ELSEVIER

Energy Policy 35 (2007) 722–733

ENERGY POLICY

www.elsevier.com/locate/enpol

Short and intermediate economic impacts of a terrorist-initiated loss of electric power: Case study of New Jersey

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Available online 9 March 2006

Abstract

The economic impacts of potential terrorist attacks on the New Jersey electric power system are examined using a regional econometric model. The magnitude and duration of the effects vary by type of business and income measure. We assume damage is done during in the summer 2005 quarter, a peak period for energy use. The state economy recovers within a year, if we assume that economic activity is restored in the next time period. However, if the attacks prompt an absolute of loss of activity due to firm relocation, closing, and geographical changes in expansion plans, then the economy does not fully recover by the year 2010. Hence, the electrical power system's resiliency to damage is the key to the extent and duration of any economic consequences of a terrorist attack, at least in New Jersey. The policy implication is that the costs and benefits of making the electric power system more resilient to plausible attacks should be weighed and that the restorative capacity of the system should be strengthened.

Keywords: Electrical power loss; Economic impact; Terrorism

1. Introduction

The loss of electrical power in the United States due to tornadoes, hurricanes, floods, and other natural events and system failures has become familiar to the vast majority of US residents because of events in the Northeast (2003), the Gulf Coast (2005), and California (ongoing). However, it has become a realistic possibility that terrorists might precipitate a power outage. As part of a grant from the US Department of Homeland Security, we describe the results of a study that used regional economic models to examine the economic impact of a serious outage in electric power delivery. The study had specific and general objectives. The specific objective was to estimate the range of possible economic impacts using existing models and a modicum of specific parameters. This objective allowed us to measure the potential economic benefits of building resiliency into the electric power system of an actual economic region. The more generic objective was to determine the strengths and weaknesses in the existing data for meeting the first objective, and to think about how these data could be improved.

2. Context

There is a large literature on electric reliability (e.g., US Canada Power System Outage Task Force, 2004a,b; Overdomain LLC, 2002; Wacker and Billinton, 1989; Corwin and Miles, 1978). With regard to terrorism, Zimmerman et al. (2005) identified some areas in the US where an "extreme scenario" could occur. In those regions, transmission lines follow only one or two routes, and there are few substations and transformers. Moreover, there is effectively no in-region capacity to produce electric power independently, or such capacity is not resistant to regional failures. A "moderately extreme" case has the same grid limitations as the first scenario, but the affected area has the capacity to produce energy independently. Even though in-region capacity may exist, it often has to be shut down in order to protect the equipment. The "moderate" scenario involves smaller areas that have independent sources of electricity that transmit from a variety of directions.

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0301-4215/$ - see front matter
doi:10.1016/j.enpol.2006.01.017

New Jersey, the study area for this project, is a region that has a vulnerability rating that falls between moderately extreme and moderate.

Sabotage or vandalism could cause electric power outages. The data base relating to sabotage or vandalism (which is the act most closely related to terrorism) in the United States is limited. Felder (2004a) studied 451 major disturbances in generation, transmission, and distribution that occurred between 1984 and 1999. Only 3% of the disturbances were attributed to sabotage or vandalism.

Globally there have been many terrorist attacks against electric systems. Zimmerman et al. (2005) report that, of terrorist events worldwide, those targeting transmission lines and towers constituted 59% of incidents between 1994 and 2004. In the US, the percentage of outage events where transmission lines and towers were disabled (non-terrorist) was 90%. Distribution lines, circuit breakers, transformers, substations, generation facilities, and switches and fuses were the other targets of terrorists. In 2002, transmission lines and towers were selected as a target of choice by terrorists in the nation of Colombia, significantly increasing that form of disruption.

Terrorist events aside, within the US natural hazards are far more likely to damage transmission and distribution lines and towers than other electrical equipment. While transmission lines are more frequently affected than are other forms of electrical infrastructure, repairs to them are relatively easy and, hence, quickly made. Longer outages tend to follow damage to equipment, such as transformers and cables, that cannot be easily and quickly repaired.

There is also a literature on the economic consequences of major power outages. For example, ICF consulting (2003) reported that the economic cost of the 1977 New York City blackout, which lasted 25 h and initially lost more than 5000 megawatts (MW), was $4.11 per kilowatt hour (kW h). The direct contribution of this loss, which includes loss of production, wages, and spoilage, was $0.66/kWh; the indirect contribution was $3.45/kWh. The authors of this report did not define "indirect." We assume that they meant all additional costs due to closing of other businesses, as well as losses of spending that would have been induced by successive rounds of spending that direct and indirect dollars produced. ICF notes that similar ratios of direct to indirect costs were observed during California's electric power outages. They used similar ratios to estimate the cost of the August 14, 2003 blackout in the Northeast United States. That blackout produced a loss of 61,800 MW and affected more than 50 million people at its peak. The authors estimated a total economic cost to the nation of between $6.8 billion and $10.3 billion. ICF underscored that terrorist attacks could exact a larger toll since the attackers might specifically target equipment that takes a long time to replace and/or repair. Moreover, the psychological "hangover" of a terrorist event would hurt tourism, including substantial losses to airlines, hotels, and other service industries.

Studying the economic impacts of power outages that have not yet happened or for which the extent of direct damage is not yet fully disclosed requires the development and use of scenarios to assure that the possible repercussions of the event are both fully thought out and bounded. In the present study, building the scenarios required choices about the size, duration, and other elements of an electrical system disruption. Eto et al. (2001) classify these decision variables. The "magnitude" of an event is the extent to which it deviates from normal operation. Prior notification and estimation of downtime can substantially reduce equipment damage and cost. Large deviations often damage equipment and interrupt service, while small deviations may not even be noticed by the consumer. "Duration" is the length of the event. While even a short outage leads to high direct costs, an outage of a week or month can exacerbate indirect costs. "Frequency" is how often an outage occurs. Frequent outages can damage equipment. "Timing" specifies when the event occurs: time of day, day of the week, and season of the year. Each variation changes the cost burden borne by business, consumers, and government. Eto et al. include a fifth dimension—"advance notice," but because early warnings of terrorist attacks are rare we did not include advance notice in our scenarios.

Eto et al. (2001) also classify the commercial and industrial costs of power outages. Production losses can occur. Some losses can be covered by increasing production at a later time, but they are likely to require higher costs through overtime payments and re-start costs. Equipment damage is a serious problem, as is damage to perishable and hazardous raw materials. Generating capacity can be extended with back-up systems, but back-up systems impose high costs for equipment, fuel, and personnel. Re-start costs can be substantial, especially for manufacturing industries that operate nonstop. Businesses realize some savings because they are not using raw materials, fuel or electricity, and damaged materials may be salvageable. Further, businesses may not have to pay labor costs during down times. The New Jersey study area, however, is heavily unionized, so that many businesses will not save wages. Eto et al. also detail striking cases of indirect impacts for commercial activity. For example, a 15 min power outage in Vancouver, British Columbia, shut down the Vancouver Stock Exchange for a day because data and data back-ups had been corrupted.

Taking a step back from the terrorist threat, Felder (2001, 2004b) distinguishes between "adequacy" and "security" in electric power systems. He argues that security requirements are a prescriptive, that is, utilities must be required to provide back-up systems. Yet he is concerned that the introduction of competitive electricity markets makes it less likely that existing regulatory approaches will be consistent with market generation needs. Felder calls for the application of probabilistic risk assessment to identify events that could trigger a loss of power. With regard to methods of analysis, the vast majority of studies rely on extrapolating multipliers derived from survey data. An interesting exception was a study by Rose and Liao (2005). As part of a study of the impact of water service disruptions, they argue that input–output models are based on rigid relationships between sectors. They assert that, under stress, systems compensate; that is, if one commodity or service becomes less available, systems show a tendency to seek a substitute or to produce with less. In the case of water, this might mean water conservation by making elements of the production process more efficient in water use, bringing in water from other sources, and relying on back-up supplies. Such tendencies toward resilience clearly would take place in the event of an electric power outage.

Resilience is an important concept in this research, and we briefly make some distinctions relevant to this work. Resilience is the adaptations within the economy that speed recovery from a shock and avoid some losses. Defined in that way, resilience is people, governments, and organizations responding by conserving, substituting, and rescheduling their activities. In other words, they would use less electricity, use non-electric forms of energy, and not perform tasks that would have used a good deal of electric power. Resilience is aided by mitigation that lessens the impact of the shock when it occurs. So, for example, if a restaurant has its own generator, it will be able to stay open, albeit perhaps with fewer customers because the customers cannot drive to the location and the food supplies are not delivered (Rose, 2004; Rose and Liao, 2005; Bruneau et al., 2003). Rose, Oladosu, and Liao (2005) simulated the economic impacts of a terrorist attack on the Los Angeles power system. Without resilience, they estimated a loss of $20.5 billion in 2 weeks. With several forms of resilience (conservation, on-site electricity generation, rescheduling of production), the loss was reduced to $2.8 billion.

3. Data and methods

The study area for this pilot project is the State of New Jersey. New Jersey has a population of 8.7 million and the highest population density of any US state, about 1200 people per square mile. That population is spread out over 566 municipal governments with no city having more than 280,000 residents. While the density of people and business is highest in the northeast part of the state adjacent to New York City, there is no single load center for electricity in New Jersey.

There are four important problems in building a hypothetical scenario for a terrorist attack on New Jersey's electrical system. First, there are no existing data on terrorist attacks on the electrical system in the United States from which to build a scenario. Second, although we can construct a very detailed scenario or set of scenarios based on hypothetical kinds of attack, to put such information in a report is inappropriate. Third, although small blackouts are frequent, using a sophisticated economic model to examine the impact of small events is the equivalent of hitting a tack with a sledge hammer.

A fourth major obstacle is the absence of very detailed data that would allow us to add nuances to our economic forecasting models. Business revenue losses by detailed industrial categories due strictly to the lack of productive operation during the postulated power outage will be estimated by assuming that national inter-industry relationships prevail in New Jersey. Losses due to the disruption of other life lines as a result of the loss of electric power were not possible to pin down because pertinent critical data do not exist for the study area. However, we do capture some of these losses indirectly. For example, the transportation industry buys electricity to run the trains. When the electric power goes out, the transaction is reduced and hence indirectly we capture loss of transport of people and goods. But, ideally, we would like to have had the time to do field interviews with experts who could provide detailed information about loss of rail commuters and the impact of those losses on the economy. The potential number of work hours lost by auto commuters also requires a special data set. The same is true for business losses that will be incurred from disruptions in the delivery of freight, water service, and the ability to use communications services. In addition, certain business will suffer losses of perishable inventories of product inputs or of the product itself. All of these are captured implicitly in part in the models because the impacts of a loss of electricity affect all businesses. But an explicit capability to capture these transactions requires field investigations before they can be incorporated into models. Given the time and resources available, it was not feasible to conduct extensive field research, and even with time, it may not be possible to collect some of the data because of security issues.

The combination of data uncertainties led us to develop a simple set of scenarios and to conduct a number of sensitivity tests on it. The numbers derived from the scenarios serve only to illustrate the potential severity of impacts, not to foretell what those impacts would be in the case of an actual attack. The goal was to span the range of probable outcomes, essentially creating upper and lower bounds. We then modified one of the assumptions and produced a second set of three simulations based on the three scenarios. In all, six sets of results were prepared.

One set of assumptions concerns where the event would occur. With regard to electrical power, the state has four main energy providers: PSE&G (Public Service Electric and Gas); JCP&L (Jersey Central Power and Light, a subsidiary of FirstEnergy); Conectiv (previously Atlantic Electric), and Rockland (a subsidiary of Orange & Rockland) (Fig. 1).

Our assumption is that the event would occur in the PSE&G service area, a part of the PJM, or Pennsylvania, Jersey, Maryland system. Within New Jersey, Public Service Electric & Gas has over 1.7 million residential customers and over 290,000 non-residential customers.

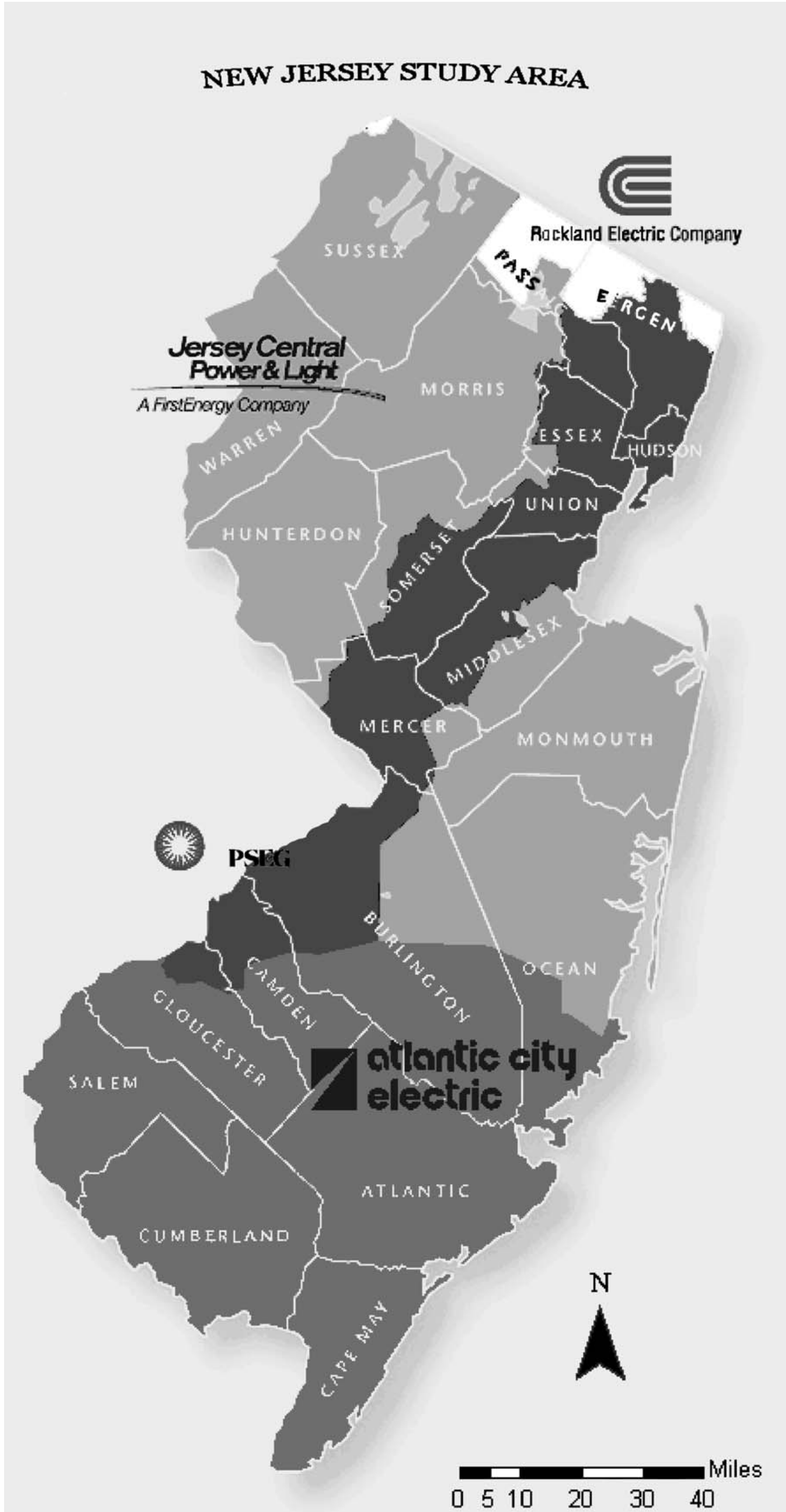
NEW JERSEY STUDY AREA
Rockland Electric Company
Jersey Central Power & Light
A FirstEnergy Company
PSEG
atlantic city electric
SUSSEX
PASS
BERGEN
MORRIS
WARREN
ESSEX
HUDSON
UNION
HUNTERDON
SOMERSET
MIDDLESEX
MERCER
MONMOUTH
BURLINGTON
OCEAN
CAMDEN
GLOUCESTER
SALEM
ATLANTIC
CUMBERLAND
CAPE MAY
N
Miles
0 5 10 20 30 40

Fig. 1.

This amounts to 55% of residential and 60% of non-residential customers in New Jersey (Board of Public Utilities, 2005). The PSE&G service area goes down the urban-industrial spine of the state from Bergen and Passaic counties in the north to Gloucester County in the south. It includes 13 counties or parts of counties: Bergen, Passaic, Essex, Hudson, Morris, Union, Somerset, Middlesex, Monmouth, Mercer, Burlington, Camden, and Gloucester. These 13 counties account for 79% of the state's population and 86% of its job base.

While the scenarios are tested on the PSE&G area, in fact, the rest of the state would be affected. State-level impacts focus the findings so that they can be more effectively linked to policy. To reiterate, the power outage is calculated for the PSE&G territory, but the impact is measured state-wide.

As noted earlier, a scenario needs to include magnitude, duration, frequency, timing, and notice. The outcomes in terms of electrical supply reduction are highly unlikely under normal conditions, but plausible as indicated by the effects of natural events and terrorist attacks elsewhere. We chose to place our hypothetical terrorist attack in summer 2005. We assume that under the middle scenario the attack knocks out 90% of electrical delivery capacity of the service area for 2 days. By the end of the second day, 25% has been restored. By the end of a week, 50% has been restored, and all the electrical supply has been restored by the end of 2 weeks. Thus annual available electrical delivery is reduced by 2.48% (Table 1). However, the full impact is to occur in a single quarter, so the reduction in electricity in summer 2005 is 9.75%. But the reduction is only in the PSE&G territory (55% of the state total electrical load). Thus, we assume a reduction in total state electrical delivery of 5.45% in the third quarter of 2005.

Table 1
Power outage scenarios,% loss

Scenario	Length, days	Amount of loss, %	Number of days lost[a] state	PSE&G summer quarter[b,c]
Middle	2	90	0.493	1.085
	5	75	1.027	2.260
	7	50	0.959	2.109
	Total event		2.479	5.454
Worse	2	95	0.520	1.145
	5	85	1.164	2.561
	24	75	4.930	10.846
	31	10	0.849	1.868
	Total event		7.463	16.415
Less	2	80	0.438	0.964
	5	50	0.685	1.506
	7	25	0.479	1.055
	Total event		1.602	3.525

[a]based on each day is 0.2739% of the total.
[b]PE&G is 55% of total.
[c]Multiplied by 0.55 to get PSE&G proportion and then by 4 to get summer quarter for PSE&G.

A more destructive version knocks out 95 of electricity delivery during the first day. By the end of the second day, only 15% has been restored. By the end of the first week, 25% has been restored, and 90% has been restored by the end of a month. The remaining 10% is not restored until the end of the second month. This accumulates to a 7.46% loss over the year. However, this is reduced to 4.10% in the service area and 16.42% in the PSE&G area for the summer quarter.

A less destructive version of the three begins with an 80% reduction during the first day, but a 50% restoration by the end of the second day, a 75% restoration by the end of the week, and full restoration by the end of second week. This would result in a 1.60% decrease if over the entire state, but 3.53% in PSE&G territory in the summer quarter (see Table 1 for calculations of power losses).

Operationally, the first three simulations reduced jobs in the third quarter (summer 2005). We then restored these losses in the fourth quarter. It is plausible that the job losses could linger because activity was not re-engaged in the state (see below for a discussion). To test this possibility, we ran another set of three simulations in which only half the jobs lost in the third quarter of 2005 were restored in the fourth quarter.

The result of these assumptions was an articulated set of six simulations. We used RECON's structural econometric time series model of the state (RECON) for estimating statewide economic impacts. An input–output (I–O) model was used to estimate the energy usage of the various industries. Both models were built and reside at our school. We used both models because of their different capabilities. I–O models are built around a matrix that describes how sectors of an economy interact with one another (Miernyk, 1967; Miller and Blair, 1985; Lahr, 2001). That is, for a given industry (e.g., steel production) it shows the "production recipe" for the goods and/or services that it sells as well as the shares of its revenues that are consumed by other industries in the economy. Our regional I–O model (RECON I–O) presently has 517 economic sectors and is built using methods outlined in Lahr (2001). For example, this model has separate categories for bricks (SIC 3251), glass (SIC 3210), and gypsum board (SIC 3275). Different amounts of these materials and equipment are needed to construct and rebuild factories, highways, generating and other facilities. RECON I–O was used to develop Table 2, which shows kWh/employee for those 13 of the 517 sectors that require more than 200,000 kWh for each employee. These sectors are highly sensitive to electrical power outages, but, with regard to value added or employment, they may not be important industries in New Jersey.

The second model is RECON—an econometric time-series model built along the lines of that by Conway (2001). It is a system of 220 equations, each of which is based on historical data for New Jersey and the nation. The model is tailor-made for New Jersey's economy. The historical data used in the equations are for the period 1970–2004.

Table 2
Electricity use per employee for selected industries
Industries that use 200,000 kWh or more per employee.

Industry	kWh/emp
Primary aluminum	786,758
Wet corn milling	383,064
Cement, hydraulic	337,973
Pipelines, except natural gas	330,867
Electrometallurgical products, except steel	329,776
Petroleum refining	289,269
Platemaking and related services	258,405
Soybean oil mills	257,097
Carbon black	232,366
Primary smelting and refining of copper	223,801
Industrial inorganic and organic chemicals	205,279
Natural gas transportation	200,415
Plastics materials and resins	200,304

Source: RECON I–O model.

Table 3
Attributes of PSE&G service area

PSE&G territory as a proportion of NJ 2004:Q3			
	Jobs (%)	Wages (%)	Wage rates
Natural resources	38	34	0.90
Utilities	62	58	0.93
Construction	79	81	1.02
Manufacturing	67	59	0.89
Wholesale trade	88	86	0.98
Retail trade	81	82	1.01
Transportation and warehousing	65	67	1.02
Information	92	92	1.01
Financial services	84	88	1.04
Professional and business services	87	88	1.01
Educational and health services	63	63	1.00
Leisure and hospitality services	65	59	0.91
Other services	84	86	1.03
Public administration	76	78	1.02
Total	75	76	1.01

Source: Bureau of Economic Analysis, Regional Economic Information System.

National forecasts of employment, wages, and prices drive the model's New Jersey forecasts.

The model has six key sectors: (1) the industry sector, including employment, gross state product, wage rates, and price deflators for major industries; (2) the personal income sector; (3) the population and labor force sector; (4) the construction and motor vehicles sector; (5) the state tax revenues and expenditures sector, and (6) the electric utility sector. The model also includes a labor-area module that distributes employment, population, and income growth among the state to the State's ten labor areas. The key focus of the model is employment. In general, employment in an industry depends on demand for the output of the sector and on wages and prices relative to national wages and prices. Other major variables are industry wage rates, the components of personal income, the inflation rate, and population. Industry wage rates depend on national wage rates in the same industry, labor market conditions, and relative inflation rates. The New Jersey inflation rate depends on the national inflation rate, and the components of personal income are essentially New Jersey's shares of national income components. Population growth is driven by total employment and by state wages and prices relative to their national counterparts.

The strength of the RECON model is its sensitivity to historical trends in the state economy. The strength of its entrenchment in historical trends is also one of its weaknesses. That is, the past cannot always inform us about how major economic events or activities will affect an economy. The second limitation is that full historical data by industrial sectors for employment and gross product are available at the three-digit NAICS level or less, depending on the sector. Lastly, RECON does not estimate federal and local taxes, but it does forecast about 80% of state tax revenues. The econometric results for income, output, jobs, and tax revenues are presented in Tables 4–8.

The weaknesses of this or any other systematic model is that the set of important relationships among sectors, as well as their magnitudes and directions, are fixed. We do not know precisely how relationships among sectors change when one or more of them suffers (or enjoys) a large, unexpected shock. Steps that can and would be taken to patch together the grid are not captured by most economic models. This is because such an action has not previously occurred at all, let alone with a sufficient frequency that would permit researchers to observe that the ramifications of the shock has statistically measurable relationships with other data internal to these models. In other words, these kinds of models do not have resiliency elements built into them. A model that incorporated resiliency would reveal shorter recovery periods than are currently predicted by such models. Hence some predictions of economic losses—most certainly business losses—would be lowered as well. Such a capability also would allow analysts to assess the economic costs and benefits of resiliency.

In producing results with the RECON model, our first step was to determine the proportion of New Jersey's employment and wage income produced in the PSE&G service territory. We looked at these proportions for the third quarter of 2004, on the assumption that the proportions would not change much between the third quarter of 2004 and the third quarter of 2005. Table 3 below shows the proportion of employment and wage income for New Jersey's major industries in the study area. Data at a more detailed industry level was used to adjust the model for the attack scenarios for all industries except farm-based sectors, which are not included in RECON. The average shares of jobs and wages accounted for by the industries in the counties served by PSE&G were 75% and 76%, respectively. These both are more than the share of

Table 4
Economic baseline for New Jersey, 2004–2010

Economic category	Year 2004 (growth rate, %)	2005 (growth rate, %)	2006 (growth rate, %	2010 (growth rate, %)
Non-agricultural employment (1000s)	31.2 (−2.5)	4053.2 (1.3)	4089.1 (0.9)	4239.1 (0.9)
Food	73.1 (−1.8)	30.7 (−1.5)	30.5 (−0.7)	30.7 (0.2)
Chemicals	31.4 (−3.0)	72.5 (−0.8)	71.2 (−1.8)	71.3 (0.1)
Computers/electronics	98.6 (−3.4)	31.0 (−1.1)	30.4 (−1.9)	28.4 (−1.7)
Information	4002.0 (0.6)	97.4 (−1.2)	96.6 (−0.8)	93.8 (−0.7)
Personal income ($billions)	31.2 (−2.5)	380.5 (5.8)	399.9 (5.1)	496.4 (5.6)
Wages/salaries	73.1 (−1.8)	202.8 (5.0)	212.6 (4.1)	257.6 (4.9)
Gross state product ($billions)[a]	31.4 (−3.0)	403.3 (3.1)	413.3 (2.5)	466.0 (3.0)
Total state tax revenues ($billions)	98.6 (−3.4)	21.621 (7.2)	22.934 (6.1)	28.578 (5.7)

Source: RECON model.
[a]Year 2000 dollars.

Table 5
Economic simulation, low impact, full return of employment

Economic category	2005 (comparison to baseline, %)	2006 (comparison to baseline, %)	2010 (comparison to baseline, %)
Non-agricultural employment (1000s)	4025.5 (−0.7)	4093.4 (1.0)	4245.2 (0.1)
Food	30.5 (−0.7)	30.5 (−0.8)	30.7 (0.1)
Chemicals	71.8 (−0.9)	71.1 (−1.9)	71.4 (0.1)
Computers/ electronics	30.6 (−1.2)	30.2 (−2.4)	28.3 (-0.2)
Information	95.9 (−1.5)	95.7 (−1.8)	94.3 (0.5)
Personal income ($billions)[a]	379.5 (−0.3)	400.0 (5.1)	496.8 (0.1)
Wages/salaries	201.4 (−0.7)	212.7 (4.9)	258.0 (0.1)
Gross state product ($billions)[a]	400.3 (−0.7)	412.1 (2.2)	466.6 (0.1)
Total state tax revenues ($billions)	21.567 (−0.2)	23.242 (7.5)	28.784 (0.7)

Source: RECON model.
[a]Year 2000 dollars.

Table 6
Economic simulation, medium impact, full return of employment

Economic category	2005 (comparison to baseline, %)	2006 (comparison to baseline, %)	2010 (comparison to baseline, %)
Non-agricultural employment (1000s)	4009.0 (−1.1)	4092.1 (1.0)	4244.4 (0.1)
Food	30.4 (−1.1)	30.5 (−0.8)	30.7 (0.1)
Chemicals	71.3 (−1.6)	71.1 (−1.9)	71.5 (0.2)
Computers/ electronics	30.6 (−1.3)	30.5 (−1.6)	28.4 (0.1)
Information	95.2 (−2.3)	95.3 (−2.1)	94.8 (1.0)
Personal income ($billions)[a]	378.8 (−0.4)	400.1 (5.1)	496.9 (0.1)
Wages/salaries	200.6 (−1.1)	212.6 (4.9)	257.9 (0.1)
Gross state product ($billions)[a]	398.6 (−1.2)	411.6 (2.1)	467.2 (0.3)
Total state tax revenues ($billions)	21.544 (−0.4)	23.221 (7.4)	28.788 (0.7)

Source: RECON model.
[a]Year 2000 dollars.

customers served by PSE&G and the proportion of electricity delivered by PSE&G of all electricity delivered to customers in New Jersey (58% in 2004Q3), because the utility does not serve all parts of each of the 13 counties. Note that the share of New Jersey's information-sector jobs in the PSE&G area was 92% whereas the share in manufacturing was only 67%. That is, there are differences in the concentration of industry in the region, and those differences are accounted for in running the simulations.

Before presenting the results, we summarize the capacity of the RECON model to capture shocks to an economic system. This kind of model is based on past behavior of the economy and relies on the most recent past more than the distant past when it is used in forecasting. When the model sees a dip in third summer quarter of 2005, it typically predicts a lesser decline in the next quarter. Its equations typically force its forecasts to slowly return a series to its long-run trend. If we did nothing, the economic predictions would eventually catch up to the long-term trend. But modelers can speed up the recovery by ''manually'' restoring some of the lost economy. In short, it is important that the reader recognize that even sophisticated models cannot directly capture the immediate reactions to economic shocks of business and government leaders and consumers.

4. Results

4.1. Baseline

The baseline forecast covers the period from 2005 to 2010. Table 4 summarizes the model results for the State of New Jersey for key indicators. We show selected data to highlight key indicators and time periods.

Table 7
Economic simulation, high impact, full return of employment

Economic category	2005 (comparison to baseline, %)	2006 (comparison to baseline, %)	2010 (comparison to baseline, %)
Non-agricultural employment (1000s)	3918.5 (−3.3)	4106.1 (1.3)	4266.5 (0.6)
Food	29.7 (−3.4)	30.5 (−0.8)	30.8 (0.5)
Chemicals	69.0 (−4.7)	71.2 (−1.7)	72.4 (1.5)
Computers/electronics	29.7 (−4.1)	30.5 (−1.7)	28.4 (0.1)
Information	90.9 (−6.6)	96.0 (−1.4)	100.8 (7.4)
Personal income ($billions)[a]	375.5 (−1.3)	400.8 (5.3)	498.4 (0.4)
Wages/salaries	196.0 (−3.4)	213.1 (5.1)	259.4 (0.7)
Gross state product ($billions)[a]	389.4 (−3.4)	411.9 (2.1)	472.5 (1.4)
Total state tax revenues ($billions)	21.417 (−0.9)	23.138 (7.0)	28.883 (1.1)

Source: RECON model.
[a]Year 2000 dollars.

Table 8
Economic simulation, medium impact, half return of employment

Economic category	2005 (comparison to baseline, %)	2006 (comparison to baseline, %)	2010 (comparison to baseline, %)
Non-agricultural employment (1000s)	3988.7 (−1.6)	4007.9 (−2.0)	4176.7 (−1.5)
Food	30.2 (−1.7)	29.8 (−2.2)	30.1 (−2.0)
Chemicals	70.9 (−2.2)	68.9 (−3.2)	68.7 (−3.6)
Computers/electronics	30.3 (−2.2)	29.6 (−2.6)	28.2 (−0.9)
Information	94.5 (−3.0)	89.0 (−7.9)	87.5 (−6.8)
Personal income ($billions)[a]	378.0 (−0.6)	396.9 (−0.7)	493.8 (−0.5)
Wages/salaries	199.6 (−1.6)	208.1 (−2.1)	253.4 (−1.6)
Gross state product, ($billions)[a]	396.9 (−1.6)	399.8 (−3.3)	457.7 (−1.8)
Total state tax revenues ($billions)	21.537 (−0.4)	23.062 (0.6)	28.571 (0.0)

Source: RECON model.
[a]Year 2000 dollars.

The number of non-agricultural jobs was 4.0 million in 2004 and the baseline simulation forecasts that it will increase to 4.24 million by 2010, that is, an increase of 240,000 jobs during 6 years (about 40,000 a year) (Mantell, 2005). This increase is consistent with the historical record of New Jersey (Hughes and Seneca, 2004). For example, the state gained 567,000 jobs during the record expansion between May 1992 and June 2001 (about 57,000 a year). In contrast, during the downturn that lasted from March 1989 to April 1992, the state lost 259,000 jobs (about 65,000 a year).

Table 4 provides employment data for four specific business sectors. Production of food, chemicals, computers and electronics, and the information industry were selected because electricity is critical to them and because they are important parts of the state economy. Each of the four has been declining in terms of jobs in New Jersey for years. For example, New Jersey lost 36% of its manufacturing job base between 1990 and 2004. Employment in three manufacturing industries—food, chemicals, and computer and electronic products declined by 20%, 26%, and 49%, respectively. Employment in the information industry declined by 22% between its peak, reached in 2000, and 2004.

Table 4 also provides baseline information for personal income, gross state product, and total state tax revenues. Personal income is a measure of the change in the aggregate wealth of the residents. For this report, we focus on wages and salaries because these should be much more sensitive to local economic shocks than from capital gains through the sales of stocks, bonds, or home sales; from rent, royalties, dividends, or inheritance received; or other sources of income. Gross state product is similar to personal income but shows where the wealth is created rather than where it was received. Moreover, it also includes government tax revenues, government subsidies, and capital depreciation allowances due to all the economic endeavors in the state. State tax revenue is important to policy makers at the state level.

4.2. Impacts with full and immediate restoration of economic activity

Table 5 shows the impacts of the low impact simulation—a 3.525% cut in power in the PSE&G area during the summer 2005 quarter. As anticipated, job losses are more substantial in the four specific energy-sensitive sectors than in the state as a whole in 2005, and these losses carry over into 2006. But by 2010, there is little residual effect.

The state actually is predicted to add 6100 jobs as a result of the event (net difference between the baseline and the simulation). With regard to wages and salaries, gross state product and state taxes, the simulations predict a negative impact in 2005. Yet by 2006, we have added back the lost employment, and so there actually is a positive rebound in these economic measures. That is, rather than losing jobs, income, and gross state product, the model predicts higher levels than had been estimated by the baseline. This is a counterintuitive finding that is discussed below.

The medium impact simulation is described in Table 6. A cut of 5.454% in power in the PSE&G study area in the third quarter of 2005 leads to reductions in all the major indicators of the state's economy during 2005. But we restore the lost jobs, and so in 2006, personal income, gross state product, and tax revenues rebound. Overall state employment also rebounds, although the four specific power-sensitive sectors fall below the baseline forecast. By 2010, however, the impact of the event is hardly noticeable.

Even a loss of 16.415% in the PSE&G study area under the worst-case scenario does not change the overall outcome by 2010. The short-run impacts are quite substantial, including the estimated loss of 135,000 jobs in 2005 (4,053,200−3,918,500), and even relatively higher losses in the four specific business sectors. Yet, assuming that the jobs are restored, Table 7 shows that much of the loss is made up in 2006, and by 2010 there is a complete rebound.

The results of Tables 5–7 are counterintuitive in the sense that returning to "business as usual" after a disaster apparently seems to imply that a region will be better off from a growth perspective. Time-series studies of the economic consequences of natural hazards show that such outcomes might be expected (Guimaraes et al.,1993; West and Lenze, 1994). But natural disasters may be different than the picture painted when there is a terrorist attack. In the case of natural disasters, major effort is undertaken to rebuild damaged regional infrastructure and to replace destroyed equipment as soon as possible after the event. Thus regions update their capital stock and adopt newer technologies in the wake of such disasters, typically improving upon their prior productivity in affected industries. Moreover, often the region's production of replacement materials and equipment and of labor service to affect the repairs in itself provides sufficient economic impetus for the region to pull itself up by its bootstraps.

With regard to the current case, what could cause New Jersey's economy to respond to a temporary electricity outage by exceeding levels of production and employment of the base case? One possible explanation for such a remarkable rebound is provided by Skidmore and Toya (2002) who show that not only is the rate of return to physical capital changed but that firms at least temporarily place more emphasis on the value of their human capital. Ewing and Kruse (2002) may provide an explanation for this when they argue that proactive public–private ventures to prevent disasters tend to improve local market conditions. That is, it may be that disasters force heretofore nonexistent cooperation between individuals in public and private organizations. This newfound cooperation reduces transactional friction within the local economy, making commerce easier and improving labor productivity and regional growth. Unfortunately, since such public–private ventures cannot be econometrically modeled, this proposed explanation cannot be inherent in the results from the model. Hence the answer lies elsewhere.

It turns out that by fully restoring the economy in the aftermath of the disaster, the modeling procedure we applied not only assured that the economy increases to restore production levels as scheduled in the scenarios but it also rises to replace economic stocks consumed during the outage, such as wood, concrete, candles, flashlights, and others. This compensating mechanism is relatively slow, so that replacing the stocks takes a few years. Interestingly, however, once the stocks return to levels that existed before the summer of 2005, the New Jersey economy manages to sustain the surplus production that it used to replace the stocks. This implies that producers would find new markets to take advantage of the productive capacity they raised to compensate for losses incurred as a result of the disaster, a plausible course of economic action.

4.3. Impacts without full restoration of economic activity

If the economic shock is due to human activity, especially a terrorist attack, can we expect the same result? That is, may we assume that all the activity lost during the impact period will return? Since we do not have much of a history of such shocks in the US, some analogies can be used for intentional acts, for example, land contamination. Contaminated sites may be the best counter case to natural hazards. The Appraisal Institute (Roddweig, 2002) published an anthology that shows measurable stigma near contaminated sites. Stigma typically disappears over time because of increased market value of the site, changeover of people living near the site, deliberate change of land uses to accommodate contamination, and attenuation of media attention. Yet stigma can last for many years. In the case of Superfund sites, stigma lasted for at least 5 years, and more in some instances (see also, Dale and Murdoch, 1999; Bible et al., 2005).

Does a place attacked by terrorists engender a response similar to an area hit by a tornado, hurricane, or earthquake, or is the response more like that to a contaminated site? That is, in the case of an attack, do businesses and residents try to make plans to find a place safe from the threat and stigma? Greenberg et al. (2004) used data from two Pew Research Center surveys after 9/11 to show that New York City residents had stronger behavioral responses, including distress, fear, and difficult time sleeping, than their counterparts in Washington, DC, and elsewhere in the nation. Some no longer went to places where terrorist attacks would be likely to occur; a few opted to leave the region; and some chose not fly on airplanes. New Yorkers as a whole were quite resilient. Studies showed that initial levels of post-traumatic shock and depression were two to three time higher than the norm. Some people did not recover from the trauma and lost their employment. Yet the vast majority did recover (Fagan et al., 2003; Boscarino et al., 2004).

With regard to businesses, however, New Jersey actually benefited by business relocation from New York City (Heilmann, 2002; Dolly, 2001). So a change in perceived risk did cause firms to reconsider their expansion and location decisions. Across the Hudson River in New York City, Chernick (2005) found that after 9/11 economic indicators were strong but that the city had lost about $3 billion in output over 2 years and that recovering from that loss would be difficult.

Would there be a complete rebound if New Jersey's electricity supply was attacked by terrorists? Two-thirds of those killed by the 9/11 attacks were residents of New York State. The second largest group was residents of New Jersey. Also, an anthrax exposure incident occurred during this same period, leading to the closing of a central post office. Hence, New Jersey residents likely were more distressed than residents of much of the United States. Whereas many of those afraid to be in the region already would have relocated after 9/11, there could be further relocation of electric-power-sensitive industries. Second, a terrorist attack would hasten the movement of businesses that were not certain about staying in the region, that is, hemorrhaging of weakly tied industries would speed up. A third related possibility is that existing businesses would stay, but expansions would take place outside the study area (Hughes and Seneca, 2005). Overall, in the short run, it is plausible to assume that some businesses and residents would relocate and that the negative dimensions of the impacts would be greater than demonstrated by Tables 5, 6, and 7.

To recognize this possibility, we reran the three simulations, but this time we did not assume that all the jobs in place when the summer 2005 quarter began would be restored in the winter. Instead, only half of the jobs are restored. Table 8 captures the essence of the difference between the first and second set of simulations. We present the results for the "medium" event scenario.

Comparing the results of Tables 6 and 8, the impact is barely perceptible in 2005. Total non-agricultural employment for the fully restored simulation was 4,009,000 compared to 3,988,700 for the half restored version, a difference of 20,000. But the difference jumps substantially in 2006. The fully restored simulation projects 4,092,100 jobs and the half restored version only 4,007,900, a difference of 84,000. By 2010, the difference has only closed slightly to 67,000: 4,244,400 compared to 4,176,700.

There is no rebound for wages and salaries or for gross state product in the half restored simulation. In 2006, personal income is $3.2 billion less, wages and salaries are $4.5 billion less, and gross state product is $11.8 billion less than forecasted by the medium impact-fully restored scenario. The difference closes only slightly by 2010. Simulations were also made for the low- and high-impact scenario versions of the half restored model. These decrease or increase the magnitude of the difference between the fully and half restored scenarios. But the message is the same. The fully restored assumption leads to a rebound and net growth, and half restored model implies a loss of in the region and migration of economic activity.

5. Discussion

Before describing the research and policy implications of the research, we re-iterate the key limitation of applying these standard regional economic models to an economic shock is good data. This corresponds to our stated objective of assessing the data and indicating how it can be improved. The models capture the key transactions in the economy. However, no simulation modeling can perfectly forecast the implications of a shock. Whether there is a sudden increase in demand for a product or a sudden decrease, models cannot anticipate what will happen in response to the significant sudden change. Simulations are limited by the underlying assumptions made by the analysts that build them, the history contained in the data that mold them, and in the reality of the equilibrium conditions assumed in the model's equations and coefficient structures. When a shock occurs, the equations embedded in the model do not change even though some of the transactions may change. Model users can change the results by changing the inputs, but the model equations themselves remain unchanged.

In this specific research, detailed information about a number of interactions would have helped. The literature indicated that medical care facilities have their own back-up power source. Using that information, we cut power loss to the health care sector of the model by only 50% rather than completely. But we had no access to similar information for many other industries. For example, it may be that chemical, food, and other highly impacted businesses in New Jersey have installed back-up systems. If they have, then the impacts on them are likely to be less than shown in the scenarios. We also know neither how many commuters would be unable to get to work nor for how long the inability to commute would last. Nor do we know what the impact of the scenarios would be on the capacity of public potable water systems or sewerage treatment systems to function at full capacity. These specifics serve to illustrate the need for detailed field-work to better understand the capacity of the existing systems. Upon receipt of such information, model inputs can be modified to produce more sensible and sensitive results. We are planning a study of resiliency using responses of utilities in the path of Hurricane Katrina as a method of capturing resiliency.

More information is also needed to attempt an analysis of multiple events, rather than of a single occurrence. The models can accommodate multiple events in multiple time periods. But we need more information about equipment destruction, back-up capacity, and other key variables before such simulations can be credibly done. If, for example, multiple events are more likely to damage equipment, we need detailed information on them to produce realistic results from economic models. We also need to think about the environmental implications of mitigating some potential impacts. For example, the use of small-scale back-up power sources instead of power plants that are unavailable due to a terrorism event may have implications for air quality because back up power sources typically have higher air emissions per unit of output than power plants. This effect could be particularly pronounced in dense urban regions like New Jersey, which have pre-existing air quality concerns. Summarizing, we need more information about the impacts of multiple events on capital and labor, resiliency, and regional constructs that are the most sensible for future analysis.

With regard to transferring this modeling approach to the national scale or to specific regions, economic models can be constructed for regions as small as counties, due largely to the wealth of data to such small areal levels. Ideally, however, economic models are constructed for functional economic areas. That is, although it is possible to do so, we prefer to build models for larger regions where most of the impacts can be internalized, rather than for cities or counties where there is likely to be significant spill-over of impacts to outside the region. This study focused on one state. Multiregional models could be built to study the impact on each member of a set of states, competing metropolitan regions, or even non-contiguous areas that maintain substantial economic transactions. Before committing substantial resources to constructing any economic model, we urge their potential users to consider carefully the set of regions to be studied. Ideally, we would construct a single model that is multi-regional, which would allow the policy maker to understand the multi-regional impacts of an event in one place, and of multiple events on many places. In the case of electrical power delivery, it makes sense to construct the regions around the service areas.

The most important policy implication of this study is obvious. If the electrical power system is resilient, then a terrorist attack on the system is likely only to have short-term consequences. If, however, the system fails to respond quickly, and businesses perceive that the region is riskier for them than it was before the event, then any location where such system failures occur can be seen as becoming a less desirable place in which to conduct business and live. While this is a pilot project—and we re-iterate the numbers are not necessarily indicative of what would actually happen in the wake of such an event—the magnitude of the possible impacts should serve as a wake-up call to federal, state and utility officials. We hope that the results will be used as a starting point from which the officials will ponder the value of building resiliency into the electricity distribution system. This is a daunting challenge, but one we think is imperative to undertake.

Acknowledgements

This research was supported by the United States Department of Homeland Security through the Center for Risk and Economic Analysis of Terrorism Events (CREATE), grant number EMW-2004-GR-0112, under a subcontract with New York University. Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the views of the US Department of Homeland Security.

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