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Science and Policy Choices

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Estimating the Economic Impacts of WMD Attacks

Peter Gordon, Bumsoo Lee, James E. Moore II, Qisheng Pan, JiYoung Park, and Harry W. Richardson

American antiterrorism policy needs risk assessment (chapter 7) to deploy U.S. scientific and technical assets more efficiently. But while the costs of various countermeasures are usually known, their benefits hinge on the losses that could be prevented. Improved analysis will require a better understanding of the short-term economic impacts of various real and hypothetical events. Can these losses be estimated? Here we review the growing social science and policy analysis literature that attempts to apply and extend existing economic analysis tools to terrorist attacks. Although the results of these studies are not detailed forecasts, they do provide first-order estimates of possible losses and provide a basis for comparing likely losses from different attacks.

Section 14.1 discusses attempts to model the nationwide impact of terrorist attacks, most notably including attacks that lead to prolonged shutdowns of the U.S. border. These are aggregate models for the entire American economy. Section 14.2 shows how spatial models can be used to trace losses at both the local level (e.g., greater Los Angeles) and across the fifty states (e.g., attacks on major seaports, theme parks). These models highlight localized effects that tend to be obscured by aggregate analyses, especially when local effects cancel each other out. They also provide a potentially compelling framework that local constituencies can use to decide when they should be politically willing to support national-level terror prevention programs. Section 14.3 addresses alternative approaches for making models more realistic. It focuses on efforts to capture the “resiliency” of real-world economies—that is, their ability to adapt, adjust, and mitigate problems as they emerge. Section 14.4 reviews attempts to use other, mostly noneconomic disciplines to explore how cities would likely respond to attack and the policy prescriptions that these analyses imply. Finally, section 14.5 presents a brief conclusion.
4.1 National Models and Impacts

There are several straightforward methods that can be used to assess the aggregate, nationwide impact of a terrorist attack. For example, the Department of Commerce’s Bureau of Economic Analysis (BEA) and the private Minnesota Implan Group (MIG) both offer user-friendly and up-to-date input-output models of the U.S. economy. These can be adapted to assess the cost of hypothetical terrorist attacks.

Our general conceptual approach is summarized in figure 4.1. The starting point is to postulate attack scenarios: This provides the initial conditions for our model. Developing plausible scenarios in enough detail to support modeling turns out to be the main challenge in our work. We use past events as well as simulations from workers in other fields to characterize such important variables as expected loss of life, likely duration of business interruptions, and the remediation costs associated with different attacks (Lee et al. 2008; Lee, Gordon, and Moore 2007). The accuracy of any input-output model depends on obtaining plausible estimates for these exogenous (direct) effects. Once these direct effects are specified, we use input-output modeling to estimate the various indirect (endogenous) effects that would likely flow from them.
14.1.1 Discrete Impacts

Proceeding in this way, we have analyzed the economic impacts of various localized, one-time attacks on U.S. targets. These include an agroterrorist attack on romaine lettuce farming, an attack on a major U.S. airport terminal, an attack on a major U.S. urban center, and an attack on a major league sports stadium. Table 14.1 summarizes the results of our estimates.

The losses range from $77 million (the romaine lettuce attack) to $422 billion (the air terminal attack) (Lee, Gordon, and Moore 2007). The large losses from the latter come from reduced postattack passenger air travel, modeled on actual air travel losses in the two-year period after September 11. This is the only one of our four models that predicts an economic impact beyond the first year. This result agrees with an earlier study by Gordon et al., which found similarly large loss estimates associated with a shutdown of U.S. airports, primarily for the same reason: Long-term reductions in air travel demand similar to those observed following the nation-wide airport shutdown on September 11 (Gordon et al. 2007). We assumed that this drop in demand would be repeated by a shutdown following a successful surface-to-air missile ("MANPADS") attack on a commercial airliner. Given this result, countermeasures may be cost-effective for attack probabilities as low as 30 percent.

14.1.2 Border Closing

We have also conducted a related but much more ambitious study to investigate the national economic impacts of restricting or even closing the nation’s borders. In the maximum impact case, there is no travel or trade except for piped energy like oil and natural gas. These extreme measures may be realistic for an international epidemic, which could either be manmade (e.g., smallpox) or natural (e.g., avian influenza). We conducted our simulations for 2001, the year for which we have the most data, using USIO, a forty-seven-sector aggregation of the national IMPLAN model. Demand-side and supply-side versions were used. Our most optimistic scenario showed that a one-year border shutdown would reduce U.S. output by $1.68 trillion. Since our models are linear, shorter closings would generate proportionately smaller impacts.

These disruptions are severe, well beyond anything that the U.S. economy has ever experienced in any one year. Given the size of our extrapolation, these estimates are subject to many caveats. Nevertheless, the size of our projected economic losses is striking and comparable to the dollar value of the 383,000 mean estimated fatalities predicted for the pandemic itself (Murray et al. 2006).

These losses can be disaggregated into several distinct components. First, the effects of terminating international air traffic in both directions create a $215 billion
Table 14.1
Economic impacts of four hypothetical terrorism scenarios

<table>
<thead>
<tr>
<th>($ thousands)</th>
<th>Direct</th>
<th>Indirect</th>
<th>Induced</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stadium scenario</strong></td>
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<td></td>
<td></td>
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<tr>
<td>a. Low-impact scenario</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Loss of lives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remediation expenditures (+)</td>
<td>290,505</td>
<td>216,267</td>
<td>423,056</td>
<td>929,827</td>
</tr>
<tr>
<td>Reduced household spending (-)</td>
<td>-286,158</td>
<td>-186,561</td>
<td>-303,210</td>
<td>-775,929</td>
</tr>
<tr>
<td>Reduced demand for sports attendance (-)</td>
<td>-1,635,638</td>
<td>-433,480</td>
<td>-2,797,730</td>
<td>-4,866,448</td>
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<tr>
<td>Substitutions (+)</td>
<td>817,818</td>
<td>820,591</td>
<td>919,293</td>
<td>2,557,702</td>
</tr>
<tr>
<td>Business interruption costs (-)</td>
<td></td>
<td></td>
<td></td>
<td>-538,875</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>-61,952,949</td>
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<tr>
<td>b. High-impact scenario</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Loss of lives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remediation expenditures (+)</td>
<td>290,505</td>
<td>216,267</td>
<td>423,056</td>
<td>929,827</td>
</tr>
<tr>
<td>Reduced household spending (-)</td>
<td>-286,158</td>
<td>-186,561</td>
<td>-303,210</td>
<td>-775,929</td>
</tr>
<tr>
<td>Reduced demand for sports attendance (-)</td>
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<td>-1,444,933</td>
<td>-9,325,763</td>
<td>-16,222,822</td>
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<tr>
<td>Substitutions (+)</td>
<td>2,726,063</td>
<td>2,735,306</td>
<td>3,064,312</td>
<td>8,525,680</td>
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<tr>
<td>Business interruption costs (-)</td>
<td></td>
<td></td>
<td></td>
<td>-538,875</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>-73,308,923</td>
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<tr>
<td><strong>Urban-center scenario</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Loss of lives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remediation expenditures (+)</td>
<td>133,932</td>
<td>93,803</td>
<td>183,611</td>
<td>411,346</td>
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<tr>
<td>Reduced household spending (-)</td>
<td>-131,929</td>
<td>-86,011</td>
<td>-139,791</td>
<td>-357,731</td>
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<tr>
<td>Business interruption costs</td>
<td></td>
<td></td>
<td></td>
<td>-3,850,951</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>-5,957,336</td>
</tr>
</tbody>
</table>


loss in the transportation industry including ancillary sectors like hotels, meals, shopping, and the like. This estimate includes mitigation in the form of an assumed 25 percent increase in telecommunications purchases by grounded U.S.-based business travelers. Alternatively, it is possible to assume more extensive mitigation in which 65 percent of U.S.-based international outbound trips are for pleasure and are replaced by domestic trips. This reduces net losses to about $96 billion.

Second, we estimated the separate impacts of export and import closures on commodity trading, including the extreme case in which only oil and gas imports are allowed to continue. In the interests of conservatism we also assumed that U.S. exporters and importers would mitigate by selling to each other once the borders were closed. We did this by analyzing trade flows at the six-digit NAICS level. This scenario is very optimistic since it ignores specializations beyond the six-digit NAICS level and also neglects transactions costs. Nevertheless, it does make the impacts from our modeling assumption of fixed technological coefficients less severe. Even with this mitigation, however, trade reduction still costs the economy more than $1 trillion.
Third, we estimated the losses expected from shutting off legal immigration for one year. There are approximately one million legal immigrants each year, and their job sectors are known. Applying Borjas’s (2003) labor supply elasticity of 0.3, and boosting wages correspondingly, we used a Leontief price model to calculate higher prices in all forty-seven USIO economic sectors. Household final demand was then reduced in light of these higher prices. This resulted in a $10 billion loss.

Fourth, we explored the effects of stopping illegal immigration. Because the annual number of illegal immigrants is unknown, we explored low (406,000), middle (628,000), and high rate (850,000) scenarios. A similar range of assumptions was used to explore the distribution of illegal immigrants across U.S. industry. Using the same approach previously applied to legal immigrants, we found annual losses ranging from $1.3 billion to almost $2.8 billion.

Finally, we also considered results from the loss of cross-border shopping. Incoming crossings (not by air) at all ports of entry are reported online by the Bureau of Transportation Statistics at http://www.transtats.bts.gov/Fields.asp?Table_ID=1358. There were 302 million crossings in 2005. We assumed that each shopping visit included $100 in retail expenditures and that about 60 percent of all crossings were by foreign-based shoppers entering the United States (Soares, n.d.). This led to an impact of almost $29 billion. On the plausible assumption that U.S.-based shoppers would substitute domestic purchases for shopping abroad, we arrived at a mitigated net loss of slightly less than $10 billion.

The foregoing conclusions ignore state-by-state impacts. Better estimates will require spatially disaggregated models.

### 14.2 Spatial Models

Assessing local impacts requires subnational models that combine spatial and economic detail. Our group uses the Southern California Planning Model (SCPM) to investigate impacts over scales embraced by the Greater Los Angeles metropolitan area’s 3,000+ traffic analysis zones. The SCPM integrates an input-output model, a model of the region’s highway network, and a spatial allocation model. We have also studied impacts across states by using the National Interstate Economic Model (NIEMO). NIEMO is a multiregional input-output model that estimates impacts for the fifty states and the District of Columbia. NIEMO is currently available in both demand- and supply-side versions. We frequently use both models, often in a single study. For example, when we model port closures, demand side models allow us to model losses when foreign markets for U.S. goods are abruptly cut off. Conversely, supply-side models tell us what happens when American industry can no longer sell to foreign markets.
In addition to spatial data, all of our models separately track forty-seven different industrial sectors. We refer to these as the “USC Sectors” in what follows.6

14.2.1 SCPM Applications: Studying the LA Metropolitan Area
Leamer and Thornberg (2006) point out that the resiliency of the U.S. economy makes it difficult for highly localized shocks to trigger a recession: the economy did not slow down, for example, after September 11. They also argue that it would be difficult to mount a successful attack of sufficient magnitude to close the Ports of Long Beach and Los Angeles. While we agree with this general assessment, we believe that a few scenarios are large and feasible enough to justify studying the secondary costs that a successful attack could inflict. We have used SCPM to explore the Los Angeles metropolitan area’s expected economic losses from various attack scenarios. These include radiological and/or high explosive attacks on Los Angeles’ twin ports and a radiological attack on downtown LA.

Attacks on the Twin Ports of Los Angeles—Long Beach We used SCPM to study an attack on the twin ports of Los Angeles and Long Beach using radiological bombs with and without the concurrent destruction of freeway access bridges leading into the ports. Our loss estimates cover a wide range, depending on whether the ports are shut down by very small bombs (15 days) or whether the access bridges are also destroyed (120 days). In the minimum case, the direct, indirect and induced losses only total $138.5 million, with two-thirds of the impact confined to the LA region. In the 120–day case, estimated damages rise to more than $34 billion, with two-thirds of the impact being felt outside the region.

As before, these estimates can be disaggregated into several components. We start with explicit and imputed transportation costs. Because SCPM features a highway network with finite (congestible) carrying capacity, our model allows us to estimate traffic flows and allocate indirect and induced losses that flow from greater delays across LA’s traffic analysis zones (TAZs, census tractor–like spatial units). We find two kinds of impacts that largely offset each other. When ports are closed there are many fewer freight trips and this reduces traffic. However, the loss of critical bridges also increases congestion on the remaining highways. The net impact can be positive or negative. We have explored alternative scenarios assuming $35 per hour for freight travel costs and a plausible value-of-time estimate for passenger travel of between $6.50 and $13.00 per hour. For the case of the 120–day disruption and assuming a baseline travel cost of $7.9 billion, gains from the reduced number of trips keeps net losses below 1 percent. Assuming higher travel-time values yields baselines of $18.8 to $37.5 billion. In these scenarios, passenger travel cost impacts range from very small net improvements to losses of about 2 percent.
We have also attempted to measure the effects of a radiological bomb on *household disruption, business losses, and real estate values*. According to our best estimate, these would total $4 billion. Blast damage would be minor, with deaths and serious injuries limited to a range of perhaps 50 meters. Physical infrastructure damage would similarly be negligible, except at ground zero. All remaining economic losses would be attributable to evacuation from areas contaminated by the bomb’s radiological plume. Conversations with government officials suggest that the outer evacuation zone would be defined by the need to limit occupants' entire accumulated exposure from the incident to one rem. There are standard formulas for converting releases of radiation to plume areas and shapes, subject to wind direction and other climatic conditions. We assumed that the radiation plume would occupy a long narrow ellipse four kilometers long and more than 200 meters wide with an inner and more contaminated zone about 200 meters across (0.03 km²). In the ports case, the wind usually comes from the southwest, so the plume would not affect Los Angeles International Airport or other strategic locations except for the ports themselves. We assumed a one-week evacuation in the Outer Zone. This may be conservative because some firms and households may only trickle back with a lag after being given permission to return. Because the health effects are long-term, the decision to allow a return may be determined as much by normative and political choices as scientific knowledge.

The economic impacts in this scenario depend sensitively on the assumed radiation plume, including such variables as the amount of explosive used, the mass of radioactive particles released, wind direction and weather, and downwind population and business densities. Losses also depend on policymakers’ reactions, for example whether they decide to order an evacuation and if so when they allow people to come back. Given these uncertainties, we only report our estimate of *maximum* economic impacts under reasonable assumptions. We assume that 377,442 of 401,147 persons living in the 30 TAZs as of the 2000 census would be evacuated. This leads to a total estimated output loss of over $4.1 billion. Two-thirds of the losses take place within Los Angeles County, but almost one-quarter would leak outside the five-county metropolitan region.

*Declining property values* would contribute only a small part (about $167 million) of the loss. This is based on our assumption that the first year after the attack would witness a 25 percent drop in both residential property values and retail trade. We also assume a 10 percent fall in other business activities and that these businesses leave the region. If businesses relocate elsewhere within the region, net effects would be minimal apart from redistributing geographic trade patterns.
As for travel behavior, we assume that authorities will permit citizens to drive through the plume area (with suitable advice about the use of windows, air conditioning, and regular car washes). Despite this, the average length of personal trips would increase as plume area residents were forced to shop and access services outside their neighborhoods. Although there are fewer total trips, the remaining trips are longer and produce more congestion. We estimate the imputed value of the resulting lost time at $1.63 billion.

An Attack on Terminal Island  Terminal Island accounts for about 55 percent of the ports’ trade and could in principle be isolated by taking down three high-22- foot bridges and a single rail bridge. We assumed simultaneous conventional bomb attacks large enough to destroy all four bridges. We then estimated the potential economic losses associated with isolating Terminal Island. The major problem was estimating how long the island would remain closed. Our shortest assumption was three to four months based on a scenario in which one or more of the destroyed bridges was replaced with relatively high-capacity friction pile bridges. However, these low clearance structures would interfere with shipping lanes. The other “book-end” was two years to permit the total rebuilding of the bridges in their original form. Although physically realistic, this choice is likely to be driven more by institutional pressures than physical constraints.

We estimate that a one-year closure would have an economic cost of $45 billion, with roughly two-thirds outside the region and one-third within. Because our model is linear, this estimate can easily be adjusted for longer or shorter closures yielding bookend impacts ranging from $15 to $90 billion. Even though other estimates of how long it would take to reopen Terminal Island are somewhat speculative, it is clear that a successful attack would be costly and that substantial investments to defend the facility are justified. If an attack did occur, substantial cost savings could similarly be derived from efforts to accelerate the reopening date.

We also investigated the geographic distribution of impacts. About 65 percent of both output and job impacts were experienced outside the region. Of the intraregional impacts, 68 percent occur within Los Angeles County, although the impacts in the other counties and especially in Orange County (parts of which are relatively close to the ports) were substantial. Not surprisingly, within Los Angeles County, about one-half of the impacts occurred in the two port cities and these fall overwhelmingly in Los Angeles rather than Long Beach.

According to our model, highway travel time costs would only increase by about 0.04 percent or $58 million per year. As in our radiological bomb scenario, reductions in freight traffic largely offset the cost of longer personal trips. Here,
however, delays from increased congestion on freeways and arterial roads largely stem from the fact that cars can no longer use the Vincent Thomas Bridge as a convenient link from cities in the Los Angeles Harbor area to Long Beach. This value is lower than the $90 million delay cost associated with our 120-day radiological bomb scenario because disruptions to LA’s transportation infrastructure are more localized.

It is important to note that the foregoing delay costs do not include bridge repairs. Current estimates from the California Department of Transportation suggest that replacing the Oakland Bay Bridge’s eastern span will eventually cost more than $6 billion. This span carries 275,000 passenger-car equivalents per day, approximating the Vincent Thomas Bridge. The other bridges serving Terminal Island are smaller and would be cheaper to replace. This suggests, very roughly, that all four bridges could be replaced for $12 billion. These costs would rise if construction was accelerated, although it is difficult to tell by how much. We have seen that the benefits of accelerated construction are easy to estimate and would total $3.75 billion per month.

The foregoing discussion suggests that government planning to protect, reconstruct, or rapidly erect temporary replacements for these bridges should be a clear priority. This result resembles earlier work by us that helped convince policymakers that accelerated repairs to freeway bridges following the Northridge Earthquake were amply justified on economic efficiency grounds.

An Attack on the Los Angeles Central Business District  We also studied a radiological bomb attack on a prominent downtown Los Angeles office building (Pan et al. 2007). Although there are several large office buildings in LA’s core Central Business District (CBD), choice of target (especially with a radiological bomb) does not significantly affect our conclusions. We estimate that a radiological bomb attack on downtown Los Angeles might cause economic losses totaling $6 billion. This impact is much smaller than a comparable attack on more CBD-oriented metropolitan areas like New York, Chicago, or San Francisco. It would also be much less damaging than an attack on the city’s ports. Measured by dollars of trade, Los Angeles hosts America’s largest port complex. By comparison, its financial and office sector is comparatively minor.

These economic facts suggest that pressures to reopen quickly would be much greater following a port attack than an attack downtown. An additional factor would be the authorities’ much greater ability to control how workers and/or the military reentered the ports. This could include a variety of preventive measures potentially including asking workers to wear film badges, protective clothing and other equipment. In the downtown case, control over the general public would be much
more limited. This would probably imply a more cautious schedule for resuming activities, particularly in the inner plume zone.

14.2.2 NIEMO Applications: Studying Nationwide Impacts

**Attacks on Any of Three Major U.S. Seaports** We used our interstate model NIEMO to estimate industry and state-level impacts from the short-term closure of three major U.S. seaports—Los Angeles/Long Beach, New York/Newark, and Houston (Park et al. 2007). We estimated that a one-month closure of the Los Angeles/Long Beach port complex would cost the U.S. economy approximately $21 billion. Closing the New York–New Jersey and Houston ports would inflict losses of $14.4 billion and $8.4 billion, respectively. In general, the indirect economic losses felt in other states would depend on the size of each state’s economy and its distance from the attack.

**Attacks on Theme Parks** We also applied NIEMO to trace the interregional economic effects of attacks on major theme parks (eleven individual parks plus two geographical clusters) located across eight states. In some of our scenarios, we assumed that an attack on one theme park would be perceived as an attack on all (“spillovers”). However, we also examined a more conservative assumption in which an attack on one park did not affect attendance at others. Finally, we investigated the very probable scenario that even a major terrorist attack would not eliminate American vacations, but only shift them from theme parks to other destinations. We modeled this scenario by substituting visits to national parks for theme parks.

Based on these assumptions, we found that a theme park attack with spillovers would cause business interruption losses of between $19 billion and $23 billion plus up to $12 billion of additional airline revenue losses. Without spillovers, the impacts range from just $500 million to $11.3 billion. These numbers are comparable to the costs of September 11. Allowing tourists to substitute other destinations produces only partial mitigation because of people who decide to stay home, increase their savings, and/or postpone vacation decisions. There are also offsets. Despite having important national parks, Florida and California are net losers while states such as Arizona, Utah, and Wyoming gain overall.

These results certainly justify more expenditures on prevention. The problem is spillover scenarios. Small parks may not be able to afford prevention, particularly when most of the benefits flow to larger rivals. Methods for overcoming this problem potentially include government subsidies and/or coinsurance schemes among theme park owners.
Hurricane Katrina and the Ports of New Orleans  While we have used NIEMO to study various hypothetical terrorist attacks, it is important to check the model against actual events. Natural disasters provide this opportunity. However, applying NIEMO to the effects of Hurricane Katrina presented difficult challenges. We approached the problem by extrapolating monthly data for historic export and import trends. Comparing actual post-Katrina port performance against these extrapolations then let us estimate direct import and export losses by product sectors. Inserting these losses into our model led to the following key findings:

- **Resilience**  Seaborne exports to foreign countries from the Customs District slowly recovered. However, exports to other parts of the United States took much longer to recover. Imports from other U.S. ports were less affected than imports from abroad.
- **Ripple effects**  The interruption in foreign trade triggered additional losses throughout the U.S. economy. The estimated size of these multipliers were slightly larger for analyses based on the demand-side (2.2–2.4) compared to the supply side (1.8–1.9).
- **Distribution effects**  Several states gained from the disruption, producing a positive sum for the nation as a whole. Nearly three-quarters of all export losses were located in Louisiana. Apart from Louisiana, the biggest indirect impacts were felt in Texas and California.\(^{17}\)

An FMD attack on the United States  We also applied NIEMO to estimate the state-by-state and sector-by-sector economic impacts of a hypothetical bioterrorist attack using foot-and-mouth disease (FMD) pathogens. FMD is a highly contagious viral disease that affects cloven-hoofed animals such as cattle, swine, sheep, goats, and deer. It can be transmitted not only by direct contact but also by air and even inanimate objects like animal byproducts, water, and straw. In theory, terrorists can easily disseminate the FMD virus by introducing a single piece of contaminated meat or sausage to a farm or feedlot.

The assumptions that drive our model are summarized in table 14.2. We assumed an attack on feedlots in California. The state's expenditures on decontamination, quarantine, and indemnification activities enter the model as increased final demands for industrial sectors such as veterinary services and environmental and other technological consulting services. However, the net effect to the overall California economy is negative and leads to reduced household spending. We model this using known expenditure patterns by households in the $35,000–$50,000 income bracket. Federal reimbursement for state-level decontamination, quarantine, and indemnification activities shifts some of this loss to taxpayers nationwide, reducing household consumption across the United States.
We used NIEMO to estimate the economic impacts of a hypothetical bioterrorist事件, however, applying the model to highly-specific threats poses several challenges. We had to carefully adjust for differences in trade, export and import shocks among these sectors and across specific product sectors. Some observations:

1. The US Meat Inspection District slowly recovered from the BSE scare, but it took much longer to recover than from the avian flu outbreaks from abroad.
2. Additional losses associated with reduced consumer demand were slightly more significant on the supply side than on the demand side.
3. Recovering a positive net effect for the US meat import losses were not realized until 18 months into the recovery, although impacts were felt sooner.

To estimate the economic impacts of a hypothetical bioterrorist attack, we assessed the impact of a highly contagious disease on livestock: horses, cattle, sheep, goats, pigs, and turkeys. Infections could be transmitted by air and even through foot, and direct losses to livestock, terrorrists can expect us to monitor the spread of contaminated livestock.

Table 14.2

<table>
<thead>
<tr>
<th>Foot-and-mouth disease: Direct impacts</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td><strong>Changes in meat demand</strong></td>
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<tr>
<td>Foreign exports of red meat</td>
</tr>
<tr>
<td>Scenario 1: -65%</td>
</tr>
<tr>
<td>Scenario 2: -80%</td>
</tr>
<tr>
<td>Scenario 3: -65%</td>
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<td>Scenario 4: -80%</td>
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<td>Domestic demand for red meat</td>
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<tr>
<td>Scenario 1: -10%</td>
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<td>Scenario 2: -10%</td>
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<tr>
<td>Domestic demand for poultry</td>
</tr>
<tr>
<td>Scenario 1: +10%</td>
</tr>
<tr>
<td>Scenario 2: +10%</td>
</tr>
</tbody>
</table>

| **Response costs**                     |
| Compensation costs                     |
| Scenario 1: -$1,171.126 millions x 1.05 reduction in overall household expenditure |
| Scenario 2: -$118.829 millions x 1.05 reduction in overall household expenditure |
| Cleaning and decontamination costs     |
| Scenario 1: +$118.829 millions in environment consulting and waste and disposal services in California |
| Scenario 2: +$286.9 millions in veterinary services in California |

Notes: The lower bound for the decrease in foreign exports (65%) is drawn from the 2001 FMD case in the United Kingdom, while the upper bound (80%) is based on the 2003 BSE case in the United States. The decrease in domestic demand for red meats and the increase in poultry demand are based on the results of a CGE study by Devadoss et al. 2006. Response costs are funded by tax dollars, which reduce household consumption; the cost of administering the tax adds at least 5% to the total. In the interests of conservatism, we ignore the efficiency losses associated with taxation.

We also model the social costs that are incurred in transferring purchasing power from taxpayers to government. These broadly consist of the administrative cost of collecting taxes, compliance costs for taxpayers, and deadweight losses. In the interests of conservatism we did not consider the deadweight loss associated with additional taxation. After looking at the relevant economic literature, we decided to reduce household consumption (final demand) by $1.05 for each dollar that the government spent on FMD mitigation. We also estimated direct losses in final demand for red meat and associated substitution effects from 2001 IMPLAN data for each of our four scenarios. These industries correspond to two of the forty-seven product sectors in our model. Finally, we calculated direct impacts by state and used them as inputs to the demand-side version of NIEMO. 18

Depending on scenario, the model yielded indirect economic impacts ranging from just under $23 billion to just over $34 billion. Domestic and international demand reductions were overwhelmingly the largest source of these losses. Although
the scenario outbreak was presumed to occur in California, reduced demand hit all major farm states hard.

14.3 Other Macroeconomic Impact Models

Existing economic impact models are short-term. Long-term effects would allow society to restructure the economy to provide work-arounds for lost or damaged assets. These effects have never been adequately modeled. But even in the short term, existing models do not simulate the market’s ability to adjust. The heart of economics, after all, is the ability of markets to reallocate production and consumption to accommodate new facts of life.

Rose (2006) explores various concepts of resilience and adopts a working definition of "economic resilience" as the ability of a system to maintain function (e.g., continue producing) when shocked... A more general definition that incorporates dynamic considerations, including stability, is the ability and speed at which a system recovers from a severe shock to achieve a desired state.” He then subdivides resilience into two main categories:

- Inherent Inherent resilience refers to individual firms’ and markets’ normal ability to deal with crises (e.g., by substituting other inputs for those curtailed by an external shock, or reallocation of resources in response to changing prices).
- Adaptive Adaptive resilience refers to people’s ability to overcome crises through ingenuity or extra effort (e.g., by increasing substitution possibilities in individual businesses, or strengthening markets by providing information to match suppliers with customers).

Rose also suggests that computable general equilibrium (CGE) models can be used to model of this phenomenon: “In terms of actual measurement of resilience, input-output (I-O) models of disaster impacts capture only quantity interdependence, often referred to as indirect or multiplier effects. Computable general equilibrium (CGE) models and macromacrometric models capture both price and quantity interaction through the explicit inclusion of market forces.” Rose, Oladosi, and Lao (2007) used this approach to simulate a major water outage in Los Angeles county. Business interruption costs of a two-week event were found to be $20.7 billion but only $2.3 billion once a variety of rescheduling options are included. The resilience opportunities are, however, the authors’ rough estimates and they concede that further study is needed.

We take a different approach, studying how measured input-output coefficients change in real economies following a major disaster. One of the sharpest limitations associated with conventional input-output models is that they assume fixed
coefficients. This means that they cannot be used to study input substitution—that is, technology choice. Standard input-output models combine observed final demand with fixed coefficient matrices to estimate total value added. Our FlexNIEMO model takes a fundamentally different approach. It assumes that the value added and final demand are fixed and then uses maximum likelihood methods to estimate how much the coefficients change following a shock. Since final demand is not really fixed, our results only set an upper bound on resiliency. Nevertheless, our analysis of Louisiana Customs District data from 2003 to 2005 suggests that substantial input substitution may well have occurred following Katrina. For now, this research is still in its early stages. The inferred coefficient changes will become much more useful when they have been checked for realism against evidence of what is technically feasible.

Finally, Stinson (2007) analyzed resilience by analyzing several widely used macroeconomic models in which the consumption function includes a consumer sentiment variable. He then looked at how various terrorist attacks had depressed the well-known Michigan Consumer Sentiment Index in the past. This enabled him to conduct various macroeconomic simulations. For example, if future attacks were large enough to depress the consumer sentiment index one standard deviation below previous experience, Stinson found that U.S. GDP would fall by $200 billion over four years. Similarly, a two-standard deviation drop would depress GDP by $400 billion over five years.

### 14.4 Microeconomic Impact Studies and Other Approaches

The formal analysis of terrorist attacks is still a relatively new field and many approaches have yet to be investigated. This section reviews several leading efforts to extend existing academic disciplines into this new field.

#### 14.4.1 Hedonic Land Studies

Real estate economists have pioneered the application of hedonic land-value studies¹⁹ to explore how real property's various attributes affect market value. Redfearn (2005) has extended this approach to test the market's perception of post-September 11 risk for single-family homes surrounding Los Angeles's most plausible targets—its twin seaports, its downtown, and its international airport. He found no evidence that homebuyers had reduced their bids because of proximity to these possible terrorist targets.²⁰

Interestingly, this result may not hold for commercial real estate markets. Abadie and Dermisi examined Chicago office vacancy data and found that properties in the vicinity of landmark buildings experienced significantly higher vacancy rates
than other nearby office buildings (Ahadie and Dermisi 2007). Similarly, Drennan (2007) studied the relocation decisions of large firms displaced by September 11. He found that almost half decided to stay in downtown Manhattan and that nearly 30 percent relocated to midtown. Only 1 percent left the metropolitan region. Drennan emphasized the importance of New York’s agglomeration opportunities (positive spillovers resulting from proximity) for these enterprises. Many of these may now be network-based (and thus less dependent on proximity) but the fact that almost 80 percent of the relocators chose to stay in the high-rent areas of Manhattan is revealing.

14.4.2 Experimental Economics
The new field of experimental economics, which relies on laboratory experiments involving human participants, offers promising new analysis tools. Schuler (2007) reports on an experiment in which “buyers” and “sellers” in a simulated electricity market were faced with a limited number of buy and sell choices. The market was cleared each day by computer to update prices and quantities, allowing experimenters to evaluate the efficiency gains of various pricing options. Not surprisingly, allowing actors to make real-time price adjustments increased the system’s performance and reliability. Operators of electrical systems under terrorist threat can learn much from these and similar experiments.

14.4.3 Engineering Systems Approaches
Lave et al. (2005) apply an engineering systems approach to power system vulnerability that focuses on “infrastructure failure interactions”—for example, when power failures cause traffic lights to fail, which then impedes emergency response. Some practical technological options (e.g., installing long-life batteries at each traffic stoplight) have obvious dual-use advantages in reducing vulnerability to both terrorist attack and extreme weather blackouts.

14.4.4 Cost-Benefit Analysis
In a more recent paper, Lave, Apt, and Morgan (2007) apply formal cost-benefit analysis to compare the improved reliability offered by various backup systems against costs. Eleven policies that would augment both reliability and resiliency (improved operator transmissions and communications, multiple transmission lines, physical barriers at key substations, and so on) are tested. Once again, the value of backup systems is multiplied by the fact that they offer four benefits (improved protection against ordinary mechanical failure, natural hazards, human error, and terrorist threats). In most cases, the crucial step is to recognize interactions when they exist.
14.4.5 Scenario Analysis

Scenario analysis has been pioneered and applied by researchers at RAND (Meade and Molander 2006). The method depends on assembling experts to examine various “what-if” questions; the experts also interact via a “strategic planning” exercise in order to suggest realistic policy choices and responses. The resulting studies emphasize how unexpected effects are not always captured by economic approaches based on extrapolating events at the margin.

14.4.6 Urban Planning Methods

Finally, urban planning techniques hold great promise for future research. Many countries are fortifying their major cities and public buildings to prevent attacks by vehicle bombs and weapons of mass destruction. However, some observers are concerned about erecting ever more barriers, bollards, armed guards, and gatehouses around buildings and public spaces. Do hard, physical barriers around buildings and public spaces make us safer, and if so at what cost? Of course, fortifying our cities may increase rather than reduce our fear, and the enhanced fear may reinforce the demand for protection. But it is not clear that the substantial resources expended make us any safer and the consequent reduction in access detracts from the value of urban life and its built-up environment. As pointed out by Coaffee (2003) and Glaeser and Shapiro (2002), security concerns explained why we originally lived in cities. In practice, however, defense requires so many resources that we end up protecting only parts of our cities. Of course, there are merits in reducing terrorists’ access to target buildings because the effects of an explosion decay rapidly with distance so that buffers (e.g., concrete bollards) can reduce the risks from vehicle bombs (Little 2007). However, there is also considerable damage to the quality of urban life: we may end up with mass agoraphobia and what Little calls “architectural taxidermy.”

The private sector tends to protect office buildings, shopping malls (against both crime and terrorism), and residential developments by limiting access while the public sector concentrates its attention on a limited number of public buildings. The inevitable consequences are increased social segregation and reduced mobility. The urban transportation sector illustrates these problems. In New York, London and Madrid (though not Los Angeles and Houston), trip makers frequently use public transport to minimize door-to-door travel times. Security measures that increase trip times and transit fares raise these costs significantly. Conversely, measures that reduce congestion can actually improve security. One rationale for the London Congestion Charging Scheme (LCCS) introduced in 2003 and the LCCS extension, which followed in 2007, is that introducing surveillance cameras to the Boroughs
of Westminster, Kensington and Chelsea would deter terrorism. This is another example of the “dual-function” approach: policy instruments that reduce congestion cost can also improve security.

14.5 Conclusion

For the first time since the War of 1812, defending targets on U.S. soil has become a national priority. The number of potential domestic targets for terrorists is nearly infinite and resources for homeland defense are annually allocated on a very large scale. This has prompted DHS and others to ask policy analysts to adapt their toolkit to this new problem. This chapter has surveyed recent contributions from a number of social scientists who have taken up the challenge.

Nearly all politics are local and economic assessments are more interesting when the “who pays” and “who benefits” questions are addressed. This makes detailed economic impact studies an important corrective to earmarks and pork-barrel politics. Investigating key scenarios also helps bound the set of policy steps that public authorities should consider. Resources for mitigation, protection, and response are scarce; the set of projects to which they might be committed is large; and, as we have seen, the expected cost of defending the wrong structures can be expensive.

The best approach may be more fundamental. Historically, security implied compact cities, such as the medieval walled cities—for example, York, Avila, or Carcassonne. However, changes in technology suggest that the preferred urban form of the future will likely be much more widely dispersed. Urban targets are attractive because of their spatial concentration. Conversely, urban decentralization not only reduces the damage but makes targets easier to protect (Frey and Leuchinger 2007; Glaeser and Shapiro 2002). In the Digital Age, there may no longer be any great benefit to having government buildings centrally located. The same is true of private facilities; a centrally located sports stadium poses much higher risks than one on the periphery.21

Interestingly, most city and regional planners now advocate compact “livable city” plans that are thought to offer environmental and sustainability benefits. In our view, it is time to rethink this conclusion from a counterterrorism perspective. Decentralization increases resilience, regardless of whether we are talking about the electrical system (Lave, Apt, and Morgan 2007), protecting buildings against vehicle bombs (Little 2007), or the ability of firms to relocate to other centers within the same metropolitan area if one location is attacked. Indeed, much of the resilience following September 11 flowed from the rapid relocation of economic activities to other sites in midtown Manhattan, suburban New Jersey, and other locations.22
Notes

1. These losses are based on the differences between actual monthly post-event air-travel volumes and those projected by extrapolating from past trends.

2. The demand-side version of the model includes multipliers that track the repercussions following from reduced demands, in this case reduced export demands. The supply-side version of the model includes multipliers that track the repercussions following from constraints on inputs, in this case reduced availability of imports.

3. In the interests of a conservatism, we reported only Type I multiplier results. Type I multipliers exclude the repercussions associated with reduced labor use and therefore reduced consumption by households. Multiplier results would be approximately 50 percent greater if Type II results were computed. Type II multipliers include the further multiplier effects associated with changes in labor demand and resulting changes in consumption. Given the limited mitigations that we were able to include, we prefer the more conservative results. Dividing the low-range estimated gross output loss by an aggregate multiplier of approximately 1.77 (from our results), we get an overall GDP loss of approximately $1 trillion or approximately 12 percent of 2001 GDP.

4. We divided international travel into four types of trips: U.S.-based (inbound and outbound) and international-based (inbound and outbound). We assumed that each round trip costs $1,000 in airfare and that two-thirds were purchased from U.S. carriers. We also estimated ground expenditures for each type of trip.

5. An alternative mitigation approach would be to assume that buyers run down inventories, effectively deferring transactions until the borders reopen.

6. The USC system categories are designed to reconcile data from several major industrial classification systems including SIC, SCTG, NAICS, HS, and others.

7. Induced losses include the effects of changes in household income and spending.

8. EPA guidelines suggest that the critical early phase of exposure would last about four days (Rosoff and Von Winterfeldt 2007). The duration of intermediate and later phases is variable and subjective, and could range from weeks to years.

9. For the most part, shopping and services consumption would shift outside the plume area. As a result, we expect input-output effects to be modest.

10. A more extreme measure would be to close entry and exit roads and especially freeways.

11. The figure is based on a personal trip imputed cost of $13 per hour and a freight trip cost of $35 per “passenger car equivalent,” which assumes that one truck is the equivalent of 2.25 cars.

12. The Terminal Island docks are accessed by three major highway bridges: the Vincent Thomas Bridge, the Gerald Desmond Bridge, and the Commodore Schuyler F. Heim Lift Bridge. A rail bridge (Badger Bridge) runs parallel to the Heim Bridge and handles 21 percent of Terminal Island’s trade. The bridges are all high enough to permit ship traffic in the waters between the coast and Terminal Island. The Desmond Bridge, for example, rises 250 feet above the water, although some experts think that it is still too low for problem-free movement.
13. This is true partly because Los Angeles' large size captures a high share of the indirect and induced losses and partly because most of the Terminal Island facilities are owned by Los Angeles rather than Long Beach.

14. President George W. Bush has said that Los Angeles' tallest office building, sometimes called the Library Tower but more precisely the U.S. Bank building, was a potential target on September 11.

15. We used demand-side NIEMO to study the effects of export losses but refrained from using supply-side NIEMO to estimate import losses. This was done to avoid counting some impacted firms twice.

16. We identified the theme parks by state but intentionally refrained from using smaller geographic units in order to avoid identifying individual facilities.

17. Our analysis should be considered provisional because it combines results from both the supply- and demand-side versions of NIEMO. Conceivably, this may have produced some double-counting of losses. If a business fails for demand-side reasons (e.g., inability to obtain raw materials), for example, it cannot be destroyed a second time for supply-side reasons (e.g., inability to ship finished products to foreign markets). In principle, our approach could generate such results.

18. We believe that demand-side impacts would dominate supply-side impacts originating in shortages of livestock due to animal slaughter.

19. These are statistical estimates of how location, neighborhood, and building attributes contribute to total property value.

20. This result is in marked contrast to a similar study by Smith and Hallstrom (2005) of how Florida home buyers viewed hurricane risk. They found that markets in Lee County, Florida, received a kud wakeup call following Hurricane Andrew even though no properties were damaged. The analysts found that property values fell by 19 percent in response to the event.

21. See Blomberg and Sheppard 2007 for a dissenting view.

22. Drennan (2007) points out that one-half of the offices displaced by September 11 found alternative space in downtown Manhattan itself. This suggests that, contrary to Glaeser and Shapiro, the advantages of agglomeration still outweigh high rents and the anticipated risk of terrorism. That said, the destruction that occurred on September 11 was geographically confined. Decentralization incentives will be much more powerful if and when terrorists demonstrate a convincing WMD capability.