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Title: COMPUTABLE GENERAL EQUILIBRIUM MODEL FISCAL YEAR 2014 CAPABILITY DEVELOPMENT REPORT

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SCOPE

Within the Department of Homeland Security (DHS), the Office of Cyber and Infrastructure Analysis (OCIA)'s National Infrastructure Simulation and Analysis Center (NISAC) develops capabilities to support the DHS mission to support the resilience of the Nation's critical infrastructure. Under OCIA's direction, NISAC is developing a Computable General Equilibrium (CGE) economic modeling capability at Los Alamos National Laboratory (LANL) called the NISAC CGE Model (NGGEM). This capability will improve DHS's ability to assess how the different sectors of the economy, for example, households, businesses, government, etc., interact to allocate resources in an economy. This report describes development of this capability performed under the Fiscal Year 14 NISAC program plan.

LONG-TERM GOAL

The long-term goal of this capability development is to provide NISAC with the ability to examine virtually any economic impact that affects the United States or individual regions of the United States. The intent of future capability development includes: 1) refining the analysis of trade impacts, 2) adding dynamic analysis to the model, and 3) tightening linkages in the model between economic industries/sectors and critical infrastructure. Most importantly, developers will integrate the model into the LANL AGAVE/MIST user interface common to all NISAC products, which will allow a broad range of users to access and use the model to examine a wide variety of issues germane to the OCIA mission.

OVERVIEW

This report provides an overview of the development of the NISAC CGE economic modeling capability since 2012. This capability enhances NISAC's economic modeling and analysis capabilities to answer a broader set of questions than possible with previous economic analysis capability. In particular, CGE modeling captures how the different sectors of the economy, for example, households, businesses, government, etc., interact to allocate resources in an economy and this approach captures these interactions when it is used to estimate the economic impacts of the kinds of events NISAC often analyzes. These models generally assume that agents, for example, buyers and sellers, nonmarket institutions, in an economy attempt to optimize their behavior—firms maximize profits or minimize costs and households maximize their well-being or utility, subject to constraints on income and preference for leisure versus work activities. The framework for CGE modeling is flexible enough to allow for behavior and other phenomena. These include rigidity in labor and factor markets—markets do not always clear instantaneously; imperfect competition, for example, oligopoly or monopoly; decisions based on factors other than prices or wage rates, in the case of labor; taxation; and externalities; that is benefits or costs not incorporated into

market pricing).[1] NISAC's CGE model does not yet incorporate these factors. Economic CGE models also divide an economy into sectors, i.e., firms, households, government, financial intermediaries, etc., and calculate how changes occur in the economy affect interactions between these sectors.

Analysts can use the CGE model to address key analytic questions. The first question is how the events NISAC analyzes, such as hurricanes, earthquakes, and floods, affect the overall economy as measured by changes in regional gross domestic product or gross domestic output. The second is how do these types of events affect specific sectors and industries, and are some specific sectors or industries affected more than others. The third question is the effects of events on prices. In many cases, the initial shock can have impacts on markets. Initial impacts on individual markets impact other industries. For example, an oil price shock that initiates abroad can affect transportation via impacts on gasoline and other fuel prices. Direct impacts on individual markets can also cause impacts on regional or international trade and industry competitiveness.

The information provided by economic impact analyses conducted with the CGE model will inform policy makers about the possible magnitude of economic impacts of an event. Moreover, CGE analysis will also inform policy makers of possible impacts on related industries, e.g., impacts of oil price shocks on the agricultural sector. When used in a broad, multi-event setting, CGE modeling allows policy makers to incorporate the relative magnitude of estimated economic impacts on different areas or of different events for purposes of prioritizing risks. Results from this model will support policy makers who are interesting in understanding the magnitude of economic impacts of events and the industry-specific impacts of the kinds of events analyzed by NISAC.

NISAC has been developing its Computable General Equilibrium model since fiscal year 2012. NISAC capability development reports provided in 2013 and 2014 document initial versions of the model. These reports also discuss how analysts create the Social Accounting Matrices (SAM) tables used to model for each region. These reports also document the methods analysts use to create different versions of the model with different levels of industry aggregation. The model provides flexibility in regions analyzed, in industry detail, and in model structure. This flexibility allows NISAC to examine many kinds of events and address questions relating to these events. The CGE model incorporates a scenario generation module that quickly creates the regional economies with associated industry definitions automatically, which speeds the analysis process. During fiscal year 2014, NISAC developed the initial graphical user interface for the model, continued to refine solution algorithms in the model to allow faster model solution times and improve the stability of the model, and integrated updated data from U.S. Bureau of Economic Analysis (BEA) and other sources into the model. To examine the behavior of the model and explore its simulation properties, NISAC modeled scenarios for different geographic areas and levels of inter-industry aggregation. Each of these simulations compared an economic baseline scenario with a scenario that assumed a 20-percent reduction in overall factor productivity in the manufacturing industries of each State. NISAC conducted these simulations to illustrate the flexibility of industry definitions in the CGE model and to examine the simulation properties of the more detailed models.

The completed SAM table contains information that the model uses to specify the technology of how goods and services are produced, the "recipe" for production that shows how capital and labor inputs and intermediate outputs from other industries are combined to produce final outputs that satisfy final demand (consumption, investment, government spending, and net exports). These will show up in the model as parameter values for coefficients on the production functions, demand functions, and other equations in the model. The SAM also shows a "snapshot" of the flows of dollars between sectors of the economy. NISAC does not expect the values of the parameter values to change very much from year-to-year, but NISAC would expect the values of the flows of dollars from sector-to-sector to change since these flows reflect not only flows of resources between sectors but also include measures of overall economic activity, such as Gross Domestic (or Regional or State) Product. The Gross Domestic Product estimates can vary dramatically from year to year.

Annual data from BEA and other sources provide the basis for the current version of the model.[2] NISAC collects quarterly regional data for each State and maintains updated quarterly and annual data from BEA, Bureau of Labor

[1] There are numerous references to computable general equilibrium modeling. One source used extensively to develop the NCGEM is Hosoe, Nobuhiro, Kenji Gasawa, and Hideo Hashimoto, *Textbook of Computable General Equilibrium Modelling Programming and Simulations*, New York: Palgrave, Macmillan, 2009. Two classic works on general equilibrium modeling are Scarf, H.E., *The Computation of Economic Equilibria*, New Haven: Yale University Press, 1973 and Shoven, J. B. and J. Whalley, *Applying General Equilibrium*, Cambridge: Cambridge University Press, 1992.
[2] The data sources for this CGE model are presented and discussed in two previous Capability Development Reports, the most recent being *Computable General Equilibrium Model Fiscal Year 2013 Capability Development Report*, National Protection and Programs Directorate, Office of Cyber and Infrastructure Analysis, US Department of Homeland Security, April 2014.

Statistics (BLS), and the U.S. International Trade Commission, but NISAC anticipates that quarterly economic analysis will be more appropriate after analysts add dynamic analysis capabilities to the model. Dynamic analysis capability means that the model will estimate impacts over multiple periods. For an annual model like the current version of the CGE model, dynamic analysis means that the model will include changes to the economy resulting from an event that last longer than one or two (or more) years. NISAC expects that for many events, the most significant economic impacts will occur within one year of the event. Other event can, however, cause impacts to remain significant over multiple periods. A severe earthquake (or tsunami), for example, could cause damages to infrastructure that might take more than one year to repair and restore. A radiological event could have impacts that last for many years. If an event causes business interruptions to last longer than one year, than the economic impacts will carry forward into future years. Adding dynamic capability to the model will allow NISAC to estimate the impacts of events that cause longer term-business interruptions. Moreover, even if the physical damages that caused business interruptions are remediated within one year, it is possible that the economic adjustment to the shock could last longer than one year and a multi-period dynamic model will include estimates of these longer-term residual economic impacts. The current version of the annual model is defined for 15 industries including government, but can be expanded to as many as 384 industries. In addition, analysts can create any number of combinations of industry aggregations that tailor the analysis to focus attention on specific industry or industry group impacts.

FISCAL YEAR 14 ACCOMPLISHMENTS

Development of the NCGEM during the current fiscal year has followed three paths: 1) programming the structural equations into code for running the model, 2) collecting the necessary source data and organizing and maintaining the data collected to ensure that it is easily updated when new source data are released, and 3) conducting trial simulations of the model to test the workings of the model and evaluating the simulation properties of the model. NISAC has followed these three paths roughly concurrently, but because data releases are sporadic, updates to the data sets used in the model will occur unevenly. Most recently, NISAC has worked to develop the internal structure of the model, added model refinements, and updated data sources. In particular, analysts have updated the annual data for each State through 2013. NISAC also created SAM tables (and hence CGE models) for each of the 10 Federal Emergency Management Administration regions. NISAC expects the 2014 BEA data to be available in December of 2015 (it is updated annually). BLS data is updated on both a quarterly and annual basis, depending on the frequency of the data. The U.S. International Trade Commission (ITC) data are updated continually by ITC and can be collected continually. Analysts continue to conduct experimental runs with the model to ensure that the qualitative results of the model conform to prior expectations on how the model should behave. NISAC has also been working with selected cases involving different levels of industry definitions, for example, developing models with more refined sub-industry definitions, and testing how these different versions of the model behave.

During the current fiscal year, NISAC participated in the Terrorism Risk Assessment working group. This participation includes attending monthly meetings via teleconference. Because this working group emphasizes using economic modeling tools to estimate the economic impacts of terrorist events, meetings and presentations have focused on surveying and evaluating the different economic analysis tools available to estimate the economic impacts of such events. NISAC have also been working with staff at Battelle to develop a reduced-form, linearized version of the model that they can apply in their Probabilistic Risk Assessment (PRA) analysis. If funded, this work would involve developing a modified version of the NCGEM capable of running large numbers of simulations over very short periods to estimate distributions around mean-based measures of economic impacts as measured by different economic variables.

REQUIREMENTS

The data requirements for the CGE model center around constructing the SAM table for given region or regions of interest. The SAM forms the core of every CGE model. Once the SAM is populated, the data in the SAM are fed into the CGE model, which then estimates the initial baseline (pre-event) state of the economy. The SAM is populated with publically available data from the BEA, BLS, and ITC. Table 1 summarized the data analysts use to populate the SAM

TABLE 1—DATA SOURCES FOR POPULATING SOCIAL ACCOUNTING MATRIX

SAM Table Component	Data Source	Frequency and Industry Detail
Input-Output Make, Use, and Total Requirements Tables	U.S. Bureau of Economic Analysis	Annual data from 1998 to 2014, 2- and 3-digit North American Industry Classification System (NAICS) industry categories
National Level Consumer Price Index (CPI)	U.S. Bureau of Labor Statistics	Annual and quarterly from 1998 to 2014
Government Current Receipts and Expenditures (Federal and State and Local)	U.S. Bureau of Economic Analysis, National Income and Product Accounts	Annual and quarterly, 1998 to 2014
General Import Tariffs	U.S. International Trade Commission	Annual and quarterly data from 1998 to 2014, 2- and 3-digit NAICS industry categories
Employment and Wages	U.S. NAICS Bureau of Labor Statistics, Quarterly Census of Employment and Wages	Annual and quarterly data from 1998 to 2014, 2- and 3-digit NAICS industry categories

ASSUMPTIONS

Like any CGE model, this CGE model assumes that the economy can be represented as an aggregation of industries and those meaningful inferences about impacts to changes in the economy can be drawn using this approach. This CGE model also assumes that the representation of the economy as it exists in the SAM table and the resulting baseline model calibration represent reasonable approximations to the actual regional or national economy that the intends to represent.

CALIBRATION

To calibrate the model, NISAC estimated the economic impacts of closing the Soo Locks in St. Sault Marie, MI, on the economy of the State of Michigan. The Soo Locks are an important component of the iron ore-steel-automobile manufacturing supply chain that begins with iron ore extracted from mines located in Minnesota primarily with some from Michigan. Steel mills located along the Great Lakes use this ore. In this analysis, the closure of the Soo Locks is due to severe weather. NISAC focused on the State of Michigan, but recognizes that a full analysis of the economic impacts of a closure of the Soo Locks requires an analysis of the economies of at least five States, including Minnesota, Michigan, Indiana, Illinois, and Ohio. An analysis of all of these States, including impacts on the U.S. economy, overall, is beyond the scope of this capability development analysis.

The standard 15-industry version of the CGE model aggregates all manufacturing into one manufacturing industry and aggregates all mining into one mining industry. To capture the economic impacts of the closure, analysts tailored the CGE model for the State of Michigan by making changes to the standard industry definitions in the model.

First, the mining industry was divided into the following sub-industries: 1) Iron, gold, silver, and other metal ore mining (BEA Industry Code: 2122A0); 2) Other mining, which combined coal, copper, nickel, lead and zinc mining, stone mining and quarrying, and other nonmetallic mineral mining and quarrying (BEA Industry Codes: 212100, 212230, 212310, and 2123A0); and 3) Oil and gas extraction combined with support activities for mining (BEA Industry Code: 211 and 213).

This disaggregation allows the analysis to focus on iron ore, which is the principal commodity of interest in the iron ore-steel-automobile manufacturing supply chain that drives the Michigan economy.

Second, manufacturing was divided into the following subcategories: 1) Iron and steel mills and ferroalloy manufacturing (BEA Industry Code: 331110) was separated from primary metals manufacturing (BEA Industry Code: 331); 2) Other primary metals (BEA Industry Codes: 331200, 33131A, 33131B, 331411, 331419, 331420, 331490, 331510, 331520); 3) Metal can, box, and other metal container (light gauge) manufacturing (BEA Industry Code: 332430) was separated from other fabricated metals product manufacturing (BEA Industry Codes: 33211A, 332114, 33211B, 332200, 332310, 332320, 332410, 332420, 332500, 332600, 332710, 332720, 332800, 33291A, 332913, 332991, 33299A, 332996, 33299B); 4) Automobile manufacturing (BEA Industry Code: 336111) was separated from other motor vehicles, bodies and trailers, and parts manufacturing (BEA Industry Codes: 336112, 336120, 336211, 336212, 336213, 336214, 336310, 336320, 3363A0, 336350, 336360, 336370, 336390); and 5) Other manufacturing (which contained the remaining manufacturing industries (BEA Industry Codes: 3364OT, 333, 321, 327, 334, 335, 337, 339, 311FT, 313TT, 315AL, 322, 323, 324, 325, 326). Developers made this disaggregation to allow focus on the impacts on iron and steel mills, and the resulting impacts on automobile and other manufacturing dependent on iron ore coming from Minnesota and transported through the Soo Locks. This represents the second link in the iron ore-steel-automobile manufacturing supply chain.

Third, retail trade was divided into the following subcategories: 1) Motor vehicles and parts dealers (BEA Industry Code: 441000); and 2) Other retail trade (BEA Industry Codes: 445000, 452000, 4A0000). This disaggregation allows the analysis to focus on potential impacts on motor vehicle and parts dealers in Michigan. This represents a potential downstream industry affected by shocks to the iron ore-steel-automobile manufacturing supply chain.

The remaining industry categories were unchanged; therefore, the model used to analyze the economic impacts of a closure of the Soo Locks on the State of Michigan contains 24 industries, which are summarized in Table 2. In this table, the second column (labeled "Industry (Base Model)") shows the industry definitions used in the basic CGE model. The third column (labeled "Industry (Soo Locks Analysis Model)") shows the industry definitions used for the analysis used for this sample simulation. If NISAC were to do a more detailed analysis of all of the directly affected states, NISAC could create a model of each of the states being analyzed using the industry definitions.

TABLE 2—INDUSTRY DEFINITIONS FOR SOO LOCKS ANALYSIS

	Industry (Base Model)	Industry (Soo Locks Analysis Model)
1	Agriculture, Forestry, Fishing, and Hunting	Agriculture, Forestry, Fishing, and Hunting
2	Mining	Iron, Gold, Silver, and Other Metal Ore Mining
3		Other Mining
4		Oil and Gas Extraction and Support Activities for Mining
5	Utilities	Utilities
6	Construction	Construction
7	Manufacturing	Iron and Steel Mills and Ferroalloy Manufacturing
8		Other Primary Metals Manufacturing
9		Metal Can, Box, and Other Metal Container (Light Gauge) Manufacturing
10		Other Fabricated Metal Product Manufacturing
11		Automobile Manufacturing
12		Other Motor Vehicles, Bodies and Trailers, and Parts Manufacturing
13		Other Manufacturing
14	Wholesale Trade	Wholesale Trade
15	Retail Trade	Motor Vehicle and Parts Dealers

	Industry (Base Model)	Industry (Soo Locks Analysis Model)
16		Other Retail Trade
17	Transportation and Warehousing	Transportation and Warehousing
18	Information	Information
19	Finance, Insurance, Real Estate, Rental, and Leasing	Finance, Insurance, Real Estate, Rental, and Leasing
20	Professional and Business Services	Professional and Business Services
21	Educational Services, Health Care, and Social Assistance	Educational Services, Health Care, and Social Assistance
22	Arts, Entertainment, Recreation, Accommodation, and Food Services	Arts, Entertainment, Recreation, Accommodation, and Food Services
23	Other Services, Except Government	Other Services, Except Government
24	Government	Government

MODEL INPUT CHANGES

Analysts input the shocks to the Michigan economy resulting from the Soo Locks closure into the model as two changes: The first is to increase import prices of Iron, Gold, Silver, and Other Metal Ore Mining by 150 percent.[3] This effectively reduced Gold, Silver, and Other Metal Ore Mining imports by nearly 90 percent to mimic the reduction in imports expected from the closure. The second change was to reduce the scale coefficient for production by 10 percent for the following industries: 1) Iron, Steel, and Ferroalloy Manufacturing; 2) Other Primary Metals Manufacturing; 3) Metal Can, Box, and Other Metal Container (Light Gauge) Manufacturing; 4) Other Fabricated Metal Product Manufacturing; 5) Automobile Manufacturing; 6) Other Motor Vehicles, Bodies and Trailers, and Parts Manufacturing; 7) Other Manufacturing; 8) Motor Vehicle and Parts Dealers; and 9) Transportation and Warehousing. The first input change represents the reduction in import availability in the model. This input change reduces the ability of each industry to produce output with any given set of resources by 10 percent.

This model input change captures the effects of reduced availability of the raw materials when the Soo Locks are closed. Moreover, it also reflects the reduced rate at which producers can manufacturer goods and services from the intermediate inputs produced in Michigan with the iron ore and other commodities subject to reduced availability.

Under normal circumstances, a supply shock in a specific commodity would increase the price of that commodity and that price increase would signal: 1) other producers to increase output; 2) buyers of the raw material to seek alternative sources of supply; and 3) a reduction in consumption in the raw material suffering from the supply shock. In the case of the Soo Locks, capacity constraints in the transportation system and other constraints in the regional economy bind, preventing the delivery of the needed raw materials from alternative sources. For example, according to estimates produced by OCIA, the number of rail cars needed to transport sufficient quantities of iron ore to automobile manufacturers ranges from 1,670 to 2,500 railcars per day.[4] In addition, transporting sufficient

[3] In the current version of the model, exports and imports are changed by manipulating import and export prices. The next version of the Los Alamos CGE model will allow direct changes to endogenous variables (i.e., those variables whose values are usually determined internally by the model as it solves) such as exports and imports.

[4] Office of Cyber and Infrastructure Analysis, U.S. Department of Homeland Security, The Soo Locks: An analysis of an Unexpected Closure and Its Impacts, February 2015, page 8.

quantities of iron ore from Minnesota would require so many trucks that highways would need to close to other traffic to accommodate the truck traffic.[5]

RESULTS

The initial shock to the industries affected by the model input change is an increase in the cost of producing goods and services. In the parlance of supply and demand analysis, a reduction in supply, or a leftward shift in the supply function, for each industry would reflect this change. This will cause a reduction in output for each industry, but the output of each industry will not be reduced by the same percentage. Industries that depend on iron ore and other mining are most affected. The output reduction will then cause secondary effects that will be felt most by those industries that depend on intermediate outputs from these industries. In this case, the largest output impacts occur in the Iron, Gold, Silver, Metal Ore Mining industry, as well as in manufacturing, especially other primary metals, metal can, box, and containers, automobile, other motor vehicle manufacturing, and transportation and warehousing. Table 3 provides a summary of these results.

The intent of analysis reported in this document is to demonstrate the capabilities of the CGE model. This analysis does not attempt to recreate the results of the DHS/OCIA study. That report focuses on a much broader and complete scenario that describes the direct and other impacts on off the states affected by the Soo Locks closure. This report examines a much more limited scenario.

TABLE 3—GROSS DOMESTIC OUTPUT AND GROSS DOMESTIC OUTPUT PRICE IMPACTS – STATE OF MICHIGAN SOO LOCKS SCENARIO (PERCENT DEVIATION FROM BASELINE)

Industry	Gross Domestic Output	Gross Domestic Output Price
Agriculture, Forestry, Fishing, and Hunting	6.5	2.0
Iron, Gold, Silver, Metal Ore Mining	-16.7	0.8
Other Mining	-5.5	3.3
Oil & Gas Extraction, Mining Support	-4.9	1.3
Utilities	7.2	1.7
Construction	4.5	2.3
Manufacturing - Iron, Steel & Ferroalloy	-13.0	6.6
Manufacturing - Other Primary Metals	-15.8	6.8
Manufacturing - Metal Can, Box, Container	-39.9	11.4
Manufacturing - Other Fabricated Metal	-8.2	6.5
Manufacturing - Automobile	-24.1	8.8
Manufacturing - Other Motor Vehicles	-14.4	6.5
Manufacturing - Other	-11.3	7.4
Wholesale Trade	-2.0	1.2
Motor Vehicle & Parts Dealers	-5.7	10.3
Other Retail Trade	0.8	1.7
Transportation & Warehousing	-13.3	8.2
Information	12.9	1.5
Finance, Insurance, Real Estate, Rental and Leasing	11.0	1.2

[5] Office of Cyber and Infrastructure Analysis, U.S. Department of Homeland Security, The Soo Locks: An analysis of an Unexpected Closure and Its Impacts, February 2015, page 9.

Industry	Gross Domestic Output	Gross Domestic Output Price
Professional, Scientific, and Technical Services	5.1	1.2
Educational Services, Health Care & Social Assistance	9.5	1.5
Arts, Entertainment, Recreation, Accommodation & Food Services	5.4	1.9
Other Services (except Public Administration)	2.1	1.4
Government	3.7	1.7
Total	-1.5	4.1

ACCESSIBILITY TO DHS USERS

Developers are working to integrate the NISAC CGE model into the Los Alamos National Laboratory Applied Geospatial Analysis and Visualization Environment Web client application. At present, analyses must be run at the Laboratory.

FUTURE ANALYSIS

In terms of validation and verification, the use of SAM tables to specify the underlying technology of the economy and to incorporate that technology into baseline simulations ensures that the baseline represented in the SAM table will calibrate exactly to the real-world data collected by BEA, BLS, and the other agencies that produce the data that the CGE model uses. In addition, NISAC is continually examining the simulation properties of the model to ensure that the results are sensible qualitatively, that is, are consistent with prior economic intuition on how the model should behave. When possible, NISAC will compare results from simulations using the CGE model to published reports to ensure that estimated model results are as quantitatively accurate as possible. Developers will undertake these checks throughout the continued model development and the checks will be part of the standard model development process as the model is enhanced and improved over time.

FUTURE DEVELOPMENT

This report demonstrates some of NISAC's CGE model capabilities and illustrates the flexibility that will support analyses of a wide range of issues. Future developments will capture remaining transactions between economic sectors in more detail. For example, one planned future development is to add a money market to CGE model. Adding this market will allow the model to capture capital flows between the financial sector and firms, as well as capital between the United States and foreign financial intermediaries. Another planned development is to add dynamic capability to the model that will allow analysts to estimate the duration and timing of impacts and to address issues including economic resilience post-event and the short- and long-term impacts of technology improvements. NISAC also wants to tighten linkages in the model between economic industries/sectors and critical infrastructure. Additional planned extensions include incorporating global trade impacts, which will expand NISAC economic analysis capability into the international economics arena. In addition, a future version of model will utilize Oak Ridge National Laboratory Transportation Network data to integrate new economic geography factors into the CGE model. This will allow NISAC to use the model to estimate cross hauling and import-export at much finer geographic detail than possible using previous NISAC economic models.