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Computable General Equilibrium Model Fiscal Year 2013 Capability Development Report

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The National Infrastructure Simulation and Analysis Center (NISAC) performed the modeling and simulation that supports this assessment.

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Executive Summary

This report documents progress made on continued developments of the National Infrastructure Simulation and Analysis Center (NISAC) Computable General Equilibrium Model (NCGEM), developed in fiscal year 2012. In fiscal year 2013, NISAC the treatment of the labor market and tests performed with the model to examine the properties of the solutions computed by the model. To examine these, developers conducted a series of 20 simulations for 20 U.S. States. Each of these simulations compared an economic baseline simulation with an alternative simulation that assumed a 20-percent reduction in overall factor productivity in the manufacturing industries of each State. Differences in the simulation results between the baseline and alternative simulations capture the economic impact of the reduction in factor productivity. While not every State is affected in precisely the same way, the reduction in manufacturing industry productivity negatively affects the manufacturing industries in each State to an extent proportional to the reduction in overall factor productivity. Moreover, overall economic activity decreases when manufacturing sector productivity is reduced. Developers ran two additional simulations: (1) a version of the model for the State of Michigan, with manufacturing divided into two sub-industries (automobile and other vehicle manufacturing as one sub-industry and the rest of manufacturing as the other sub-industry); and (2) a version of the model for the United States, divided into 30 industries. NISAC conducted these simulations to illustrate the flexibility of industry definitions in NCGEM and to examine the simulation properties of in more detail.

Future development of the model will include:

1) Integrating NCGEM into the Applied Geospatial Analysis and Visualization Environment Web client application

2) Expanding the capability to estimate export and import impacts across Federal Emergency Management Agency regions

3) Adding a financial sector (including money market) to facilitate analysis of financial sector shocks on the economy

4) Extending the dynamic capabilities of the model to facilitate analysis of technology and other shocks to the economy

Key Capabilities

- The NCGEM uses computable general equilibrium methods to estimate economic impact of events taking into account market, demand, and supply adjustments.
- The NCGEM estimates impacts by industry, so NISAC analysis can determine whether specific industries suffer more severe impacts than other industries.
- The NCGEM estimates multiregional impacts, analyzing impacts on regions outside the region in which the event occurred.

- The NCGEM is flexible, expanding individual sectors into more detailed subsectors to support more detailed analysis of an event's industry impacts.

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1 Introduction

Within the Department of Homeland Security Office of Cyber and Infrastructure Analysis, the National Infrastructure Simulation and Analysis Center (NISAC) performs critical infrastructure analysis, modeling, and simulation in support of the DHS mission.

In fiscal year (FY) 2012, NISAC developed the NISAC Computable General Equilibrium Model (NCGEM). The NISAC Computable General Equilibrium Model Capability Development Report, submitted in April 2013, discussed the initial development of the model. One of the advantages of CGE modeling approach is that it incorporates the effects of interactions between industries and sectors into estimates of economic impacts. To the extent possible, model impact estimates follow the flow of impacts as they would occur in the real world.

During FY 2013, NISAC developed the 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 updated data from U.S. Bureau of Economic Analysis (BEA) and other sources. To examine the behavior of the model and explore its simulation properties, NISAC used it to model 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 NCGEM and to examine the simulation properties of the more detailed models.

1.1 Questions

NISAC can use the NCGEM to answer questions about economic impacts including:

- What are the economic impacts of an event, such as a hurricane, earthquake, pandemic influenza, and flood, on a region?
- What are the impacts of an incident on overall economic activity, such as the gross domestic product (GDP) and employment, on the region and the Nation as a whole?
- How are the economic impacts across industries distributed in both the affected region and the Nation?
- Are there specific industries that bear more of the economic impact than others do?

1.2 Decision Support

Natural and manmade disasters can inflict substantial damage, causing severe economic impacts. Estimates of economic impacts of these incidents on National, State, and local economies are of particular interest to officials at all levels of government. When developed fully, NCGEM will allow NISAC to answer detailed questions about the economic impacts of events of interest.

2 NISAC Computable General Equilibrium Model (NCGEM)

The term "computable general equilibrium model" applies to many types of models. In the context of NCGEM, it refers to a class of economic models that use economic data to specify the technical parameters of the model. These models are composed of equations that describe how buyers and sellers interact in markets. They also include nonmarket institutions, such as a government sector that taxes firms and households that make and receive payment for goods and services. These models generally assume that agents (e.g., 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, including rigidity in labor and factor markets (markets do not always clear instantaneously), imperfect competition (such as oligopoly or monopoly), decisions based on factors other than prices (or wage rates, in the case of labor), taxation, and externalities (benefits or costs not incorporated into market pricing).[1]

Economic CGE models also divide an economy into sectors (firms, households, government, financial intermediaries, etc.) and calculate how changes occur in the economy affect interactions between these sectors. Figure 2-1 shows a circular-flow diagram as a simplified representation of an economy in the NCGEM.

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[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.

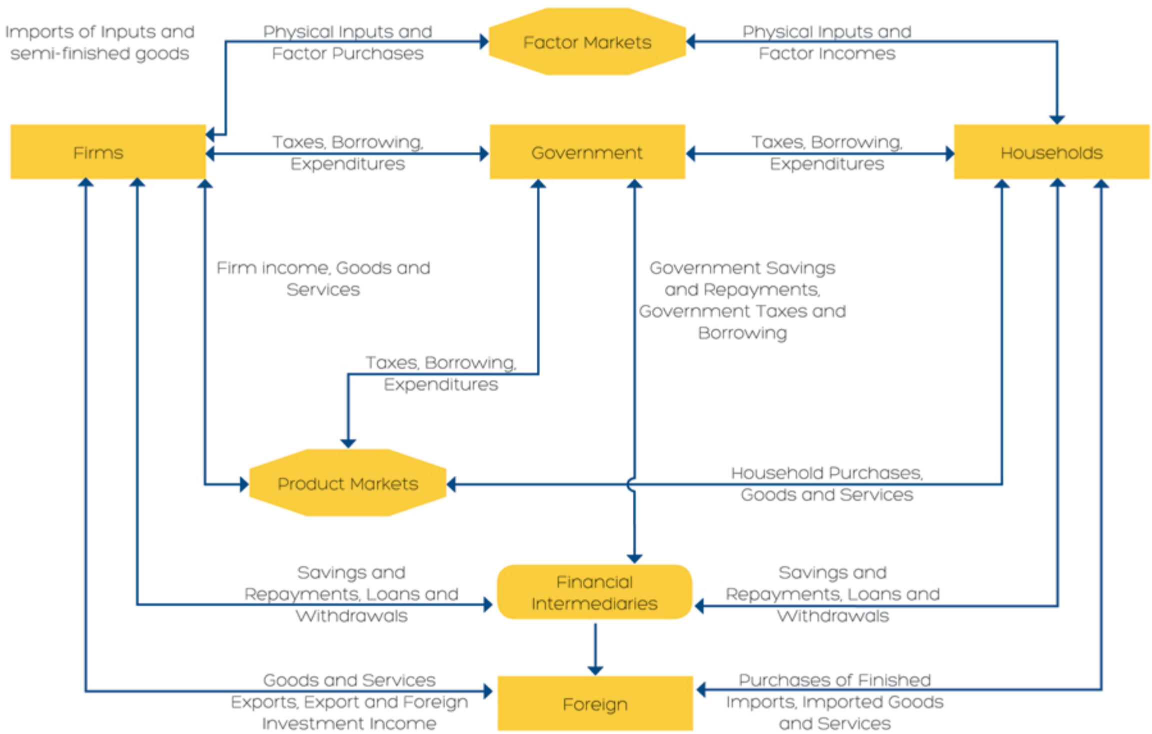

FIGURE 2-1.—Circular Flow Diagram of Economy in the NCGEM.

The diagram shows that firms and households interact through factor and product markets, government, financial intermediaries, and the foreign sector. Moreover, as detailed circular flow diagrams distinguish between "real" flows and "financial" flows. In Figure 2-1, the arrows on the connecting lines indicate that markets connect each sector through combinations of real and financial flows that go in opposite directions. Households supply physical inputs to firms (in the form of labor), receive labor income from firms through factor (labor) markets, and purchase goods and services from firms in product markets. Households also supply capital (in the form of savings) to financial intermediaries who then make loans to firms and households. The government sector receives taxes, and borrows from, households, business, and financial intermediaries. The government sector also purchases goods and services from both households and firms, and provides savings and loan repayments to financial intermediaries. All domestic sectors interact with the foreign sector through purchases of goods and services (imports), sales of goods and services (exports), and borrowing and lending from foreign countries and institutions. Appendix A of this report provides a technical discussion of NCGEM.

2.1 NCGEM Sample Simulations

During the Fiscal Year 2013, NISAC conducted three simulations using the latest version of NCGEM to examine NCGEM's simulation properties and flexibility. For each of these simulations, analysts reduced the technology (or scale) parameter for the manufacturing industry by 20 percent in the production function of the model. This parameter represents one possible application of the NCGEM, namely, the ability to simulate a productivity shock to a particular industry. The developers compared the reduced factor productivity scenarios to the baseline scenarios to assess the economic impacts. Analysts chose manufacturing because it is an important industry for all economies, but also because the relative size of the manufacturing sector varies from State to State.

The model uses data to populate the Social Accounting Matrix (SAM) representation of the national or regional economy to provide a snapshot of the interactions between the business, household, and other sectors of the economy. NISAC populates the SAM with publically available data from the BEA, Bureau of Labor Statistics, and the U.S. International Trade Commission. Analysts calibrate the model to the data in the SAM table, which ensures that the baseline model will accurately represent the economy of the region or regions in question. Appendix B of this report describes the data required for the model in more detail.

The first simulation included a sample of 20 States, ranging from small to large and covering all geographic areas of the United States. The second scenario simulated the manufacturing sector of the State of Michigan. Developers separated the automobile and other motor vehicle industries from the rest of the manufacturing sector, thereby creating a model with 16 industries, instead of 15 industries. This scenario used the same 20-percent reduction in overall factor productivity, but applied the reduction to the combined automobile and other motor vehicle manufacturing sub-industry.

The third simulation examined an expanded 30-industry model of the United States economy. Developers applied the reduction in overall factor productivity to the same combined automobile and other motor vehicle manufacturing sub-industry of the manufacturing sector. Analysts intended this final simulation as a demonstration of how the model could be applied to an economy with more detailed (less aggregated) industry definitions. The inter-industry impacts of a change in productivity in one industry affect the remaining industries; how these impacts vary across industry are of particular interest.

In all three sets of simulations, the model creates the baseline simulation when it reads the information in the SAM table. The baseline calibrates exactly to the SAM table; therefore, it represents the regional or national economy as presented in the data from the U.S. agencies (BEA, BLS, etc.). The alternate simulation, which analysts compare to the baseline, assumes a change to the underlying economy, i.e., the economy with reduced factor productivity.

2.2 Overview of Simulation Results

For all simulations, a reduction in the technology (or scale) parameter in the production function of the model for the manufacturing industry means that a particular industry can apply the same amount of capital, labor, and intermediate goods to production, but output will be smaller. A disruption of this nature to the manufacturing sector would initially cause output to decrease, even if firms in this industry apply the same inputs. This will increase the costs of producing output, which will set in motion changes in the manufacturing industry and in other industries that will affect prices and outputs. Ultimately, the impacts of the reduction in productivity will result from a combination of changes on both the supply and demand sides of each market, based on the following changes:

First, the reduction in overall factor productivity means that the cost of producing any given level of output will increase. The model will represent this change as an increase in the supply price of manufacturing output, meaning that the price of supplying profit-maximizing quantities of manufactured output will be higher than before the productivity shock.

Second, higher supply price will cause domestic prices in manufacturing to increase, reducing the demand for manufactured outputs as intermediate goods and also reducing the demand for manufactured outputs sold as final goods.

Third, unless there is an offsetting increase in demand for manufacturing output, the equilibrium rate of manufacturing output will decrease.

Fourth, the reduction in manufacturing output will draw these resources away from manufacturing to other industries. In many cases, this will cause output of other industries to increase. However, not all other industries experience an increase; output will decrease in industries that depend more on intermediate inputs from manufacturing because the reduced supply of these inputs will increase production costs. In some cases, consumers will substitute equivalent imported goods for the now more expensive domestic (i.e., within the state) production.

Fifth, because the initial shock results in higher production costs, overall economic activity, as measured by output in the state, decreases.

Finally, higher manufacturing supply prices will increase the price of manufactured goods produced domestically (i.e., inside the state), relative to manufactured goods produced externally. This will cause imports of manufactured goods to increase and cause exports to decrease.

2.3 20-State Simulation Results

For each of the 20 States, analysts reduced the technology (or scale) parameter in the production function of the model for the manufacturing industry by 20 percent.[2] Based on a statewide, output-weighted average of the percentage change in supply prices for each State, the 20-percent reduction in manufacturing factor productivity increases the supply price for manufactured goods by an average of 12 percent, which is by far the largest increase for any industry. The impacts on the supply prices in the remaining industries are much smaller, but show considerable variability. Figure 2-2 illustrates the differences in supply price impacts for the remaining 14 industries in the base simulation. Because the impacts on manufacturing supply prices are roughly equal for all States and proportional to the reduction in manufacturing production efficiency, developers

[2] The 20 states are Alabama, Alaska, Arizona, California, Colorado, Florida, Illinois, Indiana, Kentucky, Louisiana, Massachusetts, Michigan, Montana, North Carolina, New Jersey, New York, Ohio, Pennsylvania, Texas, and Washington.

excluded manufacturing from this figure because it would mask variability in impacts for the remaining industries.

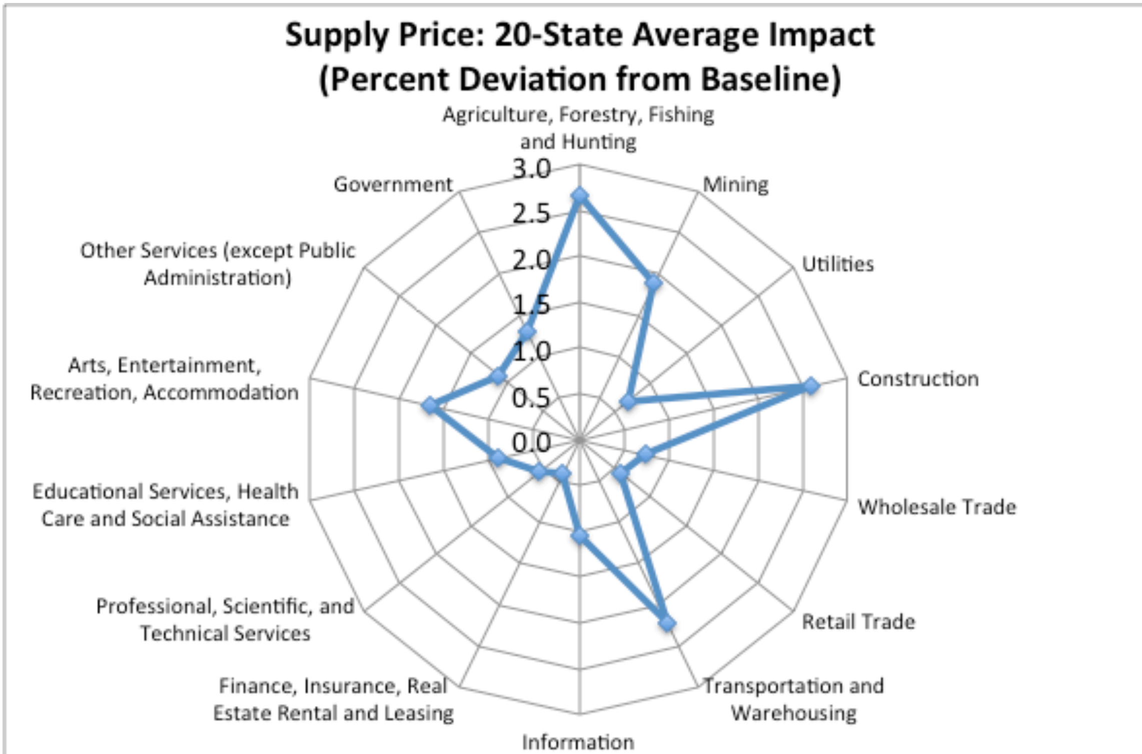

FIGURE 2-2.—Average Supply Price: Percent Deviation from Baseline.

As Figure 2-2 shows, the largest impacts on supply prices for industries other than manufacturing are for agriculture, forestry, fishing, and hunting (2.7 percent); construction (2.6 percent); transportation and warehousing (2.2 percent); mining (1.9 percent); and arts, entertainment, recreation, accommodation, and food services (1.7 percent). The supply prices in other industries increase as well, but to a much lesser extent. As discussed before, the increase in the supply price of manufactured output causes firms that previously relied on manufactured intermediate inputs to use less and rely more on intermediate inputs from other industries and, possibly, to substitute capital and labor for manufactured intermediate inputs. In addition, consumers of final manufactured outputs will substitute final outputs from other industries and, possibly, import manufactured goods from other States to satisfy demand for manufactured output.

In the NCGEM, households and firms consume what is called an "Armington Composite Good," composed of a combination of domestically produced goods (i.e., within State) and goods imported from outside the State.[3] In the model, firms will maximize profits by choosing the right combination of imported and domestically produced goods. The profit-maximizing combination of imports and domestic goods is determined by how much output households and firms demand and by domestic and foreign prices. On the supply

[3] Armington, P. "A Theory of Demand for Products Distinguished by Place of Production," *IMF Staff Papers*, 16(1) (1969): 159-178.

side, producers sell composite commodities made up of domestically produced goods and exports. Because the model differentiates between domestically produced goods, imports, and exported goods (firms that produce for both domestic and foreign markets can offer different products to capture different consumer preferences across both markets), there will be less than perfect substitution between the three types of goods.

The Armington composite price captures prices faced by households and consumers. The simulated reduction in manufacturing productivity increases the Armington composite price in manufacturing by 10.3 percent. The impacts on prices in the remaining industries are smaller. Figure 2-3 shows the impacts of the reduction in manufacturing industry productivity on the Armington composite price for the remaining industries. The largest price increases occur in the mining (3.3 percent); agriculture, forestry, fishing, and hunting (3.1 percent); and construction (2.5 percent) industries. Somewhat lower price increases occur in the transportation and warehousing (1.8 percent); arts, entertainment, recreation, accommodation, and food services (1.8 percent); and information (1.6 percent) industries.

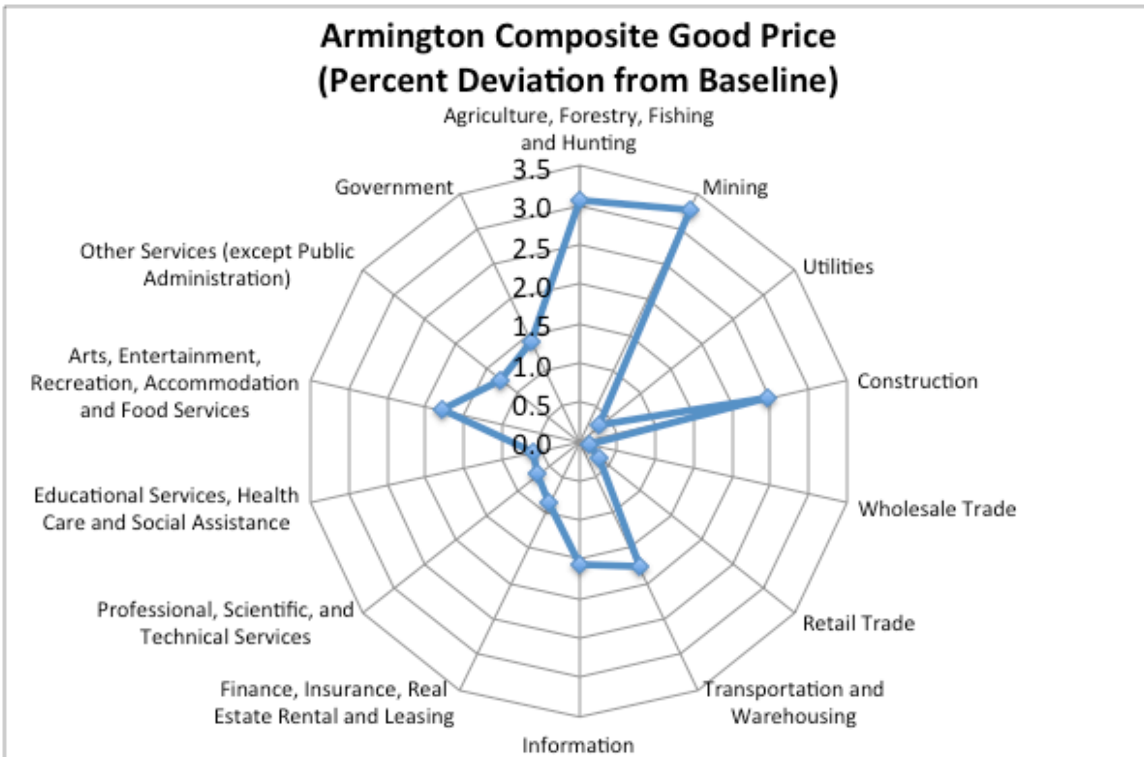

FIGURE 2-3.—Armington Composite Price: Percent Deviation from Baseline.

The combination of higher supply prices and higher Armington composite prices will not necessarily lead to reductions in outputs for all industries. While manufacturing output decreases by 8.5 percent on average, the ultimate effects of reducing manufacturing factor productivity on the outputs of other industries can be either positive or negative. Higher supply prices in other industries will reduce demand for these outputs either as intermediate inputs or as final demand consumer goods. On the other hand, substitution by businesses and households away from manufactured output will manifest as increased demand for non-manufacturing output. This increased demand will offset the reduction in output caused by higher supply prices. Figure 2-4 illustrates the effects on output in industries other than manufacturing. Output decreases the most in agriculture, forestry, fishing, and hunting (8.7 percent); mining (4.3 percent); and wholesale trade (1.6 percent). This suggests that the effects on costs outweigh the effects on demand for these industries. Output increases the most in the information (3 percent); finance, insurance, real estate rental and leasing (1.5 percent); and construction (1.5 percent) industries. This suggests that substitution away from manufacturing into these industries dominates the impacts that reduced manufacturing productivity has on costs in these industries.

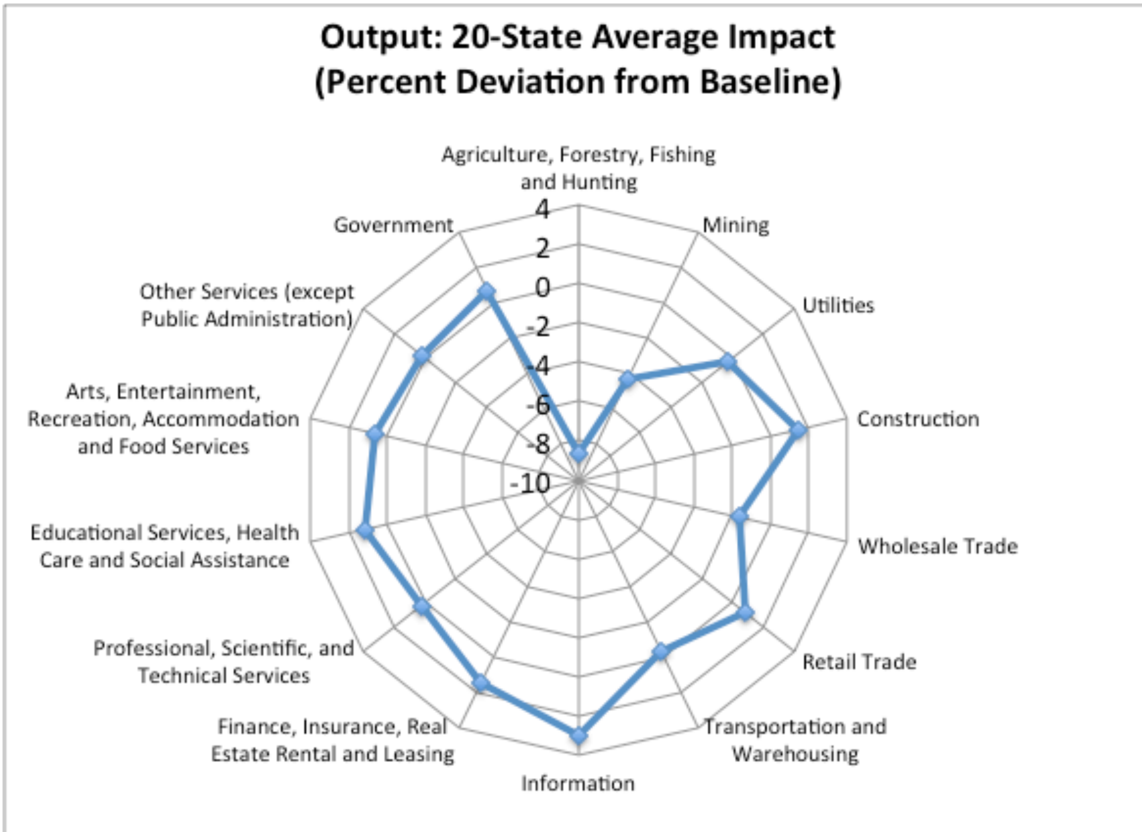

FIGURE 2-4.—Average Output: Percent Deviation from Baseline.

The higher supply price for manufactured output makes manufactured output less competitive on the export market, as evidenced by the more that 25 percent overall reduction in manufactured exports. Higher manufacturing costs in the home State cause some firms to substitute imported manufactured output for domestic manufactured output, so imports rise by a little over 5 percent.

Examining the effect of industry-wide supply price changes on industry-wide output for each State provides a more aggregated view of the simulation results. Figure 2-5 shows how industry-wide supply prices and outputs deviate from baseline for each State. This figure shows the increase in manufacturing industry supply price for each State and the resulting reduction in overall State output for all industries. Reducing manufacturing productivity reduces overall State output. The results also suggest that a higher increase in manufacturing supply price is associated with a larger reduction in overall State output, but the strength of this relationship varies from State to State. The simple correlation coefficient between the two variables is −0.5, which suggests a negative relationship, albeit not a strongly inverse relationship.

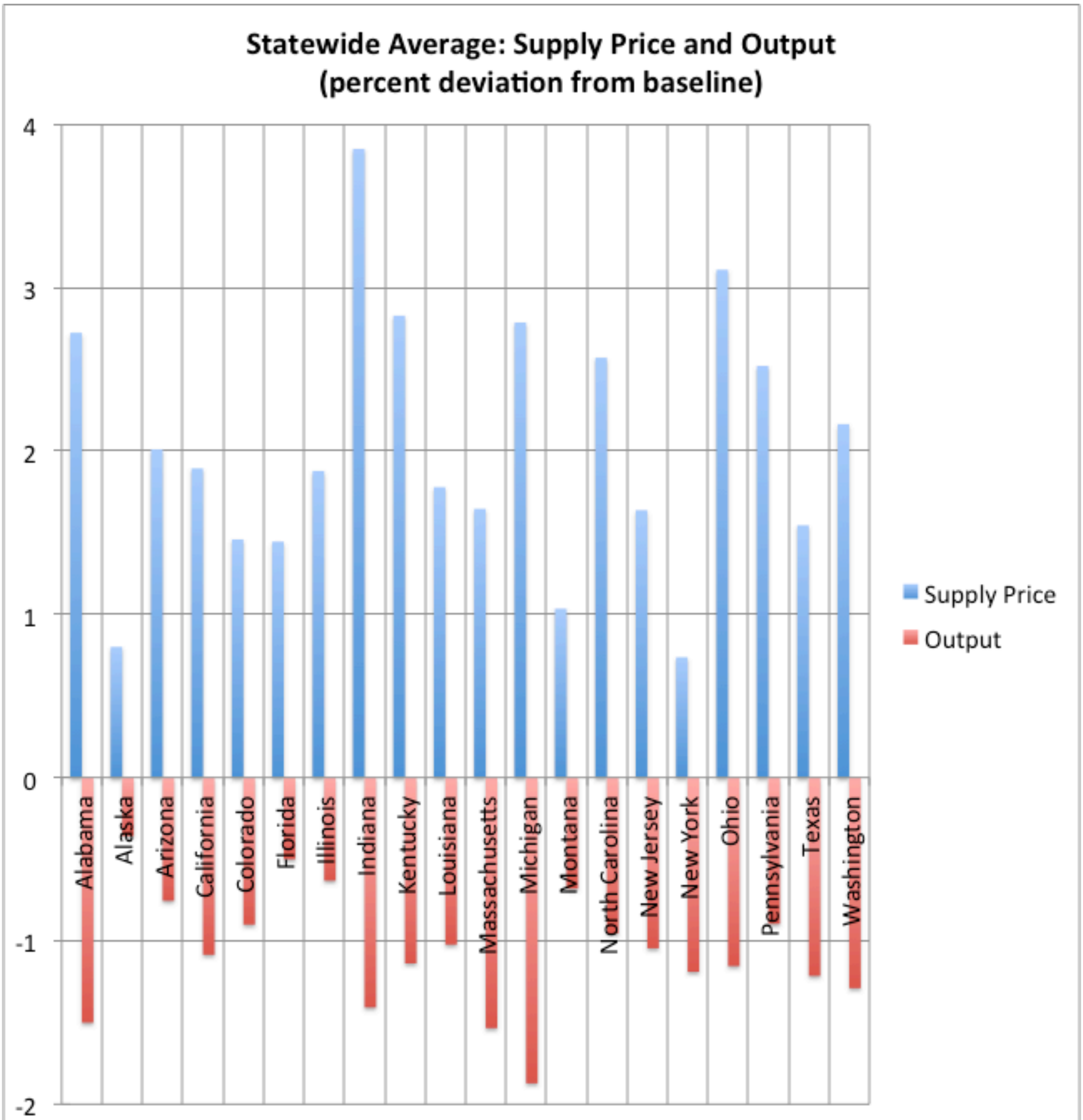

FIGURE 2-5.—Industry-wide Supply Price and Output Impacts: Percent Deviation from Baseline.

While the relationship between the supply prices and output prices is universally negative when aggregated at the State level, the relationship between supply prices and output prices by individual industry across all States is not the same for each industry. As Figure 2-6 shows, the impacts on output can vary quite dramatically when viewed on an industry-by-industry basis. In addition to manufacturing, the agriculture, forestry, fishing, and hunting, mining, and wholesale trade industries experience the largest reductions in output. Some industries have an increase in output, mostly likely due to higher rates of substitution between manufacturing and these industries, which include construction; information; and finance, insurance, and real estate rental and leasing.

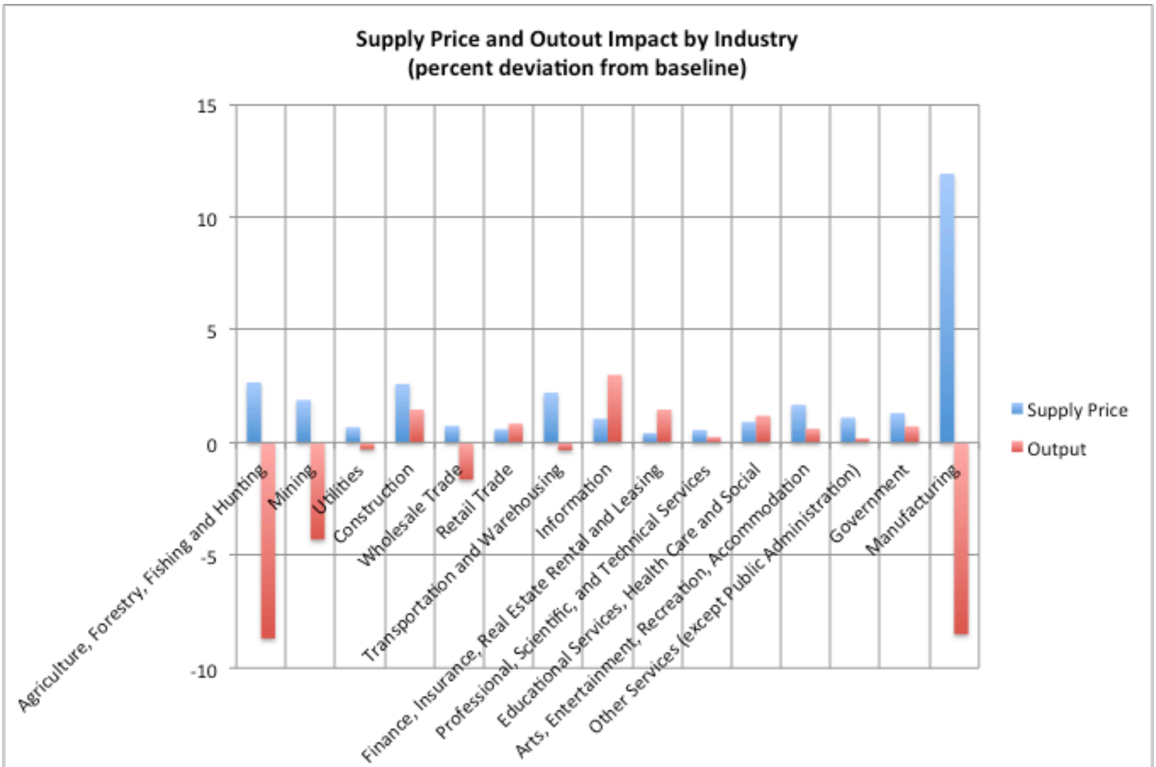

FIGURE 2-6.—Supply Price and Output Impact by Industry: Percent Deviation from Baseline.

Generally, the impacts on most of the 20 States simulated are comparable to the aggregate results reported above. In all cases, the impacts on manufacturing are proportional to the simulated reduction in manufacturing industry productivity. Alaska The largest reduction in manufacturing output (11.2 percent) occurs in Alaska, while the least severe impact on manufacturing output (3.3 percent) occurs in Michigan. On average, manufacturing output decreases by a little over 8 percent. In terms of overall output impact, Michigan suffers the largest reduction (1.9 percent), while Alaska suffers the least severe reduction in statewide output (0.36 percent). Taken together, the 20 States lose a little over 1 percent of their output.

The results of the analysis also suggest similarities in impacts across certain groups of States. Analysts grouped these States into three categories, depending on the pattern of the impacts. In the first group (Alabama, Arizona, and Michigan), the reduction in overall manufacturing productivity resulted in strong decreases in agriculture and mining output, and an increase in utility output. Figure 2-7 illustrates this pattern, showing the results for Alabama.

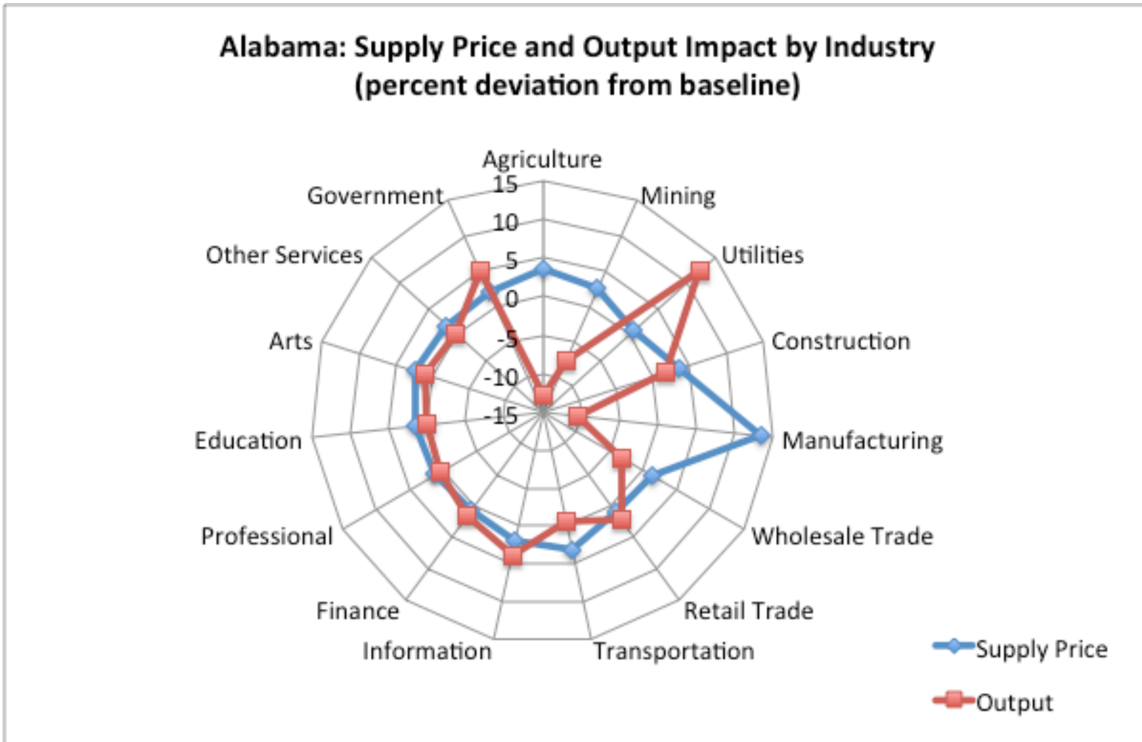

FIGURE 2-7.—Alabama, Supply Price and Output Impact by Industry: Percent Deviation from Baseline.

The second group of States (Louisiana and Texas) shows results similar to the first group, but with a reduction in utility output. Figure 2-8 illustrates this pattern for Louisiana.

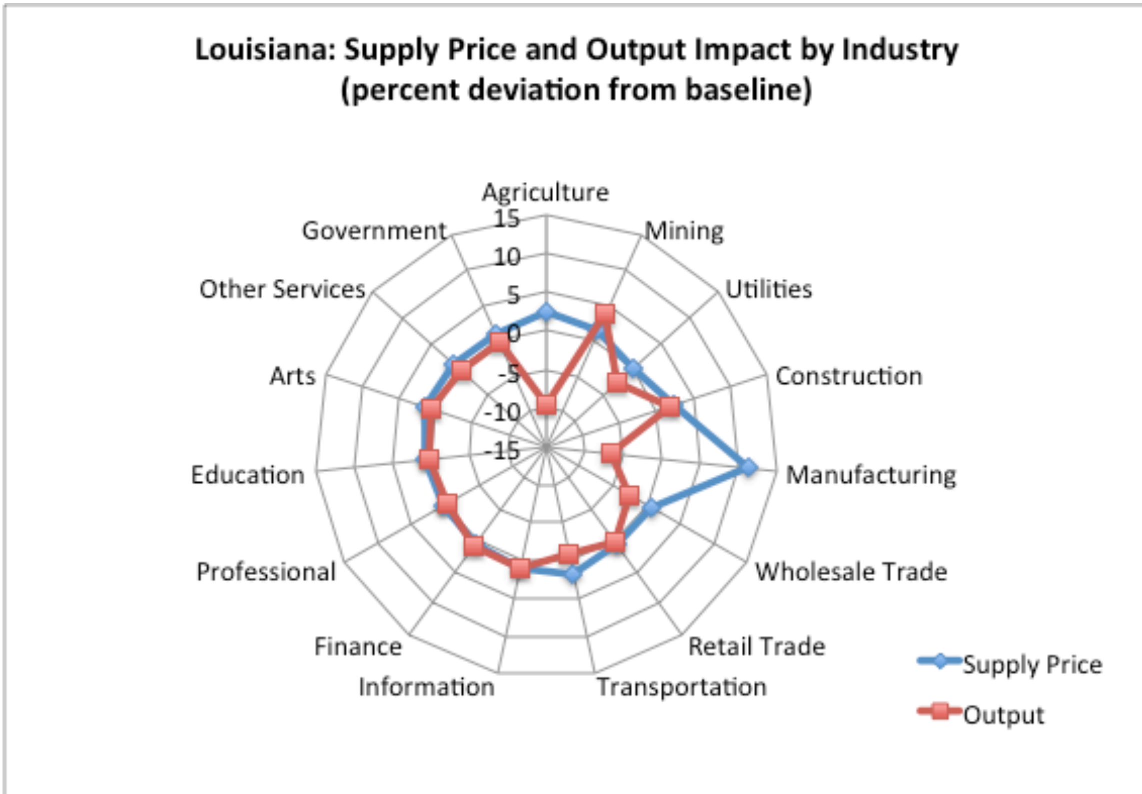

FIGURE 2-8.—Louisiana, Supply Price and Output Impact by Industry: Percent Deviation from Baseline.

Finally, the third group of States (California, Illinois, Kentucky, New Jersey, New York, and Pennsylvania) experienced negative impacts on agriculture and mining, but no discernable impact on utilities. Figure 2-9 illustrates the impacts for Kentucky, which are representative of this group.

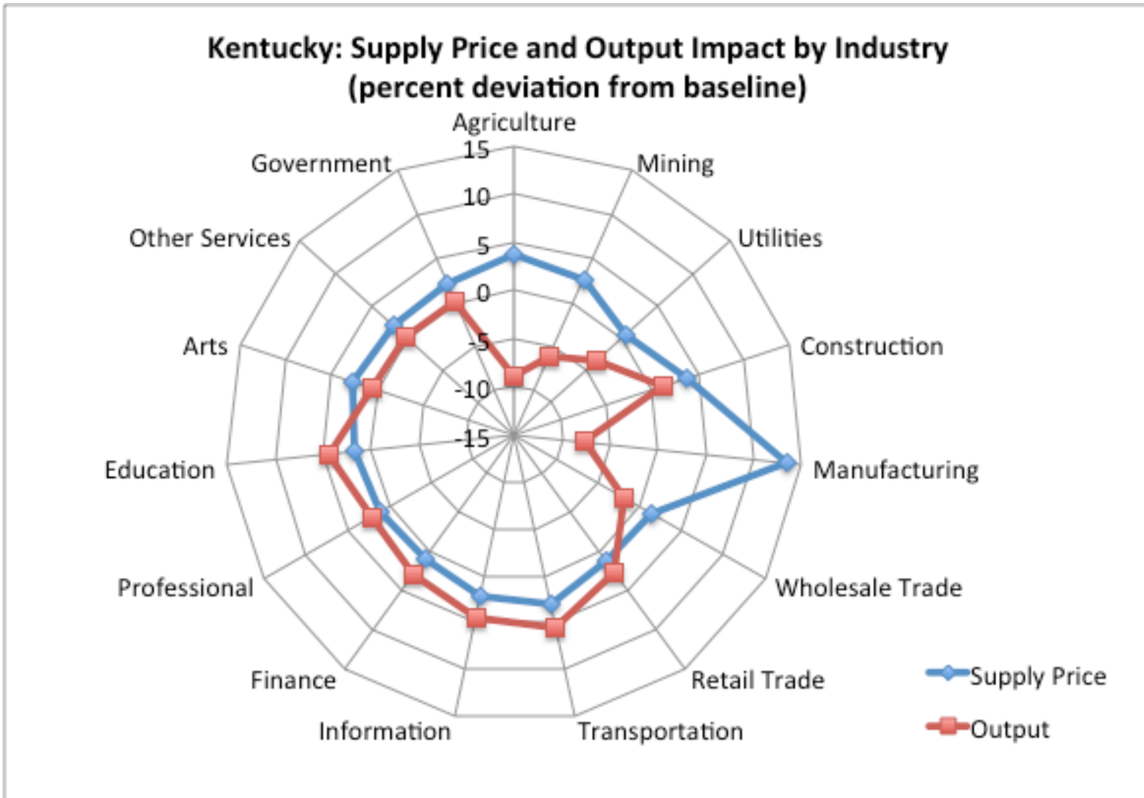

FIGURE 2-9.—Kentucky - Supply Price and Output Impact by Industry: Percent Deviation from Baseline.

Taken together, these comparisons suggest an additional advantage of the NCGEM, namely, the ability to differentiate impacts by State. A more detailed analysis is required to understand fully differences in impacts between States.

2.4 State of Michigan, 16-Industry Simulation Results

One of the advantages of NCGEM is the ability to customize the model to fit the analysis requirements by allowing for varying industry definitions and aggregations. For example, analysts can focus on a specific sub-industry of a larger industry group (e.g., manufacturing) without needing a far more detailed economic model. This example looks at the State of Michigan, focusing on motor vehicle manufacturing, and estimating the impacts of a productivity shock to that industry. To create this simulation, analysts started with the 65-industry model and created two separate manufacturing sub-industries. The first sub-industry is an aggregation of the automobile and other motor vehicle manufacturing sub-industries into an “auto” industry. The second sub-industry is an aggregation of the remaining sub-industries of the manufacturing sector into an “Other Manufacturing” industry. Separating the auto sub-industry results in a 16-industry NCGEM for the State of Michigan forms the basis for this sample simulation.

Analysts created the State of Michigan simulation by reducing overall factor productivity in the auto industry by 20 percent. This is comparable to the 15-industry model, except that, in this case, the focus is on automobile and other motor vehicle manufacturing.

Figure 2-10 shows the impacts on supply prices on output in Michigan. By focusing on the automobile and other vehicle manufacturing industry, analysts can isolate impacts on transportation manufacturing from the rest of the economy. Clearly, the results indicate strong negative impacts in the automobile and other motor vehicles manufacturing sub-industry that are unseen when all manufacturing is treated as one industry. The roughly 9 percent increase in the supply price for the automobile and other motor vehicles manufacturing has a strong negative impact on output of nearly 30 percent. Interestingly, the results also show strong positive impacts on mining (7.8 percent) and utilities (7.0 percent); and moderately positive impacts on information (3.5 percent); information (3.5 percent); agriculture, forestry, fishing, and hunting (3.4 percent); and finance, insurance, real estate, and rental and leasing (2.7 percent). A more detailed analysis of these results would likely lead to a better understanding of these impacts, as well an understanding of how these impacts compare to the original 15-industry Michigan model, which aggregates all manufacturing (including autos) into one industry.

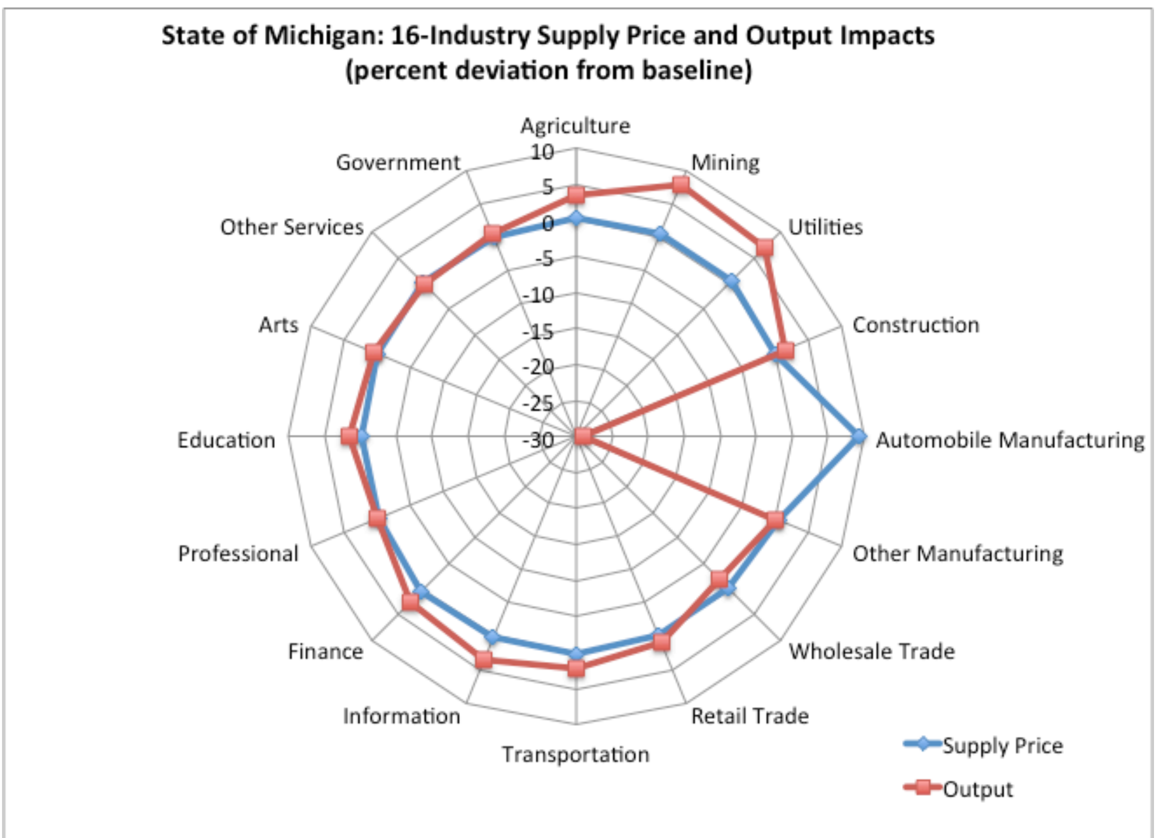

FIGURE 2-10.—Supply Price Impacts: Michigan 16-Industry Model.

Table 2-1 shows a more explicit comparison of the impacts between the 15-industry and 16-industry models of Michigan. The more aggregated (15-industry model) shows strong impacts on the manufacturing when broadly defined (9.3 percent reduction in output), but more severe impacts occur in automobile and other motor vehicle production (29.1 percent reduction in output) when the reduction in productivity is concentrated in that industry. This difference in results might indicate less substitution from within the manufacturing sector sub-industries and greater substitution between manufacturing and non-manufacturing industries. For example, when manufacturing is aggregated as in the 15-industry model, higher supply prices and reduced output in agriculture and mining accompany the higher manufacturing supply price and reduced output. This suggests a strong degree of dependence between manufacturing and these two industries. In contrast, when analysts apply the reduction in productivity to the automobile and other motor vehicle manufacturing sub-industry only, there are slight increases in the supply prices in agriculture and mining. This comparison suggests that agriculture and mining depend somewhat on automobile and other vehicle manufacturing (e.g., tractors and other industrial vehicles), but there is a larger degree of substitution between automobile and other motor vehicle manufacturing and agriculture and mining. Moreover, using the more aggregated 15-industry model applies the productivity reductions to a much larger part of the economy, namely, all manufacturing activity. Applying the productivity shock to automobile and other motor vehicle manufacturing captures inter-industry linkages that apply to that specific industry, but not to the manufacturing sector as a whole.

TABLE 2-1.—Supply Price and Output Impacts:
15-Industry versus 16-Industry Model Results Compared.

Industry	15-Industry Model		16-Industry Model	
	Supply Price	Output	Supply Price	Output
Agriculture, forestry, fishing, and hunting	4.1	-9.8	0.3	3.4
Mining	2.9	-4.1	0.4	7.8
Utilities	1.4	8.7	0.6	7.0
Construction	3.7	2.2	-0.1	1.4
Manufacturing	14.0	-9.3	NA	NA
Auto and Other Motor Vehicle Manufacturing	not applicable	not applicable	9.4	-29.1
Other Manufacturing	not applicable	not applicable	0.5	0.0
Wholesale trade	1.0	-3.3	-0.2	-2.0
Retail trade	0.9	1.8	-0.2	0.9
Transportation and warehousing	3.2	0.8	0.2	2.2
Information	1.7	5.4	0.2	3.5
Finance, insurance, real estate, rental, and leasing	1.0	4.2	0.4	2.7

Industry	15-Industry Model		16-Industry Model	
	Supply Price	Output	Supply Price	Output
Professional and business services	0.7	1.5	-0.3	-0.1
Educational services, health care, and social assistance	1.3	2.3	-0.3	1.4
Arts, entertainment, recreation, accommodation, and food services	2.4	0.9	-0.2	0.5
Other services, except government	1.7	-0.1	0.3	-0.1
Government	1.8	0.8	-0.2	0.5

An additional difference is apparent when analysts compare how import and export impacts change between the two simulations. In the 15-industry simulation, a 4.3 percent increase in imports offsets the higher manufacturing supply price and lower manufacturing output , but it is accompanied by a 20-percent reduction in exports. In this instance, higher manufacturing costs make domestically produced manufactured goods less attractive to domestic and foreign households and firms, so imports rise and exports fall. By comparison, in the 16-industry simulation, both imports and exports of automobile and other motor vehicle goods decrease. Other manufacturing imports decrease, but exports of other manufacturing goods increase. In this case, it appears that higher automobile and other motor vehicle manufacturing supply prices discourage exports (as expected) but the negligible (0.5 percent) increase in other manufacturing supply prices does little to discourage exports in other manufactured outputs.

Analysts can draw some additional inferences from these results by comparing the impacts on Armington composite prices. Table 2-2 shows the impacts on composite prices, which reflect how the reduction in manufacturing productivity affects prices for households and producers. Generally, the impacts on composite prices are dampened in the 16-industry simulation when compared to the results from the 15-industry simulation. The impacts on composite prices are lower for manufacturing in the 15-industry simulation than for automobile and other motor vehicle manufacturing in the 16-industry simulation. For the agriculture; construction industries; transportation and warehousing; and arts, entertainment, recreation, accommodation, and food services industries; the impacts on composite prices are notably lower in the 16-industry simulation than in the 15-industry simulation. Focusing the initial productivity shock on the automobile and other motor vehicle manufacturing industry (rather than all manufacturing), more tightly targets the impacts on dependent industries. In the 15-industry simulation, industries that depend more on other manufacturing (and less on automobile and other motor vehicle manufacturing) are insulated against supply-price-driven cost impacts on automobile and other motor vehicle manufacturing that would ordinarily spillover under the more aggregated manufacturing definition.

TABLE 2-2.—Armington Composite Price Impacts:
15-Industry versus 16-Industry Model Results Compared.

Industry	15-Industry Model	16-Industry Model
Agriculture, forestry, fishing, and hunting	4.7	0.3
Mining	7.4	3.6
Utilities	-3.6	-2.4
Construction	4.3	0.5
Manufacturing	15.0	NA
Auto and Other Motor Vehicle Manufacturing	NA	13.8
Other Manufacturing	NA	0.5
Wholesale trade	-0.1	-0.8
Retail trade	0.1	-0.6
Transportation and warehousing	3.4	0.6
Information	4.3	2.0
Finance, insurance, real estate, rental, and leasing	3.1	1.7
Professional and business services	-0.8	-1.1
Educational services, health care, and social assistance	0.5	-0.9
Arts, entertainment, recreation, accommodation, and food services	3.2	0.5
Other services, except government	2.0	0.5
Government	2.8	0.6

For example, in the 15-industry simulation, composite prices for the transportation and warehousing industry at 3.4 percent. In the 16-industry simulation, the corresponding impact on transportation and warehousing industry composite prices are lower at 0.6 percent. While analysts certainly expect this industry to depend on both manufacturing in general (and automobile and other motor vehicle manufacturing in particular), the results from the 15-industry simulation suggest that all of the manufacturing sub-industries that contribute to transportation and warehousing experiencing the same reduction in overall factor productivity, causing transportation and warehousing to suffer a large impact. In the 16-industry simulation, analysts limit the productivity reduction to one-sub-industry, which makes the inter-industry impact more targeted.

Clearly, separating manufacturing into the two sub-industries changes the results of the analysis, suggesting that there are advantages to having more detailed industry definitions for the analysis.

2.5 United States 30-Industry Simulation Results

The final simulation divided the U.S. economy into 30 industries. One inference from the comparison discussed in the previous section is that more detailed industry definitions will generally lead, all else equal, to smaller inter-industry impacts. This is due to the tighter targeting of model input changes. Table 2-3 shows the industry definitions for the 30-industry simulation and compares these industry definitions to the original NCGEM 15-industry simulation.

TABLE 2-3.—Industry Mapping – 2-Digit to 3-Digit Industries.

15-Industry Model Categories	30-Industry Model Categories
Agriculture, forestry, fishing, and hunting	Agriculture, forestry, fishing, and hunting
Mining	Mining
Utilities	Utilities
Construction	Construction
Manufacturing	Primary metals Fabricated Metal Products Machinery Computer and electronic products Electrical equipment, appliances, and components Automobiles Petroleum and coal products Chemical products Other manufacturing
Wholesale trade	Wholesale trade
Retail trade	Retail trade
Transportation and warehousing	Air transportation Rail transportation Water transportation Truck transportation Transit and ground passenger transportation Pipeline transportation Other transportation and support activities Warehousing and storage
Information	Information
Finance, insurance, real estate, rental, and leasing	Finance, insurance, real estate, rental, and leasing
Professional and business services	Professional and business services
Educational services, health care, and social assistance	Educational services, health care, and social assistance
Arts, entertainment, recreation, accommodation, and food services	Arts, entertainment, recreation, accommodation, and food services
Other services, except government	Other services, except government
Government	Government

Like the simulation of the 16-industry State of Michigan simulation, this simulation is based on a 20-percent reduction in factor productivity in automobile manufacturing. The 20-percent reduction in automobile factor productivity raises its supply price by 7.7

percent and reduces output by 10.2 percent. Figure 2-11 compares the impacts on supply price and output for the remaining 29 industries. Notable impacts include dramatic reductions in primary metals and fabricated metals products output, possibly because their outputs are inputs in automobile and other motor vehicle manufacturing and increases in rail and air transportation output, possibly due to substitution away from automobile and other motor vehicle manufacturing. In addition, results show a small reduction in truck transportation output and increases in agriculture, forestry, fishing, and hunting, and mining industry output. There is an insignificant increase (less than 1 percent) in chemical products output, and insignificant decreases in warehousing and storage output. Finally, there are small (roughly 0.5 percent) increases in output in the computer and electronic products, electrical equipment, and petroleum and coal products industries.

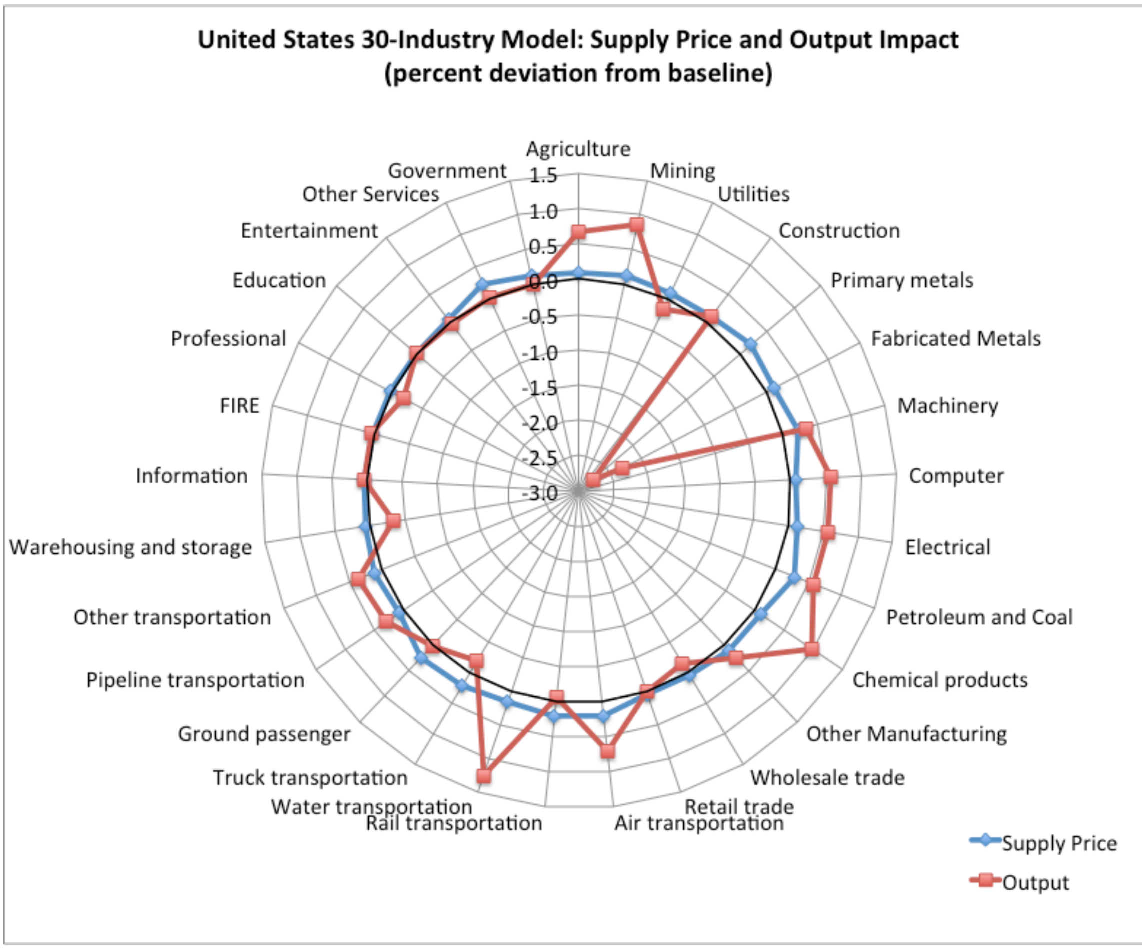

FIGURE 2-11.—United States 30-Industry Model: Supply Price and Output Impacts.

2.6 Verification and Validation

Using SAM tables to specify the underlying technology of the economy incorporates that technology into baseline simulations, ensuring that the baseline calibrates exactly to the real-world data collected by BEA, BLS, and the other agencies. In addition, NISAC is continually examining the simulation properties of the model to ensure that the results are sensible qualitatively (i.e., are consistent with prior economic intuition on how the model should behave). When possible, NISAC will compare results from simulations using NCGEM to published reports to ensure that estimated model results are as quantitatively accurate as possible. Developers will continue these checks as part of the standard model development process.

3 Conclusion

This report demonstrates some of NCGEM's capabilities and illustrates the flexibility in the model 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 NCGEM. 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 the model to estimate impacts over time. This will allow NCGEM 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. 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 NCGEM will utilize Oak Ridge National Laboratory Transportation Network data to integrate new economic geography factors into NCGEM. This will allow NISAC to use NCGEM to estimate cross hauling and import-export at much finer geographic detail than possible using previous NISAC economic models.

Appendix A: Detailed NCGEM Description

A typical CGE model is based on the assumption that households maximize utility (their well-being) by choosing quantities of goods to consume subject to a budget constraint. Households also supply labor to a labor market and receive wages in exchange for their labor time. Firms maximize profit by purchasing labor and capital from households and commodities from other firms to produce goods and services that they sell subject to a constraint on technology.

The economy in NCGEM is modeled as sectors defined as households, firms, government, financial intermediaries, and a foreign sector. One way to illustrate how sectors interact with one another is through a circular flow diagram of the economy. This diagram shows the interaction of these sectors through markets or, in the case of the financial sector, financial intermediaries (banks and other financial institutions). The following sections discuss the market sectors in NCGEM.

Production

Production of goods and services requires factors of production (capital and labor) and commodities produced by other firms. For example, the production of an automobile requires machinery, raw materials, labor, and finished components (e.g., starters, tires, windshields) purchased from other firms. Currently, NCGEM does not treat land as an explicit input, so this model ignores the land factor of production.[1] Nevertheless, economic analysis methodology typically represents the relationship between factors of production and output, referred to as a production function. This equation shows the output of one good (or service), given quantities of the inputs (factors of production and intermediate outputs from other firms). For NCGEM, production is specified using what is known as the Cobb-Douglas production function.[2] Generally, the Cobb-Douglas production function treats output as a function of two inputs, capital and labor, and includes a coefficient that reflects total factor productivity and one coefficient for each of the inputs that show, *ceteris paribus*, how output changes given a change in one of the inputs.

For the sake of computational convenience, NCGEM divides production into two stages.[3] In the first stage, the firm purchases labor and capital from households and combines these factors to produce a composite commodity. Purchases of labor and capital in the first stage are made at prevailing factor prices determined in labor and capital markets. In the second stage, the firm combines the composite commodity with intermediate inputs (goods produced by other firms and purchased from other firms) to produce the output it

[1] The land factor of production could be treated as part of the capital stock of the economy.

[2] The Cobb-Douglas form of the production function was originally presented in Cobb, C.W. and P.H. Douglas, "A Theory of Production," *American Economic Review 18 Supplement* (1928): pp. 139–165. It is widely used in economic analysis. The economics literature is filled with examples of analyses conducted with Cobb-Douglas production functions; a more recent example is in Filipe, Jesus, "The Estimation of the Cobb Douglas Function," *Eastern Economic Journal* 31(3)(2005): pp. 427–445.

[3] Analysts could combine these two stages and have the firm choose quantities of capital, labor, and intermediate goods to produce output; the results of this version of the model would be analytically identical to the results of NCGEM. It is computationally simpler to divide production into the two stages, as NISAC has.

sells in goods markets. In the NCGEM, these transactions occur simultaneously for all firms. Purchases of commodities in the goods market are made at prices determined in the respective goods markets.

The Cobb-Douglas representation of the first stage of production treats output of the composite commodity as dependent on capital and labor and includes a coefficient for total factor productivity as well as coefficients for capital and labor. The Cobb-Douglas representation of the second stage treats output of the final good (or service) as dependent on total factor productivity, the quantity of the composite commodity used, and the intermediate outputs from each of the 16 industries represented in the NCGEM.[4]

Households

The household sector is made up of households that earn income in labor markets and purchase goods and services goods market. Households also save income and pay taxes to government. Households allocate their income (net of savings and taxes) to consumption of any combination of goods available from the 16 industries in the model to maximize utility subject to a budget constraint.

Government

In the NCGEM, government raises income by levying three types of taxes: 1) a direct tax on household income (an income tax), 2) an *ad valorem* production tax on gross output (a sales tax), and 3) an *ad valorem* tax on imports (a tariff). In this version of the NCGEM, the tax rates for each tax are constant. One possible future enhancement to NCGEM would be to modify the model's tax structure to better represent the actual tax structure of the U.S. economy. These taxes represent income to the government, which it uses to purchase goods and services.

Investment and Savings

Investment refers to activities that firms undertake to increase their stock of machinery, equipment, structures, and inventories. For the household sector, investment refers mainly to the purchase of structures (e.g., housing). In terms of the national income accounts, investment is composed of nonresidential investment (business investments on capital goods, such as producer durable equipment, machinery, and structures), residential investment (household investment in structures and equipment owned by proprietors and rented to tenants), and changes in business inventories. In the NCGEM, investment funds are collected from savings by the household, government, and foreign sectors, and are spent on investment goods. Investment in any one industry will depend on the share of investment in the output of that industry, scaled by the price of the composite commodity for that industry.

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[4] The industry categories are: 1) Agriculture, Forestry, Fishing, and Hunting; 2) Mining; 3) Utilities; 4) Construction; 5) Manufacturing; 6) Wholesale Trade; 7) Retail Trade; 8) Transportation and Warehousing; 9) Information; 10) Finance, Insurance, Real Estate, Rental, and Leasing; 11) Professional and Business Services; 12) Educational Services, Health care, and Social Assistance; 13) Arts, Entertainment, Recreation, Accommodation, and Food Services; 14) Other Services, except Government; and 15) Government.

International Trade

For NCGEM, international trade represents trade between the United States and foreign countries, as well as trade between one region (e.g., State) and other regions (e.g., States) in the United States. In terms of trade between countries, NCGEM distinguishes between prices expressed in terms of a domestic (in this case, United States) currency and prices expressed in terms of a foreign currency. Because NCGEM does not currently distinguish between individual countries, it uses a composite foreign price that captures prices of goods to reflect foreign prices weighted by the amount of trade that takes place between the United States and all foreign countries. The exchange rate used in NCGEM is the ratio between U.S.-denominated prices and foreign-denominated prices.

In NCGEM, the economy faces a balance of payments constraint that requires the value of exports (valued at the composite foreign currency price) plus the current account deficit (valued in terms of the composite foreign currency) equal the value of imports (valued in terms of the domestic currency).[5,6]

In addition, NCGEM is based on the assumption that similar imported goods are not perfectly substitutable with corresponding U.S.-produced goods. This assumption allows the model to account for similar goods that are both imported and exported at the same time, a phenomenon known as *two-way trade* or *cross hauling*. To capture this, NCGEM assumes that households consume a composite good that comprises both imported and domestically produced like goods.[7] This treatment allows NCGEM to capture how changes in domestic and import prices influence substitution between imports and consumption of domestically produced goods and services (on the demand side) as well as the influence of domestic and imported prices on exports and domestic goods supply (on the supply side).

Market Clearing Conditions

The NCGEM solution is determined when the relevant equations are satisfied simultaneously. This solution occurs when each sector has allocated resources to maximize profits (firms) and utility (households), and when market clearing conditions for all markets are met (namely, when supply equals demand in all markets at prevailing equilibrium prices).

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[5] The current account refers to the balance of trade (exports less import) plus factor income (earnings on foreign investments minus payments made to foreign investors) plus cash transfers.
[6] This constraint can also be valued in terms of domestic prices by using the exchange rate.
[7] Such goods are referred to as *Armington Composite Goods*, based on analysis in Armington, P., "A Theory of Demand for Products Distinguished by Place of Production," *IMF Staff Papers* 16(1)(1969): pp. 159-178.

Appendix B: Data Requirements and Social Accounting Matrix Construction

Definition and Structure of Social Accounting Matrix

The SAM represents the national or regional economy divided into institutions and shows the flows of all financial transactions that take place inside that nation or region. For the NCGEM, the economy for each region is divided into blocks that show transactions between industries (from the IO table); transactions between industries and households; transactions between households, businesses, and government; and between households, business, government, and the foreign sector (through exports and imports). When completed, the SAM fully describes the economy. Analysts use the SAM to specify the technical parameters of the NCGEM; thus, it is important that the SAM conforms to the data requirements of the CGE model.[8]

The SAM presented in Table B-1 is divided into different blocks that represent transactions between specific sets of institutions in the NCGEM. The first transactions are production of intermediate outputs that are consumed by other firms to produce final outputs. In most cases, the distinction between an intermediate and a final good is self-evident. Some goods, however, are consumed by firms to produce output but also consumed by households as final consumption (e.g., automobile tires). In the former case, the tire is treated as an intermediate good and in the latter case as a final good. These transactions are represented in the **Industry-Industry Activity** block, which shows the flow of intermediate output of industries from each industry to the other industries that consume that output to produce its own output.

In addition to intermediate outputs purchased from other firms, production requires factors of production, namely, capital and labor. Just below the Industry-Industry Activity Block is the **Factor-Industry** block, which shows the flows from the Capital and Labor rows of the table into the Industry columns that use those inputs to produce their respective outputs. Because households are ultimately the supplier of capital and labor, there is a corresponding entry representing factor payments to households in the corresponding **Household-Factor Payment** block.

The next block is the **Tax-Tariff-Industry** block, which shows taxes and tariffs paid by each industry. Government tax collections are shown in the corresponding **Government-Taxes-Tariffs** block.

The **Industry-Final Demand** block shows purchases of final goods and services by households, investors, and government. The sum of these entries (along with net exports represented in the **Export** block and **Import** block in the table) equals GDP.

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[8] For context, the appendix includes explanatory text from the main report as an introduction to the SAM discussion.