Understanding Complex Systems: Economic Impacts from Catastrophic Events

By Brian K. Edwards and Mary Ewers

Catastrophic events cause many kinds of impacts, including injuries, fatalities, damages to road, buildings, and other infrastructure, and often disrupt economic activity both inside and outside the affected area. In many cases, economic analysis of catastrophic events will be done in concert with physics- or system-based models that identify physical disruptions to the flow of goods and services (e.g., electric power, telecommunications, transportation) that cause economic activity in regions to be interrupted. Economic analysis methods can range from simple aggregated methods to more sophisticated approaches that capture the complex dynamics from initial event to recovery. This section presents a middle ground discussion of how one such method, namely input-output methods, can be used to estimate short-term economic impacts.

What Happens to an Economy When a Catastrophic Event Occurs?

In estimating the economic impacts of a catastrophic event, economists tend to focus on how the event affects the ability of the economy to operate. This is usually assessed in terms of the extent to which that ability to produce goods and services has been impaired by the event. The ability of the affected area's economy to operate will be disrupted by losses of electric power, physical damage to roads, buildings, and infrastructure systems.

Generally, the economic impacts of a catastrophic event, such as a hurricane, will be determined by two factors: 1) the amount of economic activity interrupted by the event and 2) the duration of this interruption. Of course, there are additional economic impacts, such as those driven by injuries, fatalities, losses in property values, and possible offsetting impacts driven by restoration activities, but this discussion will focus on economic impacts caused by business interruptions. Losses in economic activity are usually measured in terms of losses of Gross Domestic Product (GDP), which is defined as the dollar value of final goods and services produced by an economy at an annual rate. If we parse the above definition into its components, we note the following: 1) GDP is expressed in dollar terms using prevailing prices for goods and services; 2) GDP measures final output, and hence does not measure the production of intermediate goods (those produced for input into other production processes); and 3) GDP is usually expressed as an annual rate, meaning that it shows what the economy would be producing over a full year of activity. Related to restricting GDP measurement to final goods and services is that GDP is a *value added* concept, meaning that it does not include the cost of goods that went into the production of the good or service for final consumption.

Estimation of economic impacts is usually done by taking estimates of the number of workers in the affected area and assuming that, as a result of the event, they are no longer able to work and therefore no longer able to produce goods and services. This disruption in economic activity will continue as long as the physical impacts and disruptions of infrastructure systems prevent these workers from returning to work; usually as long as it takes to repair the damage caused by the event. Underlying this estimation of economic impacts is the concept of a *production function*, which relates the number of different inputs to the production of output. Since most catastrophic events are short-term in duration, the analysis usually isolates the labor input. Using estimates of labor in the affected area, the analysis generally prorates production on a per-worker and per-day basis, takes the number of workers unable to work during the event and restoration period, and multiplies the amount of output per-worker lost per-day by the expected duration of the event. The resulting estimate is the lost rate of output due to the event. For example, if 10,000 workers are in an area and the event is expected to disrupt economic activity for 30 days, and if the average GDP per-person per-day is $200, then the economic impacts are estimated to be $60 million. Remember, this estimate is only in terms of lost GDP and does not include the value of damaged property, lost human life, damages to the environment, and other factors not directly connected to the production of goods and services over the short-term.

There are additional impacts that occur when businesses in the affected area stop functioning. In addition to producing goods and services, they also stop purchasing inputs from other firms. This means that we must make an additional distinction when estimating the economic impacts of a catastrophic event. The first impact, which we have already discussed, are referred to as *direct economic impacts*, and measure the loss in actual final production by businesses operating in the affected area. The second, called *indirect economic impacts*, measure the reduction in output caused by a reduction in the demand for outputs from other firms that produced inputs for those firms in the affected area. For example, when a restaurant is shut down, it not only stops serving meals, but also stops purchasing food and other inputs from other firms. The indirect economic impacts are estimated from the direct economic impacts by using a *multiplier*, which is a scalar that allows us to incorporate the value of lost production by those firms that supplied inputs to firms in the affected area into the estimate of overall economic impacts. For example, applying a multiplier of 1.5 to our initial \$60 million estimate discussed above would yield *direct* plus *indirect* economic impacts of \$90 million (in terms of lost GDP) due to the event.

Input-Output Methods

The process of estimating economic impacts described above provides an estimate of overall regional economic impacts from a catastrophic event. Another area of research is to determine whether specific industries in the affected area suffer larger impacts than other industries. In order to answer this question, we can use what is called the *input-output* approach, which views the economy as a set of interconnected industries that exchange goods and services to produce output for consumption. This view of the economy can be traced back to François Quesnay's *Tableau Économique* (Economic Table) in 1758, which viewed the economy as a flow of goods analogous to a circulatory system. It wasn't, however, until the 20th century that input-output methods became more formalized and integrated into national income accounting systems. The 1973 Nobel Prize in economics was awarded to Wassily Leontief for his work on developing the mathematical foundations for input-output analysis and research continues to this day to refine the approach.

If we focus on a single region and just the business sector, we will distinguish between two kinds of production: 1) production that is purchased by other business as inputs, e.g., one firm fabricates metal and sells that fabricated metal to a stamping plant that produces doors for automobiles; and 2) production for consumers at the retail level, e.g., a barbershop that produces haircuts for consumers. Demand for the first kind of production is referred to as *intermediate demand* and demand for the second kind of production is referred to as *final demand*. In addition to businesses, the economy is made up of households (that provide labor and purchase goods from firms), government agencies, and a foreign sector. Figure 1 is one example of a *circular flow* diagram that illustrates the flows of goods and services and the flows of payments in this sector.

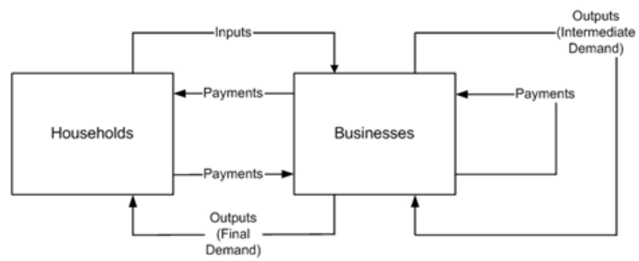

Figure 1. *Circular flow in a simple model of the business sector.*

The business sector is also divided into *industries*, e.g., manufacturing and agriculture, which allows us to examine how intermediate and final goods flow between industries and consumers and allow us to make comparisons between the outputs of different industries in the economy.

The Simple Mathematics of Input-Output Models

The simplest input-output model assumes that what an industry produces will be the sum of intermediate output and output produced for final consumption. Let the vector **Y** represent production for **N** industries and let the vector **D** represent the final demand for the same **N** industries. In addition, we must specify how inputs are translated into outputs. This will depend on the existing state of technology that is represented by the *technology coefficient* $\mathbf{N} \times \mathbf{N}$ matrix, **a**. The basic input-output model will then consist of the following three equations:

$$(1)\ \mathbf{Y} = \begin{bmatrix} Y_1 \\ Y_2 \\ \cdot \\ Y_{N-1} \\ Y_N \end{bmatrix};\ (2)\ \mathbf{D} = \begin{bmatrix} D_1 \\ D_2 \\ \cdot \\ D_{N-1} \\ D_N \end{bmatrix};\ \text{and (3)}\ \mathbf{a} = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdot & a_{1,N-1} & a_{1,N} \\ a_{2,1} & a_{2,2} & \cdot & a_{2,N-1} & a_{2,N} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_{N-1,1} & a_{N-1,2} & \cdot & a_{N-1,N-1} & a_{N-1,N} \\ a_{N,1} & a_{N,2} & \cdot & a_{N,N-1} & a_{N,N} \end{bmatrix}.$$

Equations (1) through (3) are combined into the following equation:

$$(4)\qquad \mathbf{Y} = \mathbf{aY} + \mathbf{D}.$$

This equation says that total output (**Y**) equals the sum of intermediate output (**aY**) plus output produced for final demand (**D**). The technology matrix is used to translate outputs purchased from other industries to produce its own output. Solving equation (4) for **Y** yields the following equation that expressed output as a function of final demand.

$$(5)\qquad \mathbf{Y} = [\mathbf{I} - \mathbf{a}]^{-1}\,\mathbf{D},$$

where **I** is the identity matrix. The $[\mathbf{I} - \mathbf{a}]^{-1}$ matrix is known as the *Leontief–Inverse* matrix and shows how much output will change, given a change in final demand.

Industry Impacts

Since we have set up the model to distinguish industries, we can show how a change in one industry can affect the output for all industries. Let's consider a simplified economy with two industries, manufacturing (m) and services (s). In this economy, we can rewrite equation (5) as:

$$(6) \qquad \begin{bmatrix} Y_m \\ Y_s \end{bmatrix} = \left[\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} a_{mm} & a_{ms} \\ a_{sm} & a_{ss} \end{bmatrix} \right]^{-1} \begin{bmatrix} D_m \\ D_s \end{bmatrix} = \begin{bmatrix} 1-a_{mm} & -a_{ms} \\ -a_{sm} & 1-a_{ss} \end{bmatrix}^{-1} \begin{bmatrix} D_m \\ D_s \end{bmatrix} .$$

We can then solve equation (6) explicitly for manufacturing and services output, as we show in equations (7) and (8) below.

$$(7) \qquad Y_m = \frac{1}{(1-a_{mm})(1-a_{ss}) - a_{ms}a_{sm}} [(1-a_{ss})D_m + a_{ms}D_s]$$

$$(8) \qquad Y_s = \frac{1}{(1-a_{mm})(1-a_{ss}) - a_{ms}a_{sm}} [a_{sm}D_m + (1-a_{mm})D_s]$$

Simple inspection of equations (7) and (8) reveals that a change in, for example, manufacturing demand (D_m) will affect manufacturing output (from equation (7)) as well as services output (from equation (8)). We can use the U.S. Bureau of Economic Analysis (BEA) Industry-by-Industry Total Requirements table from 2008 as the basis for a numerical example involving equations (7) and (8) above, and these are given in Table 1.

The elements of Table 1 show, *on a per-dollar basis*, the industry output needed to meet the final demands in each industry. For example, the top row of the above table tells us that \$1.64 of manufacturing output plus \$0.11 of service industry output is needed to satisfy \$1 in manufacturing final demand. Similarly, the bottom row tells us that \$0.17 of manufacturing output plus \$1.18 in services industry output is needed in order to produce \$1 in services final demand. For example, if final demand for manufacturing is \$2,000 and final demand for services is \$500, then we do the following multiplication (analogous to equations (7) and (8) above):

	Manufacturing	Services
Manufacturing	1.64	0.11
Services	0.17	1.18

Table 1. *Selected cells of the industry-by-industry total requirements after redefinitions for 2008 (US Bureau of Economic Analysis).*

$$(9) \qquad \begin{bmatrix} Y_m \\ Y_s \end{bmatrix} = \begin{bmatrix} 1.64 & 0.11 \\ 0.17 & 1.18 \end{bmatrix} \begin{bmatrix} 2{,}000 \\ 500 \end{bmatrix} = \begin{bmatrix} 3{,}335 \\ 930 \end{bmatrix}$$

The example shows us that \$3,335 in manufacturing output and \$930 in services output must be produced in order to meet manufacturing final demand of \$2,000 and services final demand of \$500.

Keep in mind that this is but one example and hence it ignore many issues. For one, it ignores the possibility that the regional economy interacts with another region (or country). Some of the increase in the demand for manufacturing output could have been met with imports. This means that some of the impact of the increase in services demand on the regional economy would have been offset by an increase in the demand for imports.

The above analytical tools are used to estimate the regional economic impacts of a hurricane or other catastrophic event. Reconsider equation (4), **Y = aY + D**, which stated that total output (**Y**) equals the sum of intermediate output (**aY**) plus output produced for final demand (**D**). If business activity is interrupted due to a hurricane, then the ability of the affected region to produce goods and services will be interrupted (even if there is little or no physical damage to manufacturing facilities, they will often lose electric power that will cause them to curtail operations) and this will cause a reduction in output. These are analogous to the *direct economic* and *indirect economic* impacts we have discussed in previous sections of this paper. Since we have output divided into industries, we can also determine whether specific industries are affected more than others by the event.

These direct and indirect impacts can be estimated by using the Regional Input Output Modeling System (RIMS) multipliers produced by BEA (https://www.bea.gov/regional/rims). Other models, such as the IMPLAN (www.implan.com), REMI (www.remi.com), and REDYN (www.redyn.com) models, can also be used to estimate direct and indirect impacts resulting from a catastrophic event. The simple approach sketched in this section ignores many other factors, some of which he have alluded to already (injuries, fatalities, losses in property values, and possible offsetting impacts driven by restoration activities). We are also ignoring critical dynamic impacts that would address how quickly it takes the economy to recover and, by assuming that there is no permanent structural damage to the regional economy, we assume that the economy will recover fully from the event. An earthquake, for example, could cause severe physical damage to infrastructure assets and property that could take many years to repair and restore. Moreover, the lack a multi-regional approach ignores the possibility that long-term damage to the regional economy could occur due to loss of market share to other regions. For example, if an event causes an interruption of business activity that is lengthy, firms outside the region could begin to draw workers away from the affected area causing irreversible reductions in regional output. We are also ignoring possible environmental damages and the costs of environmental remediation, two factors that could be significant if the event were an oil spill or a release of other hazardous materials.

References

K.J. Horowitz and M.A. Planting, *Concepts and Methods of the Input-Output Accounts*, Bureau of Economic Analysis, U.S. Department of Commerce, September 2006 (Updated April 2009).

Leontief, Wassily, *Input-Output Economics*, Oxford University Press, 1986.

Rose, A., *Tracing Infrastructure Interdependencies through Economic Interdependencies*, Unpublished, 2005.

Spiegel, William Henry, *The Growth of Economic Thought, Revised and Expanded Edition*, Duke University Press, 1983.

Brian K. Edwards and Mary Ewers are economists at Los Alamos National Laboratory.