int_0^M xf(x, c_L, c_G)dx + c_L.$$ [21] (5)

$$\int_M^\infty [x - M] f(x, c_L, c_G)dx + c_G. \quad (6)$$

In general, both the launch company and the government will want to take some care, the former to avoid costs that fall below *M*, the latter to avoid payments for accidents with costs above *M*. The optimization conditions are, respectively,

$$\int_0^M xf_L(x, c_L, c_G)dx + 1 = 0. \quad (7)$$

$$\int_M^\infty [x - M] f_G(x, c_L, c_G)dx + 1 = 0. \quad (8)$$

Consider first the launch company. For any level of care by the government, the launch company will want to cut back care if the left-hand side of (7)—the sum of marginal expected harm and care costs—is positive at the levels of care given by $c_L(c_G)$. This will be true if

$$\int_M^\infty xf_L(x, c_L, c_G)dx < 0. \quad (9)$$

This condition means that exercising more care by the launch company reduces the expected harm from those accidents where the cost would exceed the MPL. This need not hold if the launch company is exercising efficient care, as specified by (3)—one can conjure up numerical scenarios where the launch company acts efficiently, but increasing care increases the expected

[21] The indemnification rules require launch companies to insure up to *M* or prove they could cover losses themselves. Because of moral hazard, if the launch companies insure, this could lead to their taking suboptimal care if their insurers cannot monitor care and make reimbursement of claims contingent on care. As Shavell (1982) has shown, when compensation covers losses and restores third parties to their pre-accident level of well-being, liability insurance will increase overall economic welfare, even if it leads to suboptimal care, because both the insurer and the insured are better off if the latter can buy liability insurance at a price at which the former will offer it, and third parties, because they are compensated, are no worse off. However, if the losses cannot be compensated *ex post*, loss of life being the obvious example, then liability insurance can reduce overall economic welfare by inducing suboptimal care without compensating benefit to third parties.

harm from accidents above the MPL if the expected harm from accidents below the MPL—the integral in (7)—is sufficiently negative. However, it seems reasonable that optimal care by the launch company would reduce the expected harm from high-cost accidents, or at least not increase it. Thus, the indemnification rule would shift down the reaction function $c_L(c_G)$ given in Figure 1. If the launch company's care has no effect on the likelihood of accidents above the MPL, then the reaction curve will remain as in Figure 1; it will not shift down.

We now turn to the government. For any level of care by the launch company, the government would reduce care below the socially optimal reaction curve if, at the level defined by (4), it finds that (8) is positive, i.e., that reducing care would reduce the sum of the expected harm costs it bears plus the cost of care. The government would thus reduce care if

$$\int_0^M x f_G(x, c_L, c_G)dx + M\int_M^\infty f_G(x, c_L, c_G)dx < 0. \quad (10)$$

The first integral above is the effect of government care on reducing expected harm for accidents with harm below *M*, the MPL. This would be negative if government care makes that expected harm less likely. Under the indemnification rule, the government bears none of this harm, so it would not take any such reductions in expected harm into account. The second integral is *M*, the harm borne by the launch vehicle company for accidents with harm above *M*, times the chance that an accident would lead to harm above the MPL.

If this sum is negative, as was the difference for the launch company, it implies reduced care and a downward shift in the government's care reaction function. This will hold with an assumption similar to but not quite the same as that which implies a reduction in launch company care, holding the government's care constant. To get a similar result for government care, we assume that government care reduces the likelihood of accidents with harm exceeding the MPL, i.e.,

$$\int_M^\infty f_G(x, c_L, c_G)dx < 0. \quad (11)$$

If so,

$$\int_0^M f_G(x, c_L, c_G)dx > 0.$$

This follows because the general property of a frequency distribution,

$$\int_0^\infty f(x, c_L, c_G)dx = 1,$$

implies that

$$\int_0^\infty f_G(x, c_L, c_G)dx = 0.$$

With that, the expression in (10) is negative because

$$\int_0^M x f_G(x, c_L, c_G)dx + M\int_M^\infty f_G(x, c_L, c_G)dx$$

$$< M\int_0^M f_G(x, c_L, c_G)dx + M\int_M^\infty f_G(x, c_L, c_G)dx$$

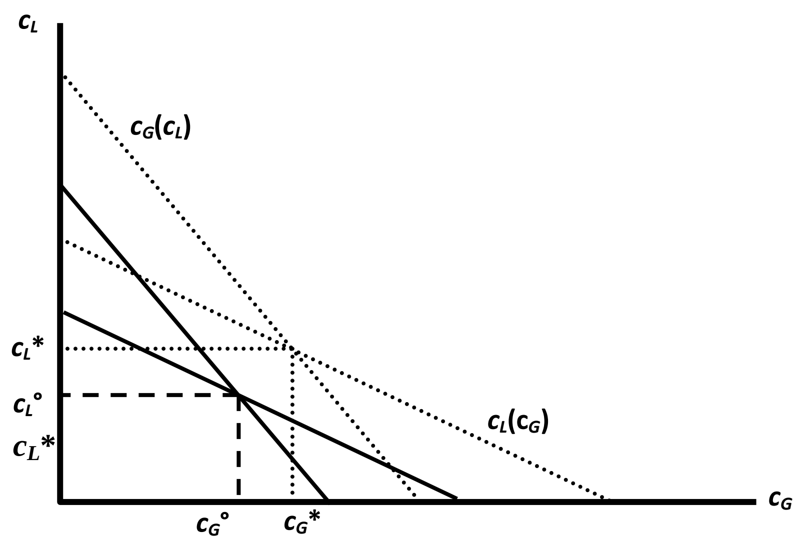
$$= M\int_0^\infty f_G(x, c_L, c_G)dx$$

$$= 0,$$

as just shown. Consequently, the expression in (10) is negative, hence the reaction curve $c_G(c_L)$ in Figure 1 will shift down as well.

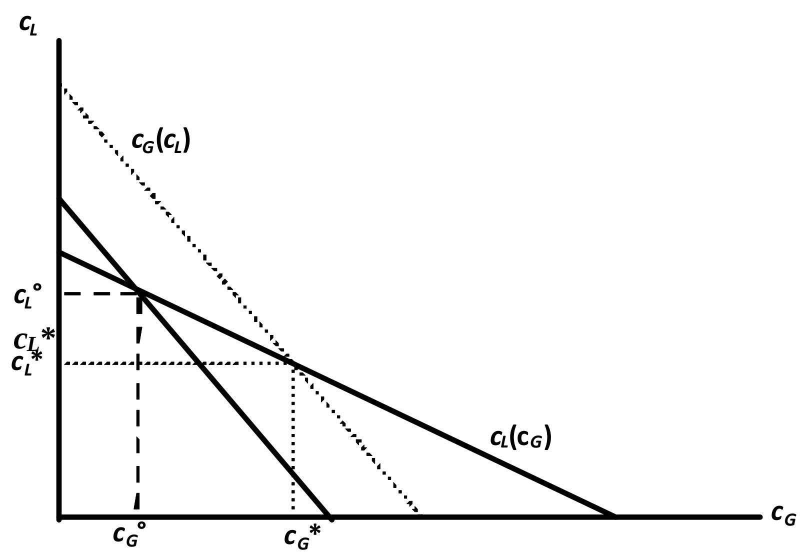
With these results, one can use Figure 1 to illustrate the effect of the indemnification rule on care. Specifically, we can show that the rule leads to suboptimal care in the aggregate, with at least one and possible both parties exercising less care than in the optimum. That the care is suboptimal in the aggregate follows from the result immediately above, that the government will reduce its level of care given the choice of the launch company, in particular at $c_L$*. That both might reduce care is illustrated by Figure 2, where the dotted lines represent the original reaction curves and the solid lines new curves under the indemnification rule; $c_L°$ and $c_G°$ represent the choices under the indemnification rule.

**Figure 2. Reduced Care by Both Parties**




It is possible that one party would increase care in response to the reduced care of the other. For example, suppose that the launch company's care has no effect on the likelihood of harms above the MPL, such that its reaction curve does not shift down. The resulting simultaneous care choices are described in Figure 3.

**Figure 3. Reduced Care by One Party**



In this scenario, the rule reduces the care the government would take. To make up for that care because the levels of care are substitutes, and because its overall incentives do not change, the launch company increases its care in response.

### *3.2 Some Complications*

As noted above, two other aspects of the current liability arrangement for commercial launches merit mention. First, care choices may be sequential rather than simultaneous. Suppose $c_L$ and $c_G$ remain substitutes, and that $c_G$ is chosen after the effects of $c_L$ are observed. From the perspective of efficient choices of care, in this case, one would want the government to be fully liable after observing $c_L$, so that it fully considers the effect of its care decisions on harm.[22] Such an efficient liability rule gives the reaction function $c_G(c_L)$ defined implicitly by (4). Knowing this liability rule, however, the launch company would have no incentive to take care to avoid third-party losses.[23] To get the launch company to take appropriate care, one could hold it liable for the costs of the care the government has to take to avoid third-party losses when it has to act in response to the launch company's choice of care.

Our analysis did not consider the effect on care levels of private losses to the launch company, such as destruction of a satellite if something goes wrong at the launch, or loss of reputation and thus business should a launch failure be deemed the company's fault. Care taken to reduce these private damages could also reduce risks to third parties. If this is the case, it is possible that the optimal care level to reduce private damages provides excessive third-party care, and thus third-party care levels will not be influenced by liability rules, since the level of care is being determined instead by the risk of private damages. Of course, what level of care will be taken to reduce private damages will depend on the availability of private insurance (including coverage and deductible levels), as well as whether premiums vary in response to care levels.

A final point to make involves the characterization of the government. This model assumes that the government acts like a private party in two respects: it treats any liability and

[22] This analysis draws from Wittman (1981).

[23] It, of course, would have incentive to take care to avoid losses of its rocket if the government had to exercise care by aborting a mission that was going badly. In this setting, the launch company would bear the risk of that loss because it is required to release the government from any liability to its own property and personnel resulting from launches (14 CFR 440).

care expenditure the government would have to make as a cost, and it posits no other interest for the government in the matter beyond that payment. Neither assumption need be valid because the government is not a principal but an agent. For the first, the money the government pays out belongs to the taxpayers, not to itself. The extent to which the government treats liability and care cost as something to be minimized depends on the strength of political clout the taxpayers exercise over the government's decisions regarding how it handles rocket launches.

In addition, the government may care about harm not merely or even primarily because of a liability payment but because any harm that takes place could reduce political support. Treating the government as an agent, we can assume that its actions are based on the welfare of its multiple principles—the launch company and its customers, third parties who would be harmed in an accident, and taxpayers who would have to pay for damages—weighted by the political clout of each.[24] If the third parties have disproportionate political clout, e.g., because their legislative representative has disproportionate influence over the specific agency's appropriations or appointments or the government believes the public outcry following damage to third parties would be enormous, the government could take care, even excessive care, absent any indemnification obligation. If so, indemnification could improve efficiency, in that the expectation of compensation for damages would reduce the inclination of such politically powerful third parties to impose excessive standards of risk or to prevent launches altogether.[25] In fact, the FAA has commented that "the assured availability of funds to compensate for loss is a significant element of public acceptability" (50 Fed Reg 19281).

Given those qualifications, one needs to be cautious in drawing conclusions from our model. We have shown that under a rule in which the launch company is exposed to liability below some limit and the government covers the residual liability above that limit, under reasonable assumptions regarding the substitutability of one's care for the other's and the effect of care on the likelihood of high-damage accidents, the rule will lead to suboptimal care, with both parties perhaps exercising less care than would be efficient. In theory, a straightforward negligence rule, under which the government fully indemnified the launch company if and only if the latter exercised due care, would lead to a better outcome.

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[24] This conception of the government actor as an agent with multiple principles comes from Peltzman (1976).

[25] For a similar result in the context of regulatory takings, see Brennan and Boyd (2006, 195–96).

But before rejecting the current practice, a number of additional considerations should be kept in mind. First, the feasibility of a negligence rule presupposes that determining whether the launch company failed to exercise due care can be done accurately. Second, even if launch companies act with sufficient care to avoid liability, each launch nevertheless creates a positive expected third-party harm that the launch company will not internalize, leading to too many launches. Third, the indemnification policy also reallocates risk between the launch company and the government, and the benefits of that risk reallocation may outweigh the expected costs from suboptimal care. Fourth, the parties, particularly the launch company, may have little discretion regarding care levels because of regulations in place. Finally, the likelihood of launch accidents with effects beyond the MPL may be so slight that for all practical purposes, the operational part of the policy is primarily that of requiring launch companies to insure against losses below the MPL, to protect against the possible inability of the launch company to cover losses after an accident, e.g., due to bankruptcy (Shavell 2006, 26–27).

## 4. Conclusions

Commercial space launches in the US feature indemnification rules that effectively divide liability for launch accidents between the public and private sectors, based on the magnitude of the damage. Under reasonable assumptions, such risk-sharing formulas reduce each party's incentive to take care and can result in suboptimal care levels. An optimal liability rule would indemnify the company if due care was undertaken, but not otherwise. This approach, however, requires that the government accurately determine the care levels undertaken by the company. If this determination is not possible, risk sharing may be a second-best policy choice. Finding ways to define care *ex ante* and verify it *ex post* could, however, improve upon the current regime.

Politics, and not economics, may also be the likely underpinning for the indemnification rules. Indemnification may simply be a political pacifier for constituents under the flight path worried about the ability of launch companies to compensate them for possible damages. Considerations such as this suggest that care levels are likely influenced by more than potential liability for damages. The government may take care in anticipation of political outcry from an accident. Determining how liability rules interact with these other incentives is difficult, but this information could significantly influence whether and what type of shared liability rule should be adopted.

Whether and how the government adapts the indemnification policy to plans for having commercial entities rather than the government carry out actual launches may provide additional information on the relative influence of political and economic rationales. A recent development is "commercial spaceports." Some are located on federal launch ranges (Spaceport Florida Authority, the California Space Authority, and Virginia Space Flight Center) and must comply with federal safety requirements. Commercial spaceports not located on federal ranges (Alaska and potentially state-owned, inland facilities) have to comply with federal range standards and procedures, but the FAA will establish safety requirements and the site operator will be responsible for protecting public safety.[26] Whether indemnification is to be extended to these activities is under consideration; our results argue against extension.

Finally, more research is warranted on the often-thorny details of optimal design of liability rules, insurance, and safety regulations in situations where the government is co-producing risk along with private entities. Since terrorism risk is largely influenced by government activities, conditional on private entities' undertaking certain standards of security, full indemnification of these losses may be warranted. Determining what types of care should be undertaken may be difficult, especially since terrorism risk is constantly changing as terrorists respond to our actions. Flood risk, another example, is co-produced by individual property owners, who make decisions about where to locate and how much mitigation to undertake; communities, which regulate floodplain development and building codes and undertake risk reduction measures for the community; and the federal government, which offers insurance and builds some structural protection measures. Inducing optimal care levels in this environment is difficult at best. Investigations to improve regulations in these settings would be useful subsequent analyses.

[26] See Subchapter C, 14 CFR 440.

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