

Single and Multiple Industry Economic Contribution Analysis Using IMPLAN



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James E. Henderson, Ph.D.¹ and Garen K. Evans, Ph.D.²

ABSTRACT

Industry economic contribution analysis is used to estimate the contribution of a sector or group of sectors to an entire economy. The methodology presented here describes a technique that accounts for input bias that results when modeling output as a final demand. This type of bias can be corrected by adjusting the direct effect to account for indirect and induced effects a sector can have upon itself and other sectors of interest. This method uses model multipliers to account for this input bias by reducing the direct effect and is described for conducting both single and multiple industry economic contribution analyses.

Keywords: multipliers, input-output models

Perhaps the best known and most widely used method for estimating economic contribution or economic impact is input-output analysis (Baumol, 2000; Watson et al., 2007). Contribution and impact have different meanings that need to be clarified as the focus of this document is single and multiple sector contribution analysis. Contribution analysis estimates the relative importance of an existing business or industry to an economy while impact analysis estimates the effects of new or expanding business or industry to an economy (Watson et al., 2007). Input-output analysis using IMPLAN (IMpact analysis for PLANning) software and data is often used to estimate the economic contribution of one or more sectors of an economy. IMPLAN was originally developed by the USDA Forest Service and is currently maintained by the IMPLAN Group LLC. Using the total production values to represent the sector's final demands in an input-output model will overestimate the value of the sector of interest and its associated economic contribution to other sectors of the economy. Following a brief review of the Leontief input-output model and the concept of multipliers, this paper describes a methodology for adjusting the direct effect value for the sector or sectors of interest using input-output model multipliers.

Input-output analysis is an analytic framework that was developed by Nobel laureate Wassily Leontief in the 1930s³. The framework explicitly tabulates the flow of goods and services between industries, and shows how output from each industry or sector of the economy becomes an input into other sectors (i.e., inter-industry transactions). Included in the framework are data on final demand and final payments. Final demand represents the value of final goods

and services purchased by consumers. Final payments are the value of payments for inputs made outside the intermediate production process, such as wages, and other factors provided by households.

Input-output models predict how changes in final demand affect the economy. Industries produce goods and services to meet changes in final demand, which requires them to purchase inputs from other industries. This relationship between final demand and inter-industry transactions is known as a backward linkage. Inter-industry transactions stimulate additional transactions *ad infinitum* as each sector of the economy responds to the initial change in final demand. The results are tabulated as the model is iteratively solved. For example, consider an economy with three sectors (Table 1): agriculture (AG), manufacturing (MFG), and services (SVC). Industries in the AG sector sell 80 units to other industries in the AG sector, 10 units to industries in the MFG sector, and 0 units to industries in the SVC sector, and 90 units to consumers to meet final demand. At the same time, The AG sector buys 80 units from itself, and 30 units

TABLE 1. Hypothetical economy with three sectors: agriculture (AG), manufacturing (MFG), and services (SVC) with final demands, final payments and total output.

Seller/Buyer	AG	MFG	SVC	Final Demand	Total Output
AG	80	10	0	90	180
MFG	30	100	20	200	350
SVC	10	30	50	120	210
Final Payments	60	210	140		410
Total	180	350	210	410	1150

from MFG, and 10 units from SVC, as well as 60 units of wages and other final payments.

To see how this framework can be used as a predictive model, consider an increase of 50 units of final demand in the manufacturing sector. Round-by-round each sector responds to the initial change in final demand. In the first round, MFG purchases 1.5 units from AG (50 times 0.03), 14.5 units from MFG (50 times 0.29), and 4.5 units from SVC (50 times 0.09). In the second round, AG purchases 0.66 units (1.5 times 0.44) from AG, 0.255 units (1.5 times 0.17) from MFG, and 0.09 units (1.5 times 0.06) from SVC. Additional second round results are then tabulated for MFG and SVC. Additional rounds refine the results. This round-by-round process traces out the changes made in each sector, and eventually the changes are diminutive enough to stop the process. An alternative, and more efficient method than the iterative process makes use of the Leontief Inverse.

The three rows and three columns that make up the upper left hand corner of the input-output model contain the inter-industry transactions, and can be represented by the matrix, Z , with z_{ij} equal to sales from row sector i to column sector j . Let x_1 equal output in the AG sector, and x_2 equal output in the MFG sector, and x_3 equal output in the SVC sector. Let y_1 equal final demand in the AG sector, y_2 equal final demand in the MFG sector, and y_3 equal final demand in the SVC sector. The following identities for each row are:

$$x_1 = z_{11} + z_{12} + z_{13} + y_1 \quad (1)$$

$$x_2 = z_{21} + z_{22} + z_{23} + y_2 \quad (2)$$

$$x_3 = z_{31} + z_{32} + z_{33} + y_3 \quad (3)$$

The input requirement for each industry to produce exactly one additional unit of output is calculated as $a_{ij} = z_{ij} / x_i$. For example, AG requires 0.44 AG units, 0.17 MFG units, and 0.06 SVC units to produce one additional unit of AG. Calculating a_{ij} for each i, j results in a table of technical coefficients (also known as a direct requirements table), and is represented by matrix A .

$$A = \begin{bmatrix} 0.44 & 0.03 & 0.00 \\ 0.17 & 0.29 & 0.10 \\ 0.06 & 0.09 & 0.24 \end{bmatrix} \quad (4)$$

Substituting each z_{ij} with $a_{ij} x_i$ results in the following identities:

$$x_1 = a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + y_1 \quad (5)$$

$$x_2 = a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + y_2 \quad (6)$$

$$x_3 = a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + y_3 \quad (7)$$

and after rearranging terms:

$$(1 - a_{11})x_1 - a_{12}x_2 - a_{13}x_3 = y_1 \quad (8)$$

$$-a_{21}x_1 + (1 - a_{22})x_2 - a_{23}x_3 = y_2 \quad (9)$$

$$-a_{31}x_1 - a_{32}x_2 + (1 - a_{33})x_3 = y_3 \quad (10)$$

can be represented in matrix form as:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \times \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} \quad (11)$$

In matrix notation this relationship is denoted $[I-A] X = Y$, or equivalently, $X = [I-A]^{-1}Y$, where $[I-A]^{-1}$ is the Leontief Inverse. The predictive model, $\Delta X = [I-A]^{-1} \Delta Y$, relates the change in total industry output as a product of the Leontief Inverse and a change in Final Demand.

From the example:

$$I - A = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.44 & 0.03 & 0.00 \\ 0.17 & 0.29 & 0.10 \\ 0.06 & 0.09 & 0.24 \end{bmatrix} \quad (12)$$

$$= \begin{bmatrix} 0.56 & -0.03 & 0.00 \\ -0.17 & 0.71 & -0.10 \\ -0.06 & -0.09 & 0.76 \end{bmatrix}$$

thus:

$$(I - A)^{-1} = \begin{bmatrix} 1.82 & 0.08 & 0.01 \\ 0.45 & 1.44 & 0.18 \\ 0.19 & 0.17 & 1.33 \end{bmatrix} \quad (13)$$

From this, any change in output, X , as a result of a change in final demand, Y , can be calculated. The column sums of the Leontief Inverse are the total multipliers for each sector (e.g., the MFG total output multiplier is $0.08 + 1.44 + 0.17 = 1.69$). For example, a 100-unit increase in final demand for MFG results in a total increase of 169 units: the initial direct effect on MFG (100 units), and 69 total units of indirect effect (AG=8, MFG=44, SVC=17).

$$\Delta X = \begin{bmatrix} 1.82 & 0.08 & 0.01 \\ 0.45 & 1.44 & 0.18 \\ 0.19 & 0.17 & 1.33 \end{bmatrix} \times \begin{bmatrix} 0 \\ 100 \\ 0 \end{bmatrix} = \begin{bmatrix} 8 \\ 144 \\ 17 \end{bmatrix} \quad (14)$$

The previous example demonstrated how the Leontief Inverse can be used to assess the effects of a change in final demand in one sector of the economy, but changes in final demand for multiple sectors are just as easily calculated by changing multiple elements in the final demand vector.

Single-Sector Contribution Analysis (SSCA)

Using input-output analysis (I-O) to estimate the contribution of one sector of the economy on total economic output is the goal of contribution analysis. It is a common practice among analysts who are requested to help industry advocacy campaigns, or to leverage interest in efforts to support continued funding that are perceived to be important to a particular sector of the economy. SSCA uses input-output methods to estimate the direct and indirect effects of one sector of the economy *in situ*, that is, without assuming any external change in the final demand vector. Since the final demand vector remains unchanged, the analysis focuses on calculating a value that represents the direct contribution of a single sector of the economy such that the sum of the total output vector is preserved. Two approaches to define the direct contribution of a sector include (1) either the direct contribution is defined as the total sector output or (2) the direct contribution is defined as total sector

output less the sector's final demand. Neither of these approaches are satisfactory, because the output vector is not preserved. If the current level of output is used as the direct contribution, then the input-output model will necessarily overestimate the total contribution because of the multiplier effect (Equation 14). On the other hand, if the direct contribution of a sector is defined as output net of final demand, then the input-output model will tend to underestimate the total contribution because of the inter-dependencies inherent within the input-output framework.

The contribution of an existing single sector of the economy can be calculated with an adjustment factor that preserves the output values in the transactions table. For the single-sector case, the adjustment factor is the reciprocal of the sector's multiplier.

$$\text{Adjustment Factor} = \text{Multiplier}^{-1} \tag{15}$$

The product of the adjustment factor and the level of output is defined as the direct contribution of the sector to the economy.

$$\text{Contribution}_{\text{direct}} = \text{Output}_{\text{total}} \times \text{Multiplier}^{-1} \tag{16}$$

In the previous example, a multiplier of 1.69 was calculated for the manufacturing sector. The direct contributions made by the manufacturing sector are obtained simply as the product of total manufacturing output and the reciprocal of its multiplier: $350 \times 1/1.69 = 207$, a value which fully preserves the transaction table's output value for manufacturing. The product of the Leontief Inverse and the column vector containing the newly calculated manufacturing direct effects is a new column vector or the preserved output vector:

$$\begin{bmatrix} 1.82 & 0.08 & 0.01 \\ 0.45 & 1.44 & 0.18 \\ 0.19 & 0.17 & 1.33 \end{bmatrix} \times \begin{bmatrix} 0 \\ 207 \\ 0 \end{bmatrix} = \begin{bmatrix} 17 \\ 298 \\ 35 \end{bmatrix} \tag{17}$$

In the example, total output in MFG is preserved; the sum of the elements in the new vector is 350 units. The primary contribution of MFG is 298, which is the direct contribution equal of 207 units, and an indirect contribution equal to 91 units (298-207) Secondary contributions from AG (17) and SVC (35) total 52 units. The total of the column vector is the initial level (350) of manufacturing output: 298 of direct manufacturing plus 52 of agriculture and service (Table 2).

TABLE 2. Contribution analysis of manufacturing sector in hypothetical economy.

Manufacturing (primary contribution)	298
Agriculture (secondary contribution)	17
Services (secondary contribution)	35
Total Manufacturing Output	350

Multiple Sector Contribution Analysis

In the previous section, we explained how to obtain primary and secondary contributions of a single economic sector. In this section, we expand the procedure to two or more sectors. Understanding the contribution of multiple sectors is often warranted because of the similarity of disaggregated activities. For example, within the broad category of trade, retail and wholesale activities are often disaggregated and tabulated separately. Another example is agriculture and forestry, which are often disaggregated into multiple sectors to represent all of their production and processing activities.

Yet disaggregated sectors that share some similarity within their larger grouping are often major components of the backward linkages of other sectors because they each make substantial transactions within the larger grouping. For example: production agriculture and food processing are both part of agriculture, but have obvious linkages; timber production and furniture manufacturing is another example. Calculation of the contribution of each sector with individual sector multipliers does not adequately account for inter-industry dependencies, and the total output vector will not be preserved. For example, consider the contribution analysis of the example economy simultaneously using AG, MFG, and SVC, which have total output multipliers of 2.46, 1.69, and 1.51, respectively. The single-sector direct contribution value for AG is 73.2 units (180/2.46), 207.1 units (350/1.69) for MFG, and 138.2 units (210/1.52) for SVC. Compared to the totals in Table 1, AG is underestimated (151 vs 180), and MFG (356 vs 350) and SVC (233 vs 210) are overestimated:

$$\begin{bmatrix} 1.82 & 0.08 & 0.01 \\ 0.45 & 1.44 & 0.18 \\ 0.19 & 0.17 & 1.33 \end{bmatrix} \times \begin{bmatrix} 73.2 \\ 207.1 \\ 138.2 \end{bmatrix} = \begin{bmatrix} 151 \\ 356 \\ 233 \end{bmatrix} \tag{18}$$

An alternative that will preserve the output vector is to first aggregate the multiple sectors into a single sector, and then apply the methodology described in the previous section. Unfortunately, aggregating multiple sectors into a single sector is known to create aggregation bias, unless the sectors have identical interindustry structures (Miller and Blair, 2009).

The solution to the multiple sector problem is obtained such that the primary and secondary contributions of all the sectors of interest (e.g., logging and furniture manufacturing) are considered simultaneously, and total output for each sector is preserved. Let X' be a non-zero column vector of output values for the sectors of interest (i.e., an arbitrary subset of the X matrix). Let [i-a] be a subset of the [I-A] matrix that corresponds to the sectors of interest. The product of the [i-a] matrix and X' is a resulting column vector Y', whose elements represent primary direct contributions for each sector of interest (i.e., [i-a] X' = Y'). In the example the primary direct contributions for the three sectors are 90.3 for AG, 196.9 for MFG, and 117.3 for SVC:

$$\begin{bmatrix} 0.56 & -0.03 & 0.00 \\ -0.17 & 0.71 & -0.10 \\ -0.06 & -0.09 & 0.76 \end{bmatrix} \times \begin{bmatrix} 180 \\ 350 \\ 210 \end{bmatrix} = \begin{bmatrix} 90.3 \\ 196.9 \\ 117.3 \end{bmatrix} \tag{19}$$

TABLE 3. Total industrial output of the wood fiber system for a county economy according to IMPLAN Study Area Data.

Industry Code	Description	Total Output
[16]	Commercial logging	\$57,764,028
[95]	Sawmills and wood preservation	\$33,367,230
[105]	Paper mills	\$314,059,904

Each element of the Y' vector represents each sector's primary contribution to itself (e.g., 90.3 for AG). The secondary contribution of each sector is equal to the total output of each sector minus its primary contribution (e.g., the secondary contribution for AG is 89.7 or 180 - 90.3).

Multiple Sectors Contribution Analysis and IMPLAN

A popular software used for input-output modeling by economic practitioners and policy analysts is IMPLAN. The modeling system produced by IMPLAN LLC has made providing economic impact data and modeling to governments, universities, and public and private sector organizations for assessing the economic impacts of project decisions in all industry sectors (MIG, 2000).

The popularity of IMPLAN can be attributed to both ease of model development, and geographic flexibility. While the use of IMPLAN to quantify economic effects has been well documented, there is very little information about how it can be used to assess the economic contributions of an existing industry or sector of the economy. IMPLAN (2013) provides a methodology for estimating the contribution of single and multiple industries. This single industry approach is similar to that which we previously described, however his extension to the multi-industry analysis involved extensive model customization.

In this section we demonstrate, using IMPLAN, how the contributions of multiple sectors are calculated without any changes to the model's structural accounting matrix. The analysis demonstrated focuses on the wood fiber industry which consists of three interrelated sectors: commercial logging, sawmill manufacturing, and paper product manufacturing (Table 3).

Enterprises that make up each of these sectors are components of the backward linkages for enterprises in other sectors of wood fiber industry. Therefore the goal is to calculate the primary direct contributions of each sector simultaneously, and preserve the output values. The total output values from these three sectors form the Y' matrix described previously.

The next step is to calculate the [i-a] matrix based on the sectors of interest.

TABLE 4. Wood fiber system multipliers for a county economy.

Description	Industry Code	[16]	[95]	[105]
Commercial logging	[16]	1.299989	0.418333	0.081726
Sawmills and wood preservation	[95]	0.002965	1.046941	0.011549
Paper mills	[105]	0.000029	0.000042	1.001880

IMPLAN's Detailed Multipliers Explorer is used to obtain Type SAM output multipliers (Table 4).

The columns contain Industry Type SAM output multipliers for each sector. For example, the Sawmills and wood preservation sector has a direct Type SAM multiplier of 1.046941, and indirect multipliers of 0.418333 and 0.000042 for Commercial logging and Paper mills, respectively. Collectively these output multipliers form a miniature Leontief Inverse, [i-a]⁻¹, which inverted becomes the [i-a] matrix.

$$(I - A)^{-1} = \begin{bmatrix} 1.299989 & 0.418333 & 0.081726 \\ 0.002965 & 1.046941 & 0.011549 \\ 0.000029 & 0.000042 & 1.001880 \end{bmatrix} \quad (20)$$

$$(I - A) = \begin{bmatrix} 0.769940 & -0.307648 & -0.059260 \\ -0.002180 & 0.956035 & -0.010843 \\ -0.000022 & -0.000031 & 0.998126 \end{bmatrix} \quad (21)$$

The next step is to calculate the vector of primary direct contributions (X')

$$\begin{bmatrix} 0.769940 & -0.307648 & -0.059260 \\ -0.002180 & 0.956035 & -0.010843 \\ -0.000022 & -0.000031 & 0.998126 \end{bmatrix} \times \begin{bmatrix} 57,764,028 \\ 33,367,230 \\ 314,059,904 \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad (22)$$

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 15,598,404 \\ 28,369,056 \\ 313,468,939 \end{bmatrix} \begin{matrix} \leftarrow \text{Commercial logging} \\ \leftarrow \text{Sawmills and wood preservation} \\ \leftarrow \text{Paper mills} \end{matrix} \quad (23)$$

The final step is to enter these values as Industry Sales in IMPLAN's Setup Activities dialog (Figure 1). After shocking the model, totals for each sector (Table 5) closely approximate IMPLAN Study Area Data (Table 3). Thus, the total effect values for the sectors of interest reflect the size of those sectors within the economy.

Sector	Industry Sales	Employment	Events
16 Commercial logging	\$15,598,404.00	124	
95 Sawmills and wood preservation	\$28,369,056.00	104	
105 Paper mills	\$313,468,939.00	392	

Figure 1. IMPLAN's Setup Activities dialog box showing the sectors of interest and associated industry sales values.

TABLE 5. Total industry output effect results from IMPLAN indicating the indirect, induced, and total effect to all other sectors of the economy resulting from the direct effect of sectors 16, 95, and 105.

Industry Code	Description	Direct	Indirect	Induced	Total
16	Commercial logging	\$15,598,404	\$42,162,680	\$2,963	\$57,764,047
95	Sawmills and wood preservation	\$28,369,056	\$4,992,392	\$5,633	\$33,367,081
105	Paper mills	\$313,468,939	\$581,664	\$9,246	\$314,059,849
	Other sectors	\$0	\$24,112,127	\$15,829,761	\$39,941,887
	Total	\$357,436,388	\$71,848,863	\$15,847,602	\$445,132,864

The results of the analysis suggest that the wood fiber industry, which consists of commercial logging, sawmills and wood preservation, has a total contribution amounting to \$445.1 million. This amount is the sum of the wood fiber industry's direct contribution of \$405.2 million and the additional \$39.9 million of indirect and induced contribution from supporting industries (Other indirect + Other Induced).

Summary

In this paper we report, in the context of input-output analysis, a method for estimating the contribution of one or more sectors of the economy. The method is grounded in the robust analytic tradition of the Leontief Inverse, and provides an alternative to existing techniques. The method calculates primary contributions of multiple sectors simultaneously, eliminates input bias such that total output values are preserved, and requires no alteration of underlying structural matrices. Finally, we provide a practical demonstration with IMPLAN, showing how the contributions of multiple sectors are calculated. The largest hurdle for economic practitioners, especially for the analysis of large industry groupings, is inverting the miniature Leontief Inverse. Spreadsheets facilitate this process, and an example using Microsoft Excel is presented in the Appendix.

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Appendix: Using Microsoft Excel for Matrix Inverse and Multiplication.

The formula for matrix inverse is MINVERSE(array)

ABS						
=MINVERSE(D2:F4)						
	A	B	C	D	E	F
1				16	95	105
2	16	Commercial logging	16	1.299989	0.418333	0.081726
3	95	Sawmills and wood preservation	95	0.002965	1.046941	0.011549
4	105	Paper mills	105	0.000029	0.000042	1.00188
5						
6				16	95	105
7			16	ERSE(D2:F4)		
8			95			
9			105			
10						

Figure 1. Demonstration of the matrix inverse function of Microsoft Excel.

D7						
{=MINVERSE(D2:F4)}						
	A	B	C	D	E	F
1				16	95	105
2	16	Commercial logging	16	1.299989	0.418333	0.081726
3	95	Sawmills and wood preservation	95	0.002965	1.046941	0.011549
4	105	Paper mills	105	0.000029	0.000042	1.00188
5						
6				16	95	105
7			16	0.769940279	-0.30764765	-0.059259708
8			95	-0.002180272	0.956035283	-0.010842682
9			105	-2.2195E-05	-3.11731E-05	0.998125698
10						

Figure 2. Demonstration of the matrix inverse function of Microsoft Excel. The formula for matrix multiplication is MMULT(array1,array2). Select an array of cells for the results and use the formula editor to select the appropriate arrays. Once the arrays are selected use the following keyboard command of CTRL SHIFT ENTER to enter the formula. Each key must be held down in sequence until all three keys have been depressed.

ABS		=MMULT(D7:F9,B10:B12)					
	A	B	C	D	E	F	G
1				16	95	105	
2	16	Commercial logging	16	1.299989	0.418333	0.081726	
3	95	Sawmills and wood preservation	95	0.002965	1.046941	0.011549	
4	105	Paper mills	105	0.000029	0.000042	1.00188	
5							
6				16	95	105	
7		=MMULT(D7:F9,B10:B12)	16	0.769940279	-0.30764765	-0.059259708	
8			95	-0.002180272	0.956035283	-0.010842682	
9			105	-2.2195E-05	-3.11731E-05	0.998125698	
10		\$57,764,028					
11		\$33,367,230					
12		\$314,059,904					
13							

Figure 3. Demonstration of the matrix inverse function of Microsoft Excel.

B7		{=MMULT(D7:F9,B10:B12)}					
	A	B	C	D	E	F	G
1				16	95	105	
2	16	Commercial logging	16	1.299989	0.418333	0.081726	
3	95	Sawmills and wood preservation	95	0.002965	1.046941	0.011549	
4	105	Paper mills	105	0.000029	0.000042	1.00188	
5							
6				16	95	105	
7		15,598,404	16	0.769940279	-0.30764765	-0.059259708	
8		28,369,056	95	-0.002180272	0.956035283	-0.010842682	
9		313,468,939	105	-2.2195E-05	-3.11731E-05	0.998125698	
10		\$57,764,028					
11		\$33,367,230					
12		\$314,059,904					
13							

Figure 4. Demonstration of the matrix inverse function of Microsoft Excel.



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