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Author(s): Boero, Riccardo
Edwards, Brian Keith

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Hurricane Sandy Economic Impacts Assessment: A Computable General Equilibrium Approach

Riccardo Boero [1,*], **Brian K. Edwards** [1]

[1] *Los Alamos National Laboratory*

Correspondence*:
PO Box 1663, MS P939, Los Alamos, NM USA 87545
riccardo@lanl.gov +1 505 665 6997

ABSTRACT

Economists use computable general equilibrium (CGE) models to assess how economies react and self-organize after changes in policies, technology, and other exogenous shocks. CGE models are equation-based, empirically calibrated, and inspired by Neoclassical economic theory. The focus of this work was to apply the National Infrastructure Simulation and Analysis Center (NISAC) CGE model to the problem of assessing the economic impacts of severe events. We used the 2012 Hurricane Sandy event as our validation case. In particular, this work first describes the empirical data available for studying the event of focus. Shocks to the model are then formalized and applied. Finally, model results and limitations are presented and discussed, pointing out the assessed total damage caused by Hurricane Sandy.

Keywords: computable general equilibrium (CGE) model, model calibration, model validation, economic impacts assessment, Hurricane Sandy, disasters economic damage

1 INTRODUCTION

Computable general equilibrium (CGE) models are some of the most advanced and widely used tools that economists use to assess how economies react and self-organize after changes in policies, technology, and other exogenous shock. CGE models are equation-based, empirically calibrated, and inspired by neoclassical economic theory. CGE models represent the self-organization of economies through the balancing of supply and demand by means of modifications of quantities and prices. Supply is represented by profit maximizing firms; their production function effectively captures both intermediates and production factors needs. Final demand is represented by utility maximizing in households, government, and investments.

CGE models also include a representation of saving and international trade. CGE models can be extended to include representations of factors markets (capital and labor). CGE models also support comparative static and dynamic analyses. Dynamic CGE models can include inter-temporal decision-making and dynamic mechanisms propagating impacts from period to period.[1]

CGE models are used extensively for policy analysis and economic impact assessment. See (Dixon and Jorgenson, 2013) for a recent and complete review of CGE applications. Because of the many analytic capabilities provided by the CGE approach, the authors used this approach to develop the National Infrastructure Simulation and Analysis Center (NISAC) CGE model (NCGEM) and a novel calibration approach that allows very spatially detailed estimations.[2]

This work focused on validating NCGEM and evaluating the model's ability to replicate empirical evidence. Evaluation is often confused with model calibration (i.e., the specification of model parameters) and verification (i.e., the verification that the model implementation actually and effectively contains all the designed components), and explaining model results to stakeholders (e.g., "back of the envelope" models as in Dixon and Rimmer, 2013). In contrast, model validation requires replicating historical events and comparing model results with historical observations.

Validation using empirical evidence is necessary but insufficient for assessing analytic and predictive capabilities of any model. Validation builds upon two further elements to provide confidence in the model's capabilities. First, economists have used the CGE modeling approach for several decades; CGE's standard structural components are included in the NCGEM model; these components have been extensively investigated and tested. Economic theory supports the structural validity of the CGE model. The standard CGE components include all of the necessary dynamics to represent the self-organization of economic systems with a high level of detail (Hosoe et al. (2010). Second, CGE models require empirical calibration. To ensure quality results, economists must calibrate economic data. In the context of NCGEM, calibration is based on an innovative estimation procedure that improves the state of the art. The estimation procedure adopted here guarantees a high level of accuracy to the model's empirical calibration. This validation is intended to evaluate whether the approach as a whole is empirically salient.

For this validation we assess the impact of Hurricane Sandy on the East Coast of the United States in 2012. By replicating the event impacts and gaining confidence in the model capabilities, we can improve the assessment of its economic costs. We compare NCGEM results to empirical results in the aftermath of this hurricane to assess whether the model can produce outcomes consistent with historical observations. The assessment of event costs relies on a comparison of two scenarios that represent the economic system with and without an event.[3]

2 THE NISAC CGE MODEL

Economists have used the CGE approach to assess the impacts of events or policy measures on national and regional economies. The CGE approach involves dividing an economy into sectors, such as household, business, government, etc. To model sector behavior, agents in each sector solve an optimization problem particular to that sector. This approach posits, for example, that the household sector is composed of agents that sell labor and capital to the business sector and purchase goods and services using income earned from the business sector to maximize utility, subject to income and possibly other constraints. The business sector purchases labor and capital from the household sector plus intermediate goods from other businesses and then transforms these inputs into goods and services for sale to other sectors in the economy. Other sectors are defined similarly. This approach calculates impacts due to events or policy measures using a process similar to that seen in the real world, i.e., different sectors interact through the different markets that connect them. Hosoe et al. (2010) is an important source for the particular CGE model used to conduct this analysis. Economists at Los Alamos National Laboratory modified that model to allow it to better suit NISAC's particular needs, including the ability to examine the impacts of shocks dynamically. We use data from the United States Bureau of Economic Analysis, the United States Bureau of Labor Statistics, and the International Trade Commission to calibrate the model. The models relies on Social Accounting Matrix (SAM) tables. SAM tables reflect how goods and services are produced, including the dependency of each industry on the activity of other industries. The methods used to create and regionalize the SAMs are discussed in Boero et al. (2017). See also Boero et al. (2016).

3 MODELING OF DIRECT ECONOMIC SHOCKS

We focused the analysis on the U.S. states directly affected by Hurricane Sandy–Connecticut, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, and West Virginia – see also Table 3)and less affected states in continental United States. We used peak power outage data as reported twice a day in emergency situation reports published by the Office of Electricity Delivery and Energy Reliability (2017). Based on those data, we selected the seven states that had at least 5% of customers without power at peak.

Hurricanes affect electric power systems and assets due to strong winds and flooding. Wind strength differentiates hurricanes and tropical cyclones from other types of storms. When the path of hurricanes passes near or intersects with land, hurricane-force winds can damage buildings. This type of damage happens because winds impact buildings directly, throw debris at built structures (e.g., uprooted trees), and winds approaching coastal areas generate storm surge, which can flood structures for several miles inland. Infrastructure system disruption may disrupt economic activities. For example, larger areas may experience power blackouts because strong winds and debris damage system assets.

Overall, those seven states account for 89.5% of Sandy-induced power outage, measured in terms of customers without power (Office of Electricity Delivery and Energy Reliability, 2017; Mansfield and Linzey, 2013) and 98.9% of buildings damaged by the hurricane (New Light Technologies and ImageCat, 2017). Figure 1 shows the NOAA International Best Track Archive for Climate Stewardship (IBTrACS) (2017) hurricane track's path through and the affected states.

Following the literature (Hallegatte and Przyluski, 2010), we introduce direct losses of assets (i.e., damaged buildings) and output losses due to infrastructural disruption (i.e., business interruptions because of power outages) as the primary direct economic shocks caused by the hurricane. Several other minor direct shocks may have existed in the historical case we investigate. For instance, fishing companies along the entire East Coast may have experienced a few days of business interruption because of the path of the hurricane and related wind and sea conditions. These direct impacts are of minor impact and not do differ significantly from the impacts of other

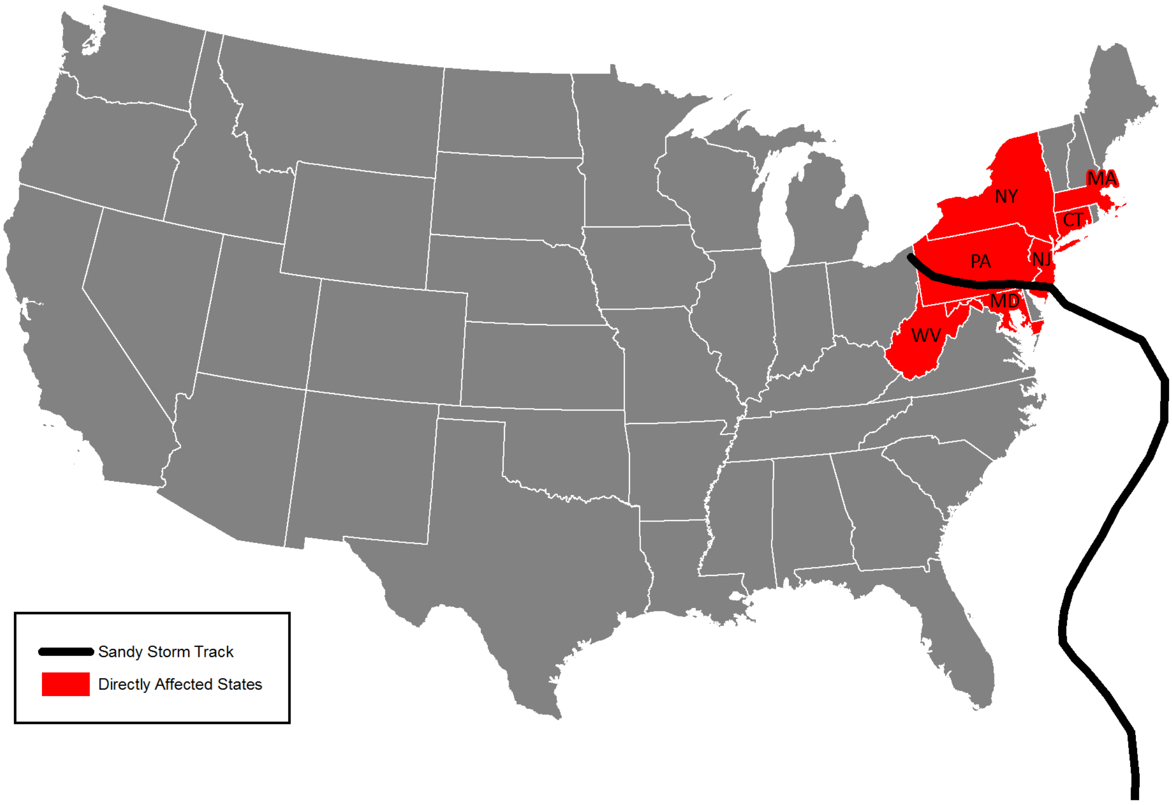

Figure 1. Hurricane Sandy center track (black) and the two regions considered: the seven states directly affected (red) and the rest of CONUS (blue).

storms and severe weather events; as such, we do not considered them for model validation or total damage assessment.

The use of NCGEM and two modeled shocks allows us to estimate indirect economic impacts, including the indirect loss of output because of the loss of assets (Hallegatte and Przyluski, 2010) and the propagation of impacts across industries, factors, time, and space.

3.1 Data Preparation

We conduct a four-step data preparation approach to transform damaged buildings into losses of capital that we can use in our CGE analysis. First, we exclude the buildings that were likely residential at the time of the hurricane. We intersect the points representing damaged buildings with a map of Census blocks that includes information about workplace characteristics in 2011 provided by Census (2017) at the same spatial scale. Damaged buildings located in blocks where there are no economic establishments are excluded from further analyses. Damage severity measurements go from "affected" through "minor" to "major" to "destroyed". "Affected" indicates superficial damage to solid structures, the displacement of mobile and light structures, and the destruction of up to 20% of the roofs in the affected area, and up to 2 feet of inundation. "Destroyed" indicates that the minority of exterior walls available for each building are all that remain. FEMA (2017) discussed the damage classification severity levels, as shown in Table 1.

Second, we equate the four damage severity levels to percentages of capital loss. In particular, "destroyed" buildings are assumed to represent total capital loss (i.e., 100%), "major" represent 50%, "minor" represent 20%, and "affected" represent 10%.

Third, we associate employment levels registered for each industry at the two-digit North American Industry Classification System (NAICS) level reported in Census (2017) for each building on blocks assumed to have business activity.

Finally, we assume that the damage assessed to a building is representative of the capital loss and economic activity on the block. We also assume that adopted technologies vary across industries but not within the area so we can use employment as proxy for the other production factors (i.e., as proxy of capital). We compute a capital loss percentage k for each industry i as

$$k_i = \frac{\sum_d (e_{i,d} s_d)}{\sum_b (e_{i,b})}, \tag{1}$$

where b represents all blocks, d represents blocks with damaged buildings, e represents the employment in 2011, and s represents the percentage associated with the severity level as discussed above. These values are transformed into 15 industries at the 2-digits NAICS code level and then annualized. We assume that the capital loss begins on the first day of the event, Monday October 29, 2012, and that it lasts through December 31, 2012.

3.2 Asset Loss: Storm Surge and High Winds Damage to Capital

The Federal Emergency Management Agency Modeling Task Force (MOTF – FEMA, 2017), New Light Technologies and ImageCat (2017) developed a comprehensive database of the buildings damaged by Hurricane Sandy. We assess damage from storm-surge inundation and damage caused by high winds. Aerial imagery damage assessments allow for the direct assessment of damage for some buildings and may represent the ground truth of inundation-based estimates of damage.

The database (New Light Technologies and ImageCat, 2017) contains about 320,000 points that correspond to damaged buildings; 315,935 of them are located in the study area. In particular, 51.26% of them are in New Jersey, 43.30% in New York, and 5.27% in Connecticut. Figure 2 presents the spatial location of damage buildings in the area through a heat map representation; darker colors correspond to spatial clusters of several damaged buildings.

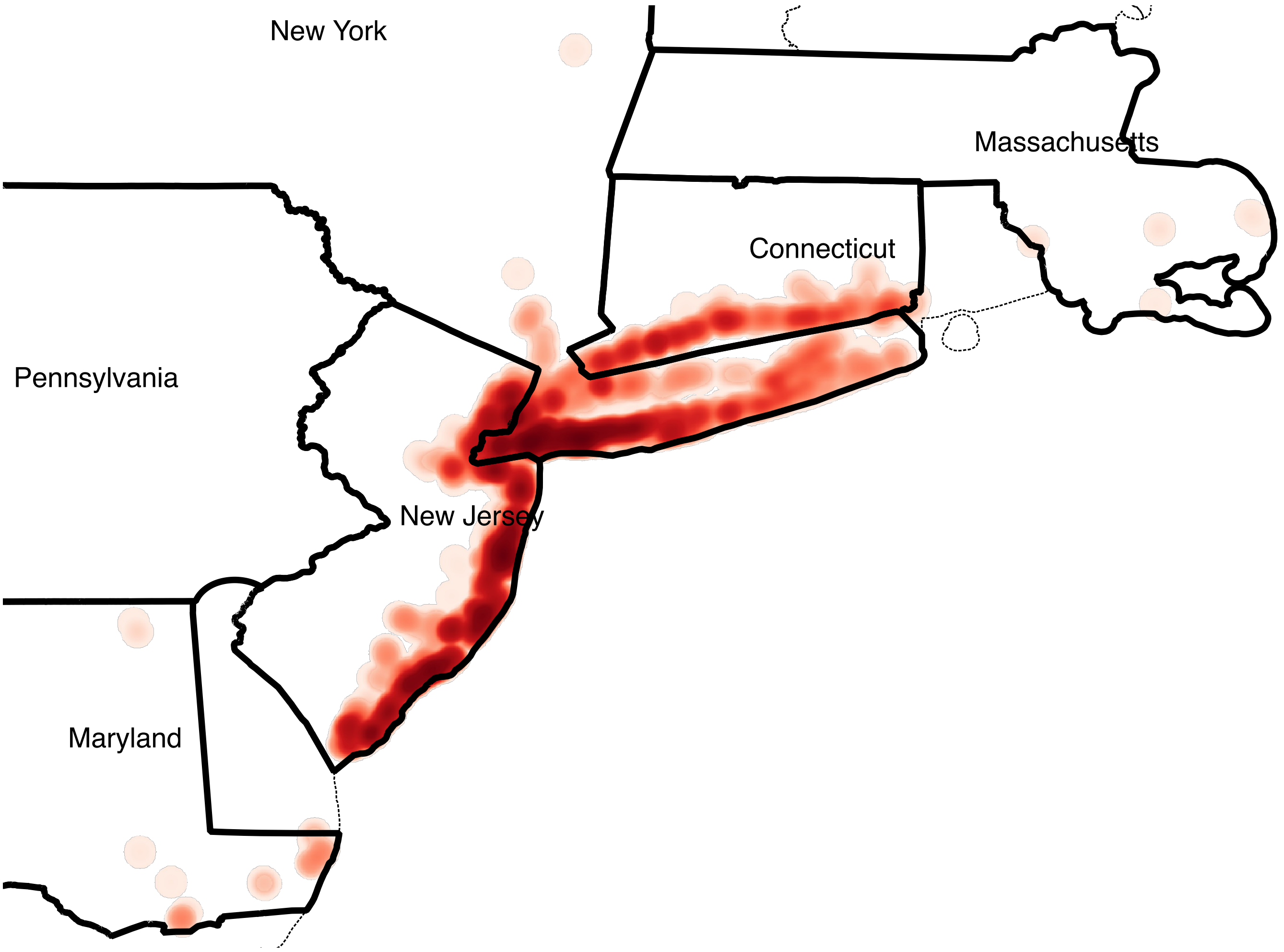

Figure 2. Spatial distribution of residential and non-residential damaged buildings (dark red indicates areas damaged buildings).

Table 1 reports the number and the percentage distribution of damaged buildings that are likely business-related at the assessed severity level. The table reports 161,151 building that are associated with business activity. We determined the number of business-related buildings by excluding buildings on Census blocks that had no measured economic activity in 2011. We assume that no economic activity is indicative of residential-only Census blocks.

Table 1. Distribution of damaged buildings by severity levels.

Severity	Number	Percent
Affected	80,317	49.84
Minor	68,522	42.5
Major	11,969	7.43
Destroyed	343	0.21

Table 2 reports the resulting values of capital loss by industry. We use these values as one of the two shocks that define the Hurricane Sandy scenario.

Table 2. Annualized capital loss by industry as percentage of capital used in 2011.

Industry	Capital Loss
Agriculture, forestry, fishing, and hunting	0.46%
Mining	0.02%
Utilities	1.57%
Construction	1.64%
Manufacturing	1.18%
Wholesale trade	2.30%
Retail trade	1.03%
Transportation and warehousing	3.89%
Information	0.66%
Finance, insurance, real estate, rental, and leasing	0.99%
Professional and business services	0.83%
Educational services, health care, and social assistance	0.94%
Arts, entertainment, recreation, accommodation, and food services	1.46%
Other services, except government	1.14%
Government	0.50%

3.3 Output Loss: Business Interruptions due to Electric Power Outages

During the event the Office of Electricity Delivery and Energy Reliability (2017) published emergency situation reports at 10 a.m. and 3 p.m. that summarized utility-reported power outages. We use the 3 p.m. emergency situation report data, aggregated at the state level, as reported in Mansfield and Linzey (2013), for the seven states. We also use state-level total retail customers reported by EIA (2017), referring to 2012 (for details about the collection of these data see EIA-861, 2017) to compute power outage as percentage over total customers. Table 3 shows the resulting peak power outage by state.

Table 3. Peak of power outage.

State	Peak Power Outage (as percentage over total customers)
Connecticut	38.92%
Maryland	10.26%
Massachusetts	8.23%
New Jersey	66.08%
New York	26.04%
Pennsylvania	20.45%
West Virginia	26.73%

The percentage of peak power outages make evident the extensive hurricane impacts in New Jersey and Connecticut. Absolute values of customers without power reported in Figure 3 indicate the impacts on New York and Pennsylvania.

Figure 3 presents the restoration process in different states for the time frame from October 29, 2012, through November 6, 2012, which is the last day considered for estimating the shock due to direct impacts of Hurricane Sandy.

The restoration process was incomplete on November 6, as shown in the figure. Emergency situation reports published at 10 a.m. on November 7 reported that in the early morning of November 7, about 650,000 customers were without power in the affected area. A subsequent storm interrupted complete restoration and outaged about 150,000 additional customers in the area. [4]

We consider the Nor'easter out of scope, although its impacts were probably exacerbated by the still-incomplete recovery from Hurricane Sandy. We consider only the power outage observed in the period represented in Figure 3 as the direct impact

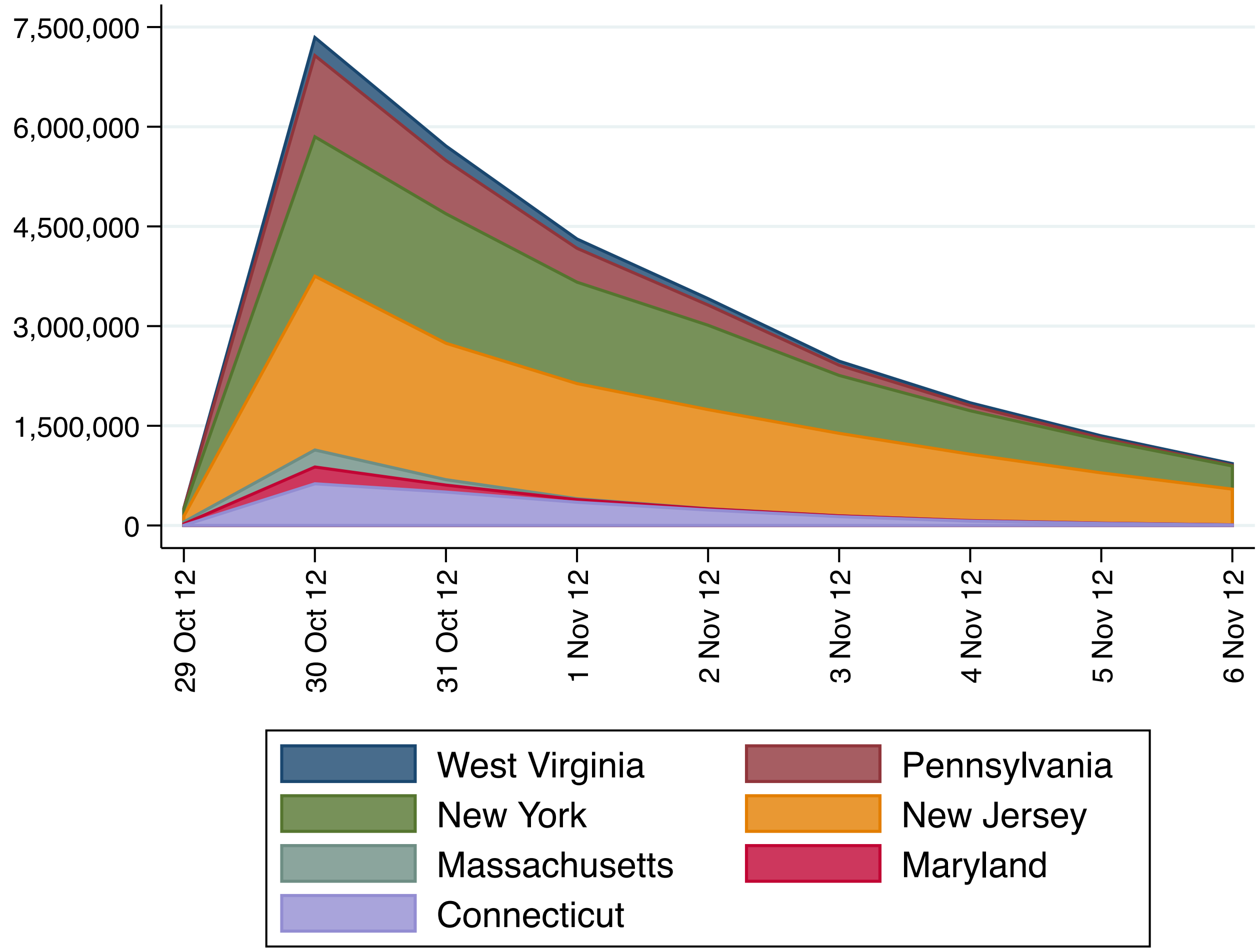

Figure 3. Customers without power by state.

of Hurricane Sandy (i.e., the nine days between October 29 and November 6).

We process the daily number of customers without electric power into an economic shock through several data transformations. First, we divide the number of customers without power by the total number of customers by state (EIA, 2017), day by day and state by state. Second, we annualize each daily value by dividing the electric power outage percentage by 365. We assume that there is no significant difference between the power outage for residential and business customers; because the numbers presented so far refer to both types of customers, we assume that percentages of the power outage can be interpreted as the percentage of business output reduction.

Finally, to compute the value of business output reduction for the focus area, we compute the weighted average value of annualized state percentage of power outage (i.e., percentage of business output reduction) using state gross domestic product (GDP) in 2011 as weights. The resulting value is an output reduction of 0.2973807% in the region. In our analysis we apply that value homogeneously as a reduction in maximum achievable output relative to the one observed in 2011 for all industries.

4 MODEL RESULTS

Table 4 shows the annual impacts on GDP and its components, as well as impacts on capital and labor expenditures for period from the 2012 through 2016.

The physical damages and associated economic impacts are short-lived because the hurricane was of short duration. The short duration of the event and resulting physical impacts mean that the bulk of the economic impacts are felt in the first year.

This analysis does not capture the effects of injections of federal and state expenditures to restore the affected areas. Because we are assessing economic damages caused by the event, we do not estimate the impacts net of recovery and restoration expenditures. Incorporating the effects of restoration and recovery expenditures into the analysis is complicated by considerations of how such expenditures would be financed. Increasing expenditures on restoration and recovery, for example, could entail diverting resources from other uses, which could mitigate any offsetting impacts of these expenditures. In addition, this analysis does not estimate losses in property values or attempt to assign values to the physical damages to roads or other physical assets. Finally, the analysis does not estimate values due to injuries or fatalities from the hurricane or health care expenditures required to treat these injuries, nor does the analysis estimate the cost of restoration and recovery activities. We discuss how this analysis compares with others in Section 5.

The results of the model show an overall reduction in output of 0.83 percent in the first year (in terms of deviation from baseline), which reduces output from its baseline of $6.33 to $6.28 trillion, or a reduction of $52.8 billion. The economy recovers during the second year, so much so that loss in output is $5.1 billion, which amounts to a 0.07 percent reduction. Over the remaining three years of the simulation, most economic activity has recovered, but the 2016 regional economy is still showing output 0.05 percent below baseline. The losses in regional GDP, which exclude the value of intermediate output, mirror the losses in overall output. The first-year reduction in regional GDP is 0.85 percent, or $31.7 billion. These losses attenuate over the simulation period, so that by 2016, losses in regional GDP are 0.04 percent, or $1.9 billion.

Personal consumption spending generally constitutes the largest component of GDP. The first-year reduction in consumption expenditures of nearly $22 billion accounts for roughly 69 percent of the reduction in GDP. Government spending (excluding any expenditures on recovery and restoration) decreases by $7.3 billion in the first year, accounting for nearly 23 percent of the decrease in GDP. Investment spending decreases by $2.9 billion in the first year, which accounts for just over 9 percent of the first-year decrease in GDP. Exports and imports decrease by about the same amount ($23.5 and $23.8 billion, respectively), so the effect on next exports is negligible. Spending on labor decreases by $28.6 billion in the first year, but recovers quickly enough so that the labor market returns to baseline by the beginning of the second year. Capital expenditures do not decrease in the fist year, but show small reductions in later years.

Table 4. Summary of Economic Impacts (billions of dollars and percent deviation from baseline).

Variable	2012	2013	2014	2015	2016
Output					
- Absolute Change	-52.77	-5.09	-4.67	-4.31	-3.94
- Percent Change	-0.83	-0.08	-0.07	-0.06	-0.05
GDP					
- Absolute Change	-31.68	-2.78	-2.43	-2.13	-1.87
- Percent Change	-0.85	-0.07	-0.06	-0.05	-0.04
Personal Consumption Expenditures					
- Absolute Change	-21.65	-2.07	-1.81	-1.59	-1.39
- Percent Change	-0.82	-0.07	-0.06	-0.05	-0.04
Investment Spending					
- Absolute Change	-2.87	-0.26	-0.23	-0.19	-0.16
- Percent Change	-0.61	-0.05	-0.04	-0.04	-0.03
Government Spending					
- Absolute Change	-7.29	-0.45	-0.39	-0.35	-0.31
- Percent Change	-0.97	-0.06	-0.05	-0.04	-0.04
Exports					
- Absolute Change	-23.48	-2.60	-2.52	-2.46	-2.33
- Percent Change	-0.82	-0.09	-0.08	-0.07	-0.07
Imports					
- Absolute Change	-23.61	-2.60	-2.52	-2.46	-2.33
- Percent Change	-0.82	-0.09	-0.08	-0.07	-0.07
Labor Expenditures					
- Absolute Change	-28.51	0.00	0.00	0.00	0.00
- Percent Change	-1.46	0.00	0.00	0.00	0.00
Capital Expenditures					
- Absolute Change	0.00	-2.87	-2.63	-2.40	-2.17
- Percent Change	0.00	-0.16	-0.14	-0.11	-0.10

Table 5 shows output losses by industry. The distribution of output losses reflects the distribution of economic impacts in the hurricane-affected areas. The internal structure of the regional economy as reflected in the input-output component of the SAM table also drives economic impacts. The response of markets for the factors of production (capital and labor) to the direct shock caused by the hurricane also drives impacts. The model results indicate that the largest first-year percentage reductions in output occur in the Education, Health Care and Social Assistance; Government, Transportation and Warehousing, Other Services, Professional and Technical Services; and the Arts, Entertainment, Recreation, Accommodation, and Food Services industries. In terms of absolute reductions in output, the largest reductions occur in the Government; Professional and Technical Services; Manufacturing; Education, Health Care, and Social Assistance; Wholesale Trade; and Arts, Entertainment, Recreation, Accommodation, and Food Services industries. Taken together, output losses account for nearly $41 billion of the total $53 billion loss.

Table 5. Output Impacts by Industry (percent deviation from baseline).

Industry	2012	2013	2014	2015	2016
Agriculture, Forestry, Fishing	-0.11	-0.64	-0.63	-0.55	-0.43
Mining	-0.54	-0.08	-0.06	-0.04	-0.03
Utilities	0.14	-0.17	-0.13	-0.10	-0.08
Construction	-0.95	-0.03	-0.02	-0.02	-0.01
Manufacturing	-0.86	-0.06	-0.04	-0.02	-0.01
Wholesale Trade	-1.04	-0.05	-0.05	-0.05	-0.04
Retail Trade	-1.08	-0.04	-0.03	-0.02	-0.02
Transportation, Warehousing	-1.40	0.01	0.02	0.02	0.02
Information	-0.65	-0.08	-0.05	-0.04	-0.03
Finance, Insurance, Real Estate, Rental, Leasing	-0.04	-0.14	-0.11	-0.08	-0.06
Professional, Technical Business Services	-1.22	-0.01	0.00	0.01	0.01
Education, Health Care, Social Assistance	-1.66	0.02	0.02	0.02	0.01
Arts, Entertainment, Recreation, Accommodation, Food Services	-1.15	-0.03	-0.02	-0.01	-0.01
Other Services Except Government	-1.38	0.00	0.01	0.02	0.02
Government	-1.44	0.00	0.00	0.00	0.00
Total	-0.83	-0.08	-0.07	-0.06	-0.05

The impacts on output discussed above with respect to industry are roughly mirrored when we consider impacts by industry on regional GDP, the individual components of GDP, and labor and capital expenditures. Table 6 shows the impacts on GDP by industry. The largest percentage reductions in GDP occur in roughly the same set of industries as did the largest percentage reductions in output. First-year reductions in GDP are highest in the Professional and Technical Services; Transportation and Warehousing; Education, Health Care and Social Assistance; Other Services; and Government industries.

Table 6. GDP Impacts by Industry (percent deviation from baseline).

Industry	2012	2013	2014	2015	2016
Agriculture, Forestry, Fishing	0.74	-0.95	-0.80	-0.64	-0.48
Mining	-1.01	-0.06	-0.05	-0.04	-0.03
Utilities	0.91	-0.23	-0.16	-0.12	-0.09
Construction	-0.99	-0.02	-0.01	-0.01	0.00
Manufacturing	-0.54	-0.04	0.03	0.09	0.14
Wholesale Trade	-1.09	-0.03	-0.02	-0.01	-0.01
Retail Trade	-1.09	-0.04	-0.03	-0.02	-0.02
Transportation, Warehousing	-2.08	0.15	0.19	0.23	0.27
Information	-0.49	-0.09	-0.06	-0.04	-0.03
Finance, Insurance, Real Estate, Rental, Leasing	0.24	-0.16	-0.12	-0.08	-0.06
Professional, Technical Business Services	-2.72	0.24	0.28	0.34	0.40
Education, Health Care, Social Assistance	-1.68	0.03	0.02	0.02	0.02
Arts, Entertainment, Recreation, Accommodation, Food Services	-1.27	-0.02	-0.01	0.00	0.00
Other Services Except Government	-1.65	0.04	0.05	0.05	0.05
Government	-1.48	0.00	0.00	0.00	0.01
Total	-0.85	-0.07	-0.06	-0.05	-0.04

The impacts on personal consumption expenditures by industry are comparable to those for GDP, shown in Table 7. The largest percentage reductions in consumption spending occur in Education, Health Care and Social Assistance; Government; Professional and Technical Services; Retail and Wholesale Trade; and the Arts, Entertainment, Recreation, Accommodation, and Food Services industries.

Table 7. Consumption Expenditure Impacts by Industry (percent deviation from baseline).

Industry	2012	2013	2014	2015	2016
Agriculture, Forestry, Fishing	-0.75	-0.11	-0.10	-0.08	-0.07
Mining	-0.76	-0.08	-0.07	-0.06	-0.05
Utilities	-0.58	-0.10	-0.08	-0.07	-0.06
Construction	NA	NA	NA	NA	NA
Manufacturing	-0.81	-0.08	-0.06	-0.06	-0.05
Wholesale Trade	-0.92	-0.06	-0.05	-0.04	-0.04
Retail Trade	-0.91	-0.06	-0.05	-0.05	-0.04
Transportation, Warehousing	-0.87	-0.07	-0.06	-0.05	-0.04
Information	-0.74	-0.08	-0.07	-0.06	-0.05
Finance, Insurance, Real Estate, Rental, Leasing	-0.56	-0.10	-0.08	-0.06	-0.05
Professional, Technical Business Services	-0.95	-0.06	-0.05	-0.04	-0.04
Education, Health Care, Social Assistance	-1.01	-0.05	-0.05	-0.04	-0.04
Arts, Entertainment, Recreation, Accommodation, Food Services	-0.90	-0.07	-0.06	-0.05	-0.04
Other Services Except Government	-0.91	-0.06	-0.06	-0.05	-0.04
Government	-1.01	-0.05	-0.05	-0.04	-0.04
Total	-0.82	-0.07	-0.06	-0.05	-0.04

The distribution of investment spending impacts by industry are comparable to those for personal consumption expenditures, as shown in Table 8. Investment spending is most affected in the Government; Professional and Technical Services; Construction; Wholesale Trade; Retail Trade; Other Services; and the Arts, Entertainment, Recreation, Accommodation, and Food Services industries.

Table 8. Investment Expenditure Impacts by Industry (percent deviation from baseline).

Industry	2012	2013	2014	2015	2016
Agriculture, Forestry, Fishing	NA	NA	NA	NA	NA
Mining	-0.51	-0.06	-0.05	-0.04	-0.04
Utilities	-0.33	-0.08	-0.07	-0.05	-0.04
Construction	-0.67	-0.05	-0.04	-0.03	-0.03
Manufacturing	-0.57	-0.06	-0.05	-0.04	-0.035
Wholesale Trade	-0.67	-0.04	-0.04	-0.03	-0.02
Retail Trade	-0.66	-0.05	-0.04	-0.03	-0.03
Transportation, Warehousing	-0.63	-0.05	-0.04	-0.03	-0.03
Information	-0.49	-0.06	-0.05	-0.04	-0.03
Finance, Insurance, Real Estate, Rental, Leasing	-0.31	-0.08	-0.06	-0.05	-0.04
Professional, Technical Business Services	-0.70	-0.04	-0.03	-0.03	-0.02
Education, Health Care, Social Assistance	NA	NA	NA	NA	NA
Arts, Entertainment, Recreation, Accommodation, Food Services	-0.65	-0.05	-0.04	-0.03	-0.03
Other Services Except Government	-0.66	-0.05	-0.04	-0.03	-0.03
Government	-0.77	-0.04	-0.03	-0.03	-0.02
Total	-0.61	-0.05	-0.04	-0.04	-0.03

The distribution of government spending impacts by industry is comparable to those for personal consumption and investment expenditures, as shown in Table 9. Investment spending is most affected in the Government; Professional and Technical Services; Construction; Wholesale Trade; Retail Trade; Other Services; and the Arts, Entertainment, Recreation, Accommodation, and Food Services industries.

Table 9. Government Expenditure Impacts by Industry (percent deviation from baseline).

Industry	2012	2013	2014	2015	2016
Agriculture, Forestry, Fishing	-0.73	-0.11	-0.10	-0.08	-0.07
Mining	NA	NA	NA	NA	NA
Utilities	NA	NA	NA	NA	NA
Construction	-0.90	-0.07	-0.05	-0.05	-0.04
Manufacturing	-0.79	-0.08	-0.06	-0.05	-0.05
Wholesale Trade	-0.90	-0.06	-0.05	-0.04	-0.04
Retail Trade	NA	NA	NA	NA	NA
Transportation, Warehousing	-0.86	-0.07	-0.06	-0.05	-0.04
Information	-0.72	-0.08	-0.07	-0.05	-0.05
Finance, Insurance, Real Estate, Rental, Leasing	NA	NA	NA	NA	NA
Professional, Technical Business Services	-0.93	-0.06	-0.05	-0.04	-0.04
Education Health Care Social Assistance	NA	NA	NA	NA	NA
Arts, Entertainment, Recreation, Accommodation, Food Services	NA	NA	NA	NA	NA
Other Services Except Government	-0.89	-0.07	-0.06	-0.05	-0.04
Government	-1.00	-0.05	-0.05	-0.04	-0.03
Total	-0.97	-0.06	-0.05	-0.04	-0.04

The distribution of exports impacts by industry is comparable to those for personal consumption and investment expenditures, as shown in Table 10. Investment spending is most affected in the Government; Professional and Technical Services; Construction; Wholesale Trade; Retail Trade; Other Services; and the Arts, Entertainment, Recreation, Accommodation, and Food Services industries.

Table 10. Exports Impacts by Industry (percent deviation from baseline).

Industry	2012	2013	2014	2015	2016
Agriculture, Forestry, Fishing	-0.06	-0.69	-0.66	-0.57	-0.44
Mining	-0.28	-0.10	-0.07	-0.05	-0.03
Utilities	0.61	-0.21	-0.16	-0.12	-0.09
Construction	-1.17	0.00	0.00	0.01	0.01
Manufacturing	-0.85	-0.06	-0.03	-0.01	0.00
Wholesale Trade	-1.22	-0.02	-0.02	-0.02	-0.02
Retail Trade	-1.30	-0.01	0.00	0.01	0.01
Transportation, Warehousing	-1.52	0.03	0.04	0.04	0.04
Information	-0.51	-0.08	-0.05	-0.03	-0.02
Finance, Insurance, Real Estate, Rental, Leasing	0.35	-0.17	-0.12	-0.08	-0.06
Professional, Technical Business Services	-1.49	0.02	0.03	0.04	0.04
Education Health Care Social Assistance	-2.07	0.07	0.06	0.06	0.05
Arts, Entertainment, Recreation, Accommodation, Food Services	-1.35	0.00	0.01	0.01	0.02
Other Services Except Government	-1.58	0.03	0.04	0.05	0.04
Government	-1.88	0.05	0.04	0.04	0.04
Total	-0.82	-0.09	-0.08	-0.07	-0.07

The distribution of imports impacts by industry is comparable to those for personal consumption and investment expenditures, as shown in Table 11. Investment spending is most affected in the Government; Professional and Technical Services; Construction; Wholesale Trade; Retail Trade; Other Services; and the Arts, Entertainment, Recreation, Accommodation, and Food Services industries.

Table 11. Imports Impacts by Industry (percent deviation from baseline).

Industry	2012	2013	2014	2015	2016
Agriculture, Forestry, Fishing	-0.81	-0.17	-0.21	-0.23	-0.22
Mining	-0.81	-0.06	-0.05	-0.04	-0.03
Utilities	-1.21	-0.05	-0.05	-0.05	-0.05
Construction	-0.56	-0.08	-0.07	-0.06	-0.06
Manufacturing	-0.88	-0.07	-0.07	-0.06	-0.06
Wholesale Trade	-0.70	-0.10	-0.10	-0.09	-0.09
Retail Trade	-0.71	-0.09	-0.08	-0.07	-0.06
Transportation, Warehousing	-0.81	-0.08	-0.08	-0.07	-0.07
Information	-0.91	-0.06	-0.06	-0.05	-0.04
Finance, Insurance, Real Estate, Rental, Leasing	-1.04	-0.06	-0.06	-0.06	-0.05
Professional, Technical Business Services	-0.60	-0.09	-0.08	-0.06	-0.05
Education Health Care Social Assistance	-0.63	-0.10	-0.09	-0.08	-0.07
Arts, Entertainment, Recreation, Accommodation, Food Services	-0.73	-0.09	-0.07	-0.06	-0.06
Other Services Except Government	-0.71	-0.09	-0.08	-0.07	-0.06
Government	-0.59	-0.10	-0.09	-0.08	-0.07
Total	-0.79	-0.08	-0.08	-0.07	-0.06

The distribution of capital spending impacts by industry is comparable to those for personal consumption and investment expenditures, as shown in Table 12. Investment spending is most affected in the Government; Professional and Technical Services; Construction; Wholesale Trade; Retail Trade; Other Services; and the Arts, Entertainment, Recreation, Accommodation, and Food Services industries.

Table 12. Capital Expenditure Impacts by Industry (percent deviation from baseline).

Industry	2012	2013	2014	2015	2016
Agriculture, Forestry, Fishing	0.18	-0.67	-0.65	-0.57	-0.45
Mining	-0.15	-0.12	-0.09	-0.07	-0.05
Utilities	0.49	-0.21	-0.16	-0.12	-0.10
Construction	-0.11	-0.12	-0.09	-0.07	-0.06
Manufacturing	-0.21	-0.13	-0.09	-0.06	-0.05
Wholesale Trade	-0.26	-0.13	-0.11	-0.09	-0.08
Retail Trade	-0.24	-0.12	-0.10	-0.08	-0.06
Transportation, Warehousing	-0.65	-0.07	-0.04	-0.02	-0.01
Information	-0.14	-0.13	-0.10	-0.07	-0.05
Finance, Insurance, Real Estate, Rental, Leasing	0.36	-0.18	-0.14	-0.10	-0.08
Professional, Technical Business Services	-0.38	-0.10	-0.07	-0.05	-0.03
Education Health Care Social Assistance	-0.65	-0.08	-0.06	-0.05	-0.04
Arts, Entertainment, Recreation, Accommodation, Food Services	-0.31	-0.12	-0.09	-0.06	-0.05
Other Services Except Government	-0.54	-0.08	-0.06	-0.04	-0.02
Government	-0.44	-0.11	-0.08	-0.06	-0.05
Total	0.00	-0.16	-0.14	-0.11	-0.10

The distribution of labor spending impacts by industry is comparable to those for personal consumption and investment expenditures, as shown in Table 13. Investment spending is most affected in the Government; Professional and Technical Services; Construction; Wholesale Trade; Retail Trade; Other Services; and the Arts, Entertainment, Recreation, Accommodation, and Food Services industries.

Table 13. Labor Expenditure Impacts by Industry (percent deviation from baseline).

Industry	2012	2013	2014	2015	2016
Agriculture, Forestry, Fishing	-1.02	-0.55	-0.56	-0.49	-0.39
Mining	-1.34	0.00	0.00	0.01	0.01
Utilities	-0.72	-0.08	-0.06	-0.05	-0.04
Construction	-1.30	0.00	0.00	0.00	0.00
Manufacturing	-1.41	0.00	0.01	0.01	0.01
Wholesale Trade	-1.46	-0.01	-0.01	-0.02	-0.02
Retail Trade	-1.44	0.00	0.00	0.00	0.00
Transportation, Warehousing	-1.84	0.06	0.06	0.05	0.05
Information	-1.34	-0.01	0.00	0.01	0.01
Finance, Insurance, Real Estate, Rental, Leasing	-0.84	-0.06	-0.04	-0.03	-0.02
Professional, Technical Business Services	-1.57	0.02	0.03	0.03	0.03
Education Health Care Social Assistance	-1.84	0.04	0.03	0.03	0.02
Arts, Entertainment, Recreation, Accommodation, Food Services	-1.51	0.01	0.01	0.01	0.01
Other Services Except Government	-1.73	0.04	0.04	0.04	0.04
Government	-1.64	0.02	0.01	0.01	0.01
Total	-1.46	0.00	0.00	0.00	0.00

5 DISCUSSION

This study estimates the economic impacts of Hurricane Sandy on the affected seven states. The study shows fairly significant economic impacts over the duration of the electric power outage and business interruption period. The study also showed that these impacts attenuate relatively quickly but are nevertheless felt over the five-year simulation period. These results sustain themselves due to damages to the capital stock of the regional economy that perpetuates into future periods. This research did not attempt to integrate possible offsetting economic impacts of restoration activities, so one could interpret these results as an underestimate of the true economic impacts of this event. We must keep in mind, however, that restoration and recovery activities are not, in and of themselves, without cost. Resources moved into restoration and recovery are diverted from alternative uses; how these activities are financed will have a bearing on the overall economic impacts of the event.

Few studies have estimated the overall economic impacts of Hurricane Sandy. A recent analysis by the United States Department of Commerce U.S. Department of Commerce (2013) examined impacts from both the event and restoration expenditures on the states of New Jersey and New York. Their analysis estimated that losses in tourism expenditures ($950 million) would reduce total GDP output in New Jersey by $1.2 billion and reduce employment by 11,000 workers in the Accommodation, Food Services, Retail, Amusements, and Performing Arts and Transportation Service industries. By way of comparison, our results indicate a loss of $7.2 billion, but these results are for the entire seven-state area and include a slightly different set of industry aggregations, namely, Arts, Entertainment, Recreation, Accommodation, Food Services; Retail Trade; and Transportation and Warehousing. Other accounts of impacts or damages due to Hurricane Sandy stressed property damages, e.g., Kurtz, Walter (2012), on the order of $50 billion, but this estimate is in terms of property damages, not losses in economic activity. This source also cited, for purposes of comparison, an estimate of losses from Hurricane Katrina of $145 billion.

An event that affects a large region can be analyzed on many different levels; an economic impact like that presented here can be analyzed in different ways. For one, the aggregated multi-state region of analysis could be divided into individual states or the states of New Jersey and New York could have been divided up and the remaining states could have been treated as a stand-alone region. Such an analysis would provide more detail about the two states most affected by Hurricane Sandy. Another approach would be to use an alternative (perhaps less aggregated) industry grouping. The analysis could have been broadened to include the value of the direct property damages and the analysis could have been broadened even further to include the potentially offsetting impacts of the restoration and remediation expenditures that in this event were significant and well publicized. Nevertheless, this study offers an estimate of the impacts of losses due to the business interruptions caused by Hurricane Sandy and, therefore, stands as a complement to other analyses that emphasize factors not accounted for in this study.

Our literature review did not reveal published studies that focus on the same region and same measures of impacts as this study, it is difficult to make direct comparisons between the quantitative results reported here to comparable studies published elsewhere. The one comparison with the Department of Commerce study cited above involves different regions (New Jersey and New York versus the seven-state region from the current study) and a slightly different set of industries. Nevertheless, the results are certainly consistent qualitatively and perhaps suggests refining the current study to separate impacts along state lines.

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NOTES

[1]Dynamic CGE models that do not include inter-temporal decision-making but that are based on dynamic mechanisms propagating impacts from period to period are usually called "recursive-dynamic" CGE models because they are solved with a process that starts from the earlier period considered and that proceeds solving each following period recursively.

[2]NISAC is overseen by the Department of Homeland Security Office of Infrastructure and Cyber Analysis.

[3]In the relevant literature, a scenario in which events do not happen is commonly referred to as the "baseline". Similarly, events are often referred to as "shocks" to the economy.

[4]More precisely, as noted in emergency reports by the Office of Electricity Delivery and Energy Reliability (2017) "beginning November 7, a Nor'easter impacted the Mid-Atlantic and Northeast with strong winds, rain or snow, and coastal flooding"