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Oregon Agricultural Experimental Station Technical Paper No. 4835

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THE DECOMPOSITION OF STANDARD
INPUT-OUTPUT MODEL ESTIMATES*

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Input-output analysis is a common analytical technique used to identify the direct and indirect economic impacts of public and private decisions. I-O models have been constructed and used for economies ranging in size from samll rural counties to large international areas. A major strength of I-O analysis is the specificity of information it generates. This paper demonstrates procedures for generating more detailed information than is commonly produced in such analysis.

For instance, I-O analysis typically identifies total household income in a modeled economy. The desire has arisen a number of times in recent years (in connection with the use of several county level I-O models developed at Oregon State University) to know how total household income is distributed among the sectors in which it is generated. It may be further asked, of the household income generated in any sector, how much is attributable to each individual component of final demand? This would be desirable, for instance, in analyzing the impact of tourist expenditures which are made to a variety of local sectors. The applications to be presented below will be related to these two questions except that the interest will be shifted, through minor computational adjustments, to employment rather than household income impacts. The potential application of the procedures developed here, however, are not limited to the impacts on any one sector. One may also want to know, of a given impact on the output of an endogenous sector i, how much of the impact will be felt as that sector's sales to each endogenous sector, j (j = 1...n)?

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Further, of sector i's sales to a given sector, j, how much is the result of each component, y_k (k = 1...n) of the final demand vector? Or, how sensitive are sector i's sales to sector j to changes in the components, y_k (k = 1...n) of the final demand. Actually the earlier questions about impacts on the household sector are merely special cases of the later, more general questions. The procedures developed below will, therefore, be developed in general terms, rather than with emphasis on any one specific sector.

What we present here, then are two levels of decomposition of any sector's output (including household income or employment). The first level identifies how output is decomposed according to the endogenous sectors to which it is sold. The second level identifies how much of the output of any sector, sold to any sector, is attributalbe to each component of final demand. The second level may also be used to identify the sensitivity of the output of any sector, sold to any sector, to unit changes in each component of final demand.

To aid the discussion of the significance of and procedures for the two levels of decomposition, we first present a brief discussion of the terminology, notation, and computational procedures of input-output analysis. This is followed by discussions of: the two levels of decomposition; computational procedures; and two applications. The discussion of the applications is limited to that part of the discussed works which demonstrates the applicability of the procedures described in this paper.

Input-Output Notation and Terminology

The principal component of an input-output model is an nxn matrix, A, of direct input coefficients, which identify the direct interrelationships among the n endogenous sectors of the modeled economy. Each element, a_{ij}, (i,j=1...n) of A is the amount of goods or services of sector i required per unit of output produced by sector j. If X is an nxl vector of the outputs of each sector (i.e.; x_j is the output of sector j, j=1..n), the demand for sector i's output by all of the endogenous sectors combined will equal $\Sigma_{j=1}^{n} a_{ij}x_j$. The product AX is an nxl vector of these total endogenous demands for each sector i's output (i=1...n). In addition to producing for the n endogenous sectors of the modeled economy, each sector will produce to satisfy some level of final, or exogenous, demand. If Y is an nxl vector of final demands, y_i (i=1...n), met by each endogenous sector i, one can write the equation:

$$X = AX + Y. \tag{1}$$

This equation states that total output of each sector will equal the sum of the endogenous and exogenous demands for its products. With minor algebraic manipulation, equation (1) may be rewritten as:

$$X = (I-A)^{-1} Y. \tag{2}$$

Here, I is an n dimensional identity matrix, and the nxn matrix $(I-A)^{-1}$ is the matrix of direct and indirect coefficients, c_{ij}. The elements c_{ij} (i,j = 1...n) of the matrix $(I-A)^{-1}$ are the total (direct and indirect) output of sector i which results from each unit of final demand met by sector j.

The impacts of private or public decisions which change any elements of A or Y will be changes in the outputs of the n endogenous sectors. Attention is usually focused on the impacts of changes in the final demand vector, Y, because it typically includes government spending, along with exports, and many private decisions may be viewed as final demand changes. If Y is viewed as a vector of <u>changes</u> in final demand, X is the vector of resultant total output <u>impacts</u> on the endogenous sectors. In the remaining discussion we address output or production resulting from a given final demand vector, but the discussion applies equally well to <u>changes</u> in output resulting from a given <u>change</u> in final demand.

The Two Levels of Decomposition

The first level of decomposition has, in fact, been applied in instances where the impacts on selected exogenous sectors were of interest. The most common application has been in identifying employment or income impacts in models where local households were not included as an endogenous sector of the modeled economy. For any final demand vector, Y, the vector X, of endogenous sector outputs, is computed, and each element x_j (j=1...n) is multiplied by e_j, the number of employees (or household income) per unit of output in sector j. Total employment is equal to $\sum_{j=1}^{n} e_j x_j$, and employment in each sector j (j=1...n) is $e_j x_j$.

This paper's contribution begins with the demonstration that the same logic can be applied to the decomposition of any endogenous sector's output as well. Once the output vector X is generated, the sales of sector i to sector j (i, j = 1...n) can be computed as $a_{ij} x_j$. This is simply the number of units of sector j's production times its per unit input requirement from sector i. Recall that the vector of endogenous production is AX. Any sector i's endogenous production is $\sum_{j=1}^{n} a_{ij} x_j$, and it can be decomposed into the amounts $a_{ij} x_j$ which sector i produces for direct use by each sector j (j=1...n).

In the second level of decomposition, each element $a_{ij} x_j$ (i, j = 1...n) generated in the first level is further decomposed into the amounts attributable to each sector k's (k=1...n) production for final demand. To achieve this, each element $a_{ij} x_j$ must be expressed as a function of the components of final demand y_k (k=1...n). Recall from equation (2) that $x_j = \sum_{k=1}^{n} c_{jk} y_k$. It follows that $a_{ij} x_j = a_{ij} \sum_{k=1}^{n} c_{jk} y_k$ (i, j=1...n). Of any sector i's production for any sector j, the amount attibutable to each sector k's (k = 1...n) production for final demand is $a_{ij} c_{jk} y_k$, and the second level of decomposition is achieved.

The second level of decomposition can also be established through a somewhat different line of reasoning. We are interested in how much of any sector i's sales to any sector j are attributable to any sector k's production for final demand. We might first ask how much of sector i's production for all endogenous sectors is attributable to any sector k's production for final demand? We know from equation (2) that total output is $X = (I-A)^{-1} Y$ and that $X - Y = [(I-A)^{-1}-I] Y$ is the production for endogenous sectors. The ik^{th} element of $[(I-A)^{-1}-I]$ is the total endogenous production of sector i per unit of final demand met by sector k. This element times sector k's production for final demand is sector i's endogenous production induced by sector k's final demand. It is relatively easy to show (using the power series expansion of $(I-A)^{-1}$) that $[(I-A)^{-1}-I] = A(I-A)^{-1}$, so the ik^{th} element of $[(I-A)^{-1}-I]$ is $\sum_{j=1}^{n} a_{ij}c_{jk}$. The second level of decomposition arrived at above follows from this result.

For the first level of decomposition, there are n^2 elements, $a_{ij}x_j$ $(i, j = 1...n)$ which identify each endogenous sector i's production for each endogenous sector j. There are n additional elements for each exogenous sector for which the distribution of sales to the endogenous sectors is desired. For the second level of decomposition, there are n^3 elements $a_{ij}c_{jk}y_k$ $(i, j, k = 1...n)$ which identify the amount of each sector i's production for sector j, which is attributable to sector k's production for final demand. At this level, there are n^2 additional elements for each exogenous sector of interest. The magnitude of computations is large enough that simple matrix computational procedures would be extremely useful. We turn to such procedures now.

Computational Procedures

The first level of decomposition is quite simple to achieve computationally. The diagonal matrix D_x is formed, having x_j as its j^{th} diagonal element and zeros everywhere else. The matrix AD_x is then computed. The ij^{th} element of

AD_x is $a_{ij}x_j$, and the $i^{\underline{th}}$ row of AD_x is the decomposition of sector i's sales to the endogenous sectors. (Those familiar with the construction of I-O models will recognize the matrix AD_x as the endogenous portion of the transactions matrix from which, for some base period, the direct coefficients are derived).

If one is interested in the decomposition of a number of exogenous sector's sales to the endogenous sectors, the appropriate computational procedure is to form the matrix BD_x. Here B is a matrix where the $ij^{\underline{th}}$ element, b_{ij}, is the quantity of the $i^{\underline{th}}$ exogenous sector's output used per unit of production by the $j^{\underline{th}}$ endogenous sector.

If one is interested in the decomposition for both the endogenous sectors and a group of exogenous sectors, the computations can be combined. Form the matrix A* by augmenting the matrix A with the matrix B, and compute A^*D_x. If there are t exogenous sectors of interest, B will be txn and A* and A^*D_x will be (t+n)xn. The first n rows of A^*D_x are the matrix AD_x, and the last t rows of A^*D_x are the matrix BD_x.

The second level of decomposition generates n times as many elements as the first. It is unlikely that all of this detail will be desired in every application. The researcher using this level of decomposition will want to be discriminating in what information he generates. One can envision all the data available through the application of the second level of decomposition as being arranged in an n-dimensional cube (ignoring for the moment interest in any exogenous sectors). The axes of the cube correspond to the subscripts i, j, and k, each of which takes on values from one through n. The individual elements are, as identified in the previous section, $a_{ij}c_{jk}\bar{y}_k$. There are three procedures which identify an n-dimensional square matrix or "plane" from within the cube. Any such plane is parallel to two of the cube's axes and intersects the third; it holds the subscript along the intersected axis constant and allows the other two subscripts to vary. Each computational procedure corresponds to holding one of the subscripts constant (at any desired value).

By selecting the proper procedure, one can generate only the information desired, and it will be in a convenient format.

The most useful of the procedures, and the one for which the inquiry was initiated, is the one in which the subscript i is held constant. For any one sector, i, the procedure identifies the sales to each sector j (j = 1...n) which are attributable to the final demand met by each sector k (k = 1...n). The computational procedure for generating this information is to form the matrix product $D_{a_i}(I-A)^{-1}D_y$, where D_{a_i} is the diagonalization of the $i^{\underline{th}}$ row of A and D_y is the diagonalization of the final demand vector Y. The $jk^{\underline{th}}$ element of $D_{a_i}(I-A)^{-1}D_y$ is $a_{ij}c_{jk}y_k$. The $j^{\underline{th}}$ row of $D_{a_i}(I-A)^{-1}D_y$ is the decomposition of sector i's production for sector j, according to the final demands met by the endogenous sectors k (k = 1...n). Also, the $k^{\underline{th}}$ column of $D_{a_i}(I-A)^{-1}D_y$ is the total endogenous production of sector i, induced by sector k's production for final demand, decomposed according to the endogenous sectors j (j = 1...n) for which it is produced. If the sector of interest is an exogenous one, D_{a_i} is the diagonalization of the appropriate row of the augmented matrix A*, discussed above.

This procedure would have to be repeated for each sector, i, for which the decomposition is desired. It would be appropriate if one was interested in the decomposition of a relatively small number of sector's outputs, particularly when it is desirable to simultaneously compare decompositions attributable to a number of sector's production for final demand.

If the components of final demand are not known (as in the case where they are to be set by a policy maker) the procedure may be used to identify the sensitivity of the decompositions to unit changes in each component of final demand. This is a special case of the general procedure, in which the final demand vector is a column of ones and D_y is the identity matrix. The appropriate computation is then $D_{a_i}(I-A)^{-1}$.

The second computational procedure holds the subscript k constant. It identifies, for a given sector k's production for final demand, the resultant production of each sector i (i = 1...n) for each sector j (j = 1...n). The computational procedure for generating this information is to form the matrix product $y_k AD_{c_k'}$, where y_k is sector k's production for final demand, and $D_{c_k'}$ is the diagonalization of the $k^{\underline{th}}$ column of $(I-A)^{-1}$. The $ij^{\underline{th}}$ element of $y_k AD_{c_k'}$ is $a_{ij}c_{jk}y_k$. The $i^{\underline{th}}$ row of $y_k AD_{c_k'}$ is the decomposition, according to the sectors to which it flows, of sector i's endogenous production induced by sector k's production for final demand. Also note that the $j^{\underline{th}}$ column of $y_k AD_{c_k'}$ identifies the inputs required by sector j to produce the portion of its total production which results from sector k's production for final demand. To accomodate interest in some exogenous sectors, one needs only replace A with the augmented matrix A* discussed previously.

This procedure must be repeated for each sector for which the importance of final demand is desired. It would be most appropriate in cases where there are few non-zero components of final demand and where complete detail about the resultant transactions is desired.

A special case of this procedure identifies the sensitivity of endogenous transactions to unit changes in sector k's production for final demand. This sensitivity is identified as $AD_{c_k'}$ (letting $y_k = 1$).

The final computational procedure holds the subscript j constant. The necessary computation is $a_j' \, 1_n D_{c_j} D_y$, where a_j' is the $j^{\underline{th}}$ column of A (or A* if desired), 1_n is a row vector of n ones, D_{c_j} is the diagonalized $j^{\underline{th}}$ row of $(I-A)^{-1}$, and D_y is the diagonalized final demand vector. We believe that interest in this procedure would be rare, and we present it only in the interest of completeness.

Applications of the Two Levels of Decomposition

Generally, the potential applications of the two decomposition levels include any applications of input-output analysis where the additional information would be helpful. The cost of generating the additional information is very small (except perhaps for very large models). The diagonalization of X, Y, and the rows and columns of A and $(I-A)^{-1}$ and the appropriate matrix multiplications can be done quickly and inexpensively by computer. Thus, the marginal value of the information would not have to be very large to justify its generation.

Generation of sectoral distributions of output, income, or employment, and the sensitivity of each to changes in various components of final demand are the most obvious uses. The most common uses would probably be analyzing income and employment inpacts of government policies or economic development. Two such applications of the second decomposition level are discussed briefly to provide a concrete example of the information available through the use of the decompositions presented here.

The first application was by Schmisseur and Obermiller to evaluate the sectoral distribution of income and employment effects of alternative growth strategies for Union County, Oregon. They examined the impacts on each sector's output; male, and female full-time employment; and part-time employment which would result from expansions in the final demand met by each of several sectors of the county economy.

The output impacts on each sector were computed for each growth strategy using equation (2). Each final demand vector, Y, included the change in final demand for a single potential growth sector. The employment impacts were computed in a manner equivalent to the second procedure above, since the final demand vector for each growth strategy had only one non-zero element. The computation $y_k BD_{c_k'}$ was repeated for each sector, k, in which output expansion was evaluated. B is a 3xn matrix with each row composed of the number of employees in one category (full-time male, full-time female, or part-time) per \$100,000 of output in each endogenous sector, and y_k is the final demand change in sector k, expressed in \$100,000's. $D_{c_k'}$ is the diagonalized $k^{\underline{th}}$ column of $(I-A)^{-1}$.

Table 1 presents the output and employment impacts of a 5% increase in agricultural exports as reported by Schmisseur and Obermiller and the impacts of a 2.9% increase in lumber and wood manufacturing exports.

Table 1. Output and Employment Impacts, by Sector, For Export Expansion in Two Sectors of the Union County, Oregon Economy, As Reported by Schmisseur and Obermiller

	5% Agricultural Export Expansion					2.9% Lumber & Wood Mfg. Export Expansion*				
	Output Change	Employment Changes				Output Change	Employment Changes			
		Full-time			Part		Full-time			Part
Sector	(\$1000)	Male	Female	Total	Time	(\$1000)	Male	Female	Total	Time
Timber Harvesting & Hauling	1.7	.1	.0	.1	.0	362.4	21.0	.6	21.6	.0
Heavy Construction	4.0	.0	.0	.0	.0	130.6	.6	.0	.6	.0
General Construction	85.1	1.3	.2	1.5	1.2	99.7	1.6	.2	1.7	1.4
Higher Education	12.2	.3	.2	.6	.7	4.3	.1	.1	.2	.2
Agriculture	1434.0	35.1	.4	35.5	3.2	17.0	.4	.0	.4	.1
Lumber & Wood Mfg.	7.3	.1	.0	.1	.0	1773.4	27.5	3.4	30.9	.1
Other Mfg.	14.6	.2	.2	.4	.0	10.6	.1	.1	.3	.1
Trans., Commun. & Utilities	77.9	.6	.3	.9	.1	124.9	1.0	.4	1.5	.2
Wholesale & Retail Serv.	164.3	1.4	3.4	4.8	3.7	137.5	1.2	2.8	4.1	3.0
Medical Services	74.0	.9	4.2	5.1	.9	29.3	.3	1.6	2.0	.3
Legal, Eng. & Acct'g. Serv.	22.0	.6	.6	1.1	.7	9.6	.2	.2	.5	.3
Recreation	12.2	.6	.5	1.1	1.4	7.4	.3	.3	.7	.8
Wholesale & Retail Trade	1250.7	13.2	8.6	21.7	10.2	433.3	4.5	3.0	7.5	3.5
Finince, Ins., & Real Est.	152.5	1.5	1.2	2.7	.9	88.1	.9	.7	1.6	.5
City & County Government	86.5	2.3	2.0	4.2	1.7	76.3	2.0	1.7	3.7	1.5
Local, State, Fed. Agencies	3.5	.0	.0	.0	.0	11.9	.1	.0	.1	.1
Households	697.0	.0	.2	.2	.8	756.3	.0	.2	.2	.9
Total	4099.5	58.3	22.0	80.2	25.5	4072.8	62.1	15.7	77.3	13.2

* Schmisseur and Obermiller's estimated impacts of a 5% Lumber & Wood Mfg. export increase, times .58
Note: Columns may not add to totals due to rounding errors.

Typically one would find the changes in output reported, with the impact on local household incomes indicated by the output change in the household sector. The employment information generated by this decomposition procedure adds significantly to the information on which the two alternatives can be compared. The purpose of presenting the data in Table 1 is not to guide a detailed discussion of the impact differentials between these particular final demand changes for Union County, Oregon. The purpose is to demonstrate the ease and usefulness of applying the decomposition procedure to generate the additional information available through its use.

A second application has been made by Ives in evaluating the economic impacts of a bill introduced into the 1977 Texas State Legislature. The full detail of the decomposition was not reported in Ives' preliminary analysis. The bill's death in committee precluded any further, more detailed analysis. The bill, H.B. 15, would have created the Texas Right-to-Work Commission. This Commission would have been charged with the responsibility of creating State jobs to maintain the unemployment rate in Texas at or below 3% for each race and sex. The types of State jobs to be created, and the resultant materials expenditures associated with them, was at the discretion of the Commission. It was desirable to identify the number and sectoral distribution of private sector jobs which would be induced by alternative State expenditure patterns. Such information would be useful in comparing the number of different types of new State jobs necessary to achieve the desired unemployment rates. It would also allow some degree of matching of the sectoral distribution of induced private sector jobs to the sectoral distribution of unemployment.

Since the final demand vector, Y, associated with the State jobs program was unknown and subject to determination by the Commission, the decomposition of employment in each endogenous sector attributable to a unit of final demand met by any sector was desired. As described above, the computation for this decomposition is $D_e\ (I-A)^{-1}$, where the diagonal elements of D_e are the rates of employment per $1,000,000 of output in the endogenous sectors. The resultant decomposition is then expressed in the units, employment (in sector j) per $1,000,000 of final demand (met by sector k). The k^{th} column of $D_e\ (I-A)^{-1}$ is the decomposition, according to the sectors in which it occurs, of the total employment generated per $1,000,000 of final demand met by sector k. The columns of $D_e\ (I-A)^{-1}$ allow a comparison of the employment impact differentials among various possible State expenditure patterns which could be used to achieve the desired 3% unemployment rates.

To conserve space, we have presented only five of the forty-nine columns of the decomposition matrix in Table 2. These columns present the decomposition of employment impacts induced by $1,000,000 of State expenditures to each of five selected sectors. The sectors selected were chosen as likely sectors from which the State would make purchases and for which significant employment impact differentials exist. The table is self-explanatory except, perhaps, for a needed word of clarification about the employment impacts listed for $1,000,000 of state expenditures to sector 49, the household sector. These employment impacts are those induced by the $1,000,000 of direct State expenditures. In the context of the job creation program under consideration, this column does not include 205 newly created State jobs which would be the vehicle through which the $1,000,000 of State expenditures was transmitted to the household sector.

As was the case with the first application, discussed above, our attention here is not centered on the particular problem, but on a demonstration of the applicability of the decomposition procedure. In fact, the information in Table 2 is not comprehensive enough to do more than this.

We believe that the decomposition procedures described in the paper are easy to compute, present, and interpret; and they are generally applicable in a variety of input-output applications in which they have not, to our knowledge, previously been used. We would anticipate their wide application, given some public attention.

Table 2. **The Decomposition, by Sector, of Employment Impacts of $1,000,000 of State Expenditures to Selected Sectors of the Texas Economy. Numbers Indicate Jobs Stimulated in** Employing Sectors

Employing Sectors		Sectors Receiving $1,000,000 of State Expenditures 15	21	24	41	49
1	Irrigated Crops	.5	.2	.4	.6	.9
2	Dryland Crops	.3	.2	.3	.4	.6
3	Livestock and Poultry	1.3	.7	1.3	1.7	2.6
4	Agricultural Services	.1	.1	.1	.1	.2
5	Primary Forestry and Fisheries	.5	.0	.0	.0	.0
6	Crude Petroleum	.3	3.3	.5	.4	.4
7	Natural Gas Liquids	.0	.1	.0	.0	.0
8	Oil and Gas Field Services	.2	2.8	.4	.3	.3
9	Other Mining	.1	.1	2.4	.1	.0
10	Residential Construction	.0	.0	.0	.0	.0
11	Comm'l., Ed., and Institutional Const.	3.2	3.2	3.1	3.6	2.8
12	Facility Construction	.7	.7	.8	.9	.6
13	Food Processing	1.2	.7	1.2	1.6	2.5
14	Textile and Apparel	.7	.2	.4	.6	.8
15	Logging, Wood, and Paper	57.5	.8	2.4	1.9	1.8
16	Chlorine and Alkalies	.2	.0	.1	.0	.0
17	Cyclic Crudes and Intermediate Pigments	.0	.0	.0	.0	.0
18	Organic Chemicals	.0	.3	.0	.0	.0
19	Inorganic Chem., Plastics and Rubber	.0	.0	.0	.0	.0
20	Drugs, Chemicals, Soaps, and Paint	.2	.2	.1	.1	.1
21	Petroleum Refining	.1	4.0	.1	.2	.2
22	Other Petroleum Products	.0	.0	.1	.0	.0
23	Tires, Rubber, Plastics	.2	.1	.2	.1	.1
24	Glass, Clay, Stone, Cement	.3	.3	38.7	.3	.3
25	Primary Metal Processing	1.1	1.2	.9	.7	.6
26	Industrial Equipment Manufacturing	.4	.8	.7	.4	.4
27	Electric Appliance Manufacturing	.1	.2	.1	.1	.1
28	Aircraft, Motor Vehicles	.6	.3	1.1	.5	.7
29	Instruments, Photography, Games	.2	.1	.1	.1	.1
30	Rail Transportation	1.2	.5	1.4	.5	.6
31	Intercity Highway Transportation	.3	.2	.3	.4	.6
32	Motor Freight Transportation	2.2	.9	2.7	1.5	1.9
33	Water Transportation	.1	.7	.3	.1	.1
34	Air Transportation	.3	.2	.3	.4	.6
35	Pipeline Transportation	.0	.5	.0	.0	.0
36	Other Transportation	.1	.1	.1	.3	.1
37	Telephone and Broadcast Communications	1.2	.6	1.2	1.9	1.6
38	Gas Services	.2	.3	.4	.2	.3
39	Electric Services	.7	.4	.8	.8	.8
40	Water and Sanitary Services	.5	.2	.4	.5	.6
41	Wholesale Trade	3.9	2.7	4.4	52.0	6.3
42	Retail Trade	11.6	6.2	11.3	15.5	23.7
43	Auto Dealers and Repair Shops	2.7	1.5	2.8	3.7	5.4
44	Finance, Ins., and Real Estate	3.7	2.3	4.3	5.5	5.9
45	Prof., Bus., and Personal Services	11.1	6.2	10.3	13.3	16.8
46	Lodging, Amusement, Recreation	1.7	.9	1.6	2.6	3.2
47	Education	4.6	4.8	5.4	5.7	7.0
48	Outdoor Recreation	.1	.1	.2	.2	.2
49	Households*	.0	.0	.0	.0	.0
	Total**	116.7	49.7	103.9	120.0	92.2

***For lack of relevant data, interhousehold employment impacts are assumed negligable.**
****Columns may not sum to totals shown due to rounding error.**

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