Generating Input-Output Tables from Supply and Use Tables: Transformation and Technology Assumptions

A Simple Introduction

Abstract

In the System of National Accounts (SNA) Input-Output Tables (IOT) are derived from Supply and Use Tables (SUT), i.e., IOT are reduced forms of SUT based on assumptions about technology. Social Accounting Matrices (SAM) can be based on either presentation of the inter-industry transactions data but should be first derived using SUT data to ensure consistent definitions. This paper outlines the processes used to convert IOT to SUT.

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Introduction

This note sets out some conventions and methods for the derivation of symmetric input-output tables from SAM series. (The term "symmetric" is used to define an input-output table where the rows and columns have the same output dimensions, i.e., they are defined by industry or commodity outputs). The methods developed follow Gigantes (1970) Armstrong (1975) and CSO (1973), UN (2018) and are consistent with the arguments made by Pyatt (1985).

The methods are initially developed under the maintained assumption that the Make matrix, and hence the Use matrices, are square.

<u>Basic Data and Structural Relationships</u>

Starting from a schematic representation of a System of National Accounts (see UN, 1973 and 1993). Assume, for the moment, that the economy is closed, imports will be introduced later, and that final demands (**f**) and primary inputs (**y** and **z**) are recorded as vectors[1].

1. Table 1 Schematic Representation of National Accounts

2.

Sellers	Buyers Commodities	Industries	Final Demand	Total
Commodities		**X**	**f**	**q**
Industries	**M**			**g**
Primary Inputs		**y'**	**z**	
Total	**q'**	**g'**		

In this representation: [2]

M is the MAKE matrix which identifies the outputs of commodities made by industries such that a typical element, m_{ij}, defines the quantity of commodity *j* produced by industry *I*, (**NB**: in this representation the Make matrix, **M,** is transposed relative to how it is commonly presented in National input-output tables);

1 More realistically these vectors would be rectangular matrices: however, this representation makes no difference to the relationships while simplifying exposition.

2 Following convention: bold upper-case letters represent matrices (**I** being the identity matrix); bold lower case letters vectors, $\mathbf{X}^{-1}$ denotes the inverse of the matrix **X**; a prime (′) a matrix transpose; and a circumflex (^) a diagonal matrix formed from a vector.

X is the ABSORPTION or USE matrix which identifies the consumption of domestically produced commodities by industries such that x_{ij} defines the quantity of commodity i consumed by industry j;

f is a vector of final demands in terms of commodities[3],

y is a vector of primary inputs purchased by industries,

g is a vector of total output in terms of industries,

q is a vector of total output in terms of commodities,

z is a scalar of primary inputs purchased by final demand.

Since the number of industry and commodity groups coincide, by assumption, **M** & **X** are (n x n) matrices and **g**, **q**, **f**, and **y** are (n x '1') 'vectors'.

Inter-Industry Coefficients and Transactions

From the schematic representation of National Accounts three simple structural matrices can be derived:

i) a matrix of industry input coefficients

$$\mathbf{B} = \mathbf{X}\hat{\mathbf{g}}^{-1} \tag{1a}$$

where each element, b_{ij}, defines the quantity of commodity i used up in the production of a unit of industry j's output;

ii) a matrix of product mix

$$\mathbf{C} = \mathbf{M}'\hat{\mathbf{g}}^{-1} \tag{2}$$

where each element, c_{ij}, defines the proportion of industry j's output accounted for by commodity i;

iii) a matrix of market shares

$$\mathbf{D} = \mathbf{M}\hat{\mathbf{q}}^{-1} \tag{3}$$

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where each element, d_{ij}, defines the proportion of commodity *j*'s output accounted for by industry *i*.

Further the following relationships that can be derived directly from the available data. From the information in Table 1

$$\mathbf{q} = \mathbf{Xi} + \mathbf{f} \tag{4}$$

$$\mathbf{q} = \mathbf{M'i} \tag{5}$$

$$\mathbf{g} = \mathbf{Mi} \tag{6}$$

where **i** is the unit vector and effects summation. And from the structural relationships

$$\mathbf{X} = \mathbf{B\hat{g}} \tag{7}$$

$$\mathbf{M'} = \mathbf{C\hat{g}} \tag{8}$$

$$\mathbf{M} = \mathbf{D\hat{q}} \tag{9}$$

and by combining (4) and (7)

$$\mathbf{q} = \mathbf{Bg} + \mathbf{f}\,. \tag{10}$$

Types of Input-Output Table

Two groups of symmetrical matrices can be identified: one where the groups are defined by commodities (the so-called Commodity by Commodity matrices), the other where groups are defined by industries (the Industry by Industry matrices). These types of tables, without distinction, are typically referred to as input-output tables in textbooks.

The basic Make and Use matrices define the quantities of commodities made and used by industries. Commodity by commodity tables identify the quantities of commodities used in the production of commodities, whereas the industry by industy tables identify the amount of each industry's output used in the production processess of each industry.

For the Commodity by Commodity matrices, the **A** matrix, where each element a_{ij} identifies the quantity of commodity *i* used in the production of commodity *j* such that, given **q** and **f**, **A** must satisfy

$$\mathbf{q} = \mathbf{A}\mathbf{q} + \mathbf{f} \tag{11}$$

and for the second, the **E** matrix, each element e_{ij} identifies the quantity of industry *i*'s output used in the production of industry *j*'s output such that, given **q**, **g** and **f**, **E** must satisfy

$$\mathbf{g} = \mathbf{E}\mathbf{q} + \mathbf{C}^{-1}\mathbf{f}\ . \tag{12}$$

The information required to derive the **A** and **E** matrices directly is not generally available and therefore requires the use of assumptions about the structure of production, i.e., 'technology assumptions. The commodity-by-commodity tables are typically derived by adjusting the rows of the Use matrix, whereas the industry-by-industry tables are usually derived by adjusting the rows of the Use matrix. One consequence of this type of adjustment process is that the final demand flows directly from the Use matrix into the commodity by commodity tables, but require adjusting for inclusion in the industry-by-industry tables.

Technology Assumptions

Technology assumptions used to generate IOT from SUT can be classified 'pure', 'hybrid' or 'by-product'[4]. Technology assumptions are derived from an evaluation of whether the commodity inputs of industries are determined by the commodities they produce or are identical across all the commodities produced by industries and/or some mix of the two.

Pure Technology Assumption

Depending on the results of such an evaluation there are two basic and distinct, technology assumptions used to derive the symmetric **A** and **E** matrices:

i) a 'pure' Commodity Technology Assumption (CTA), by which it is assumed that there is a unique input combination for each commodity produced regardless of the industry in which it is produced, and

ii) a 'pure' Industry Technology Assumption (ITA), which assumes that all commodities produced by an industry are produced using an identical input structure.

[4] The by-product technology assumption is not detailed her

Pure Commodity Technology Assumption

Using a 'pure' CTA to derive an **A** matrix amounts to presuming that inputs to industry *j* are the weighted average of the inputs to each commodity produced by industry *j*, and that these weights are the proportions in which industry *j* produces these commodities[5]. This is the information contained in the product mix matrix, **C**. Thus from (7) and (10)

$$\begin{aligned} \mathbf{M'i} &= \mathbf{C\hat{g}i} \\ \mathbf{g} &= \mathbf{C}^{-1}\mathbf{q} \end{aligned} \tag{13}$$

which on substitution into (10) produces

$$\mathbf{q} = \mathbf{BC}^{-1}\mathbf{q} + \mathbf{f} \tag{14}$$

and therefore from (4)

$$\mathbf{A}_C = \mathbf{BC}^{-1} \tag{15}$$

where the subscript *C* denotes the use of a 'pure' CTA. This is equation 5.3.1 in Armstrong (1975, p 71).

Similarly, a 'pure' CTA can be used to derive the **E** matrix. From (13)

$$\mathbf{q} = \mathbf{Cg} \tag{16}$$

which on substitution into (12) and, after rearrangement, produces

$$\mathbf{g} = \mathbf{C}^{-1}\mathbf{Bg} + \mathbf{C}^{-1}\mathbf{f} \tag{17}$$

and therefore from (5)

$$\mathbf{E}_C = \mathbf{C}^{-1}\mathbf{B}. \tag{18}$$

Pure Industry Technology Assumption

The alternative 'pure' ITA presumes that inputs to commodity *j* are the weighted average of the inputs to each industry producing commodity *j* and that the weights are the proportions in which each industry produces commodity *j*. That is the information contained in the market share matrix, **D**. Thus from (8) and (11)

[5] This invokes the standard I-O assumption of CRTS: hence the assumption of CRTS is embedded in the tables. Similarly, the possibility of joint products is assumed away.

$$\begin{aligned} \mathbf{Mi} &= \mathbf{D\hat{q}i} \\ \mathbf{g} &= \mathbf{Dq} \end{aligned} \quad (19)$$

which on substitution into (12) produces

$$\mathbf{q} = \mathbf{BDq} + \mathbf{f}$$

and from (4)

$$\mathbf{A}_I = \mathbf{BD} \quad (20)$$

where the subscript *I* denotes the employment of the ITA. This is Euqation 5.3.2 in Armstrong (1975, p 71). Similarly for the industry x industry formulation from (12), (19), and (5)

$$\mathbf{E}_I = \mathbf{DB}. \quad (21)$$

<u>Hybrid or Mixed Technology Assumptions</u>

The 'pure' CT and IT assumptions are appealing for their simplicity but, representing polar extremes, they lack reality. Recognition of the rigidity of the CTA and ITA prompted the development of Hybrid Technology Assumptions (HTA) for which numerous variants have been proposed (see UN, 1973 and Gigantes, 1970). The principal feature of all HTAs is the division of non-principal production by an IO group between that produced employing CT and that employing IT. The most common basis for this division being the assumption that by-products and joint products of the principal product are produced by an IT and other non-principal products by a CT.[6]

The mixing of technology assumptions requires the division of the make matrix so that the various elements can be handled according to the technology assumption deemed to be most appropriate, i.e.,

$$\mathbf{M} = \mathbf{M}_C + \mathbf{M}_I \quad (22)$$

where $\mathbf{M}_C$ and $\mathbf{M}_I$ contain respectively the elements treated according to the CTA and ITA. Similarly, the output vectors require splitting, i.e., $\mathbf{g} = \mathbf{g}_C + \mathbf{g}_I$ and $\mathbf{q} = \mathbf{q}_C + \mathbf{q}_I$, so that (4) can be rewritten as:

6 While for some industry/commodity groups such a division may be relatively easily achieved there does exist a 'no-man's land' where the division is difficult. Armstrong (1975) reviews some of the difficulties encountered in the preparation of the 1963 UK IO tables.

$$\mathbf{q} = \mathbf{A}_C\mathbf{q}_C + \mathbf{A}_I\mathbf{q}_I + \mathbf{f} \; . \qquad (23)$$

*The '**R**' Matrix Method*[7]

This HT variant introduces the CTA under the assumption that the output of an industry produced under the CTA is of a fixed commodity mix such that from (7) and (10)

$$\mathbf{g}_C = \mathbf{M}_C\mathbf{i} = \mathbf{C}_C^{-1}\mathbf{q}_C \qquad (24)$$

and then introduces the ITA by assuming that by-product, and other non-principal product, production maintain the same proportions of industry production as commodity output varies, thus from (8) and (11)

$$\mathbf{g}_I = \mathbf{M}_I\mathbf{i} = \mathbf{D}_I\hat{\mathbf{q}}\mathbf{i} \; . \qquad (25)$$

Consequently, **g** can, by substitution, be written as

$$\mathbf{g} = \mathbf{C}_C^{-1}\mathbf{q}_C + \mathbf{D}_I\mathbf{q} \qquad (26)$$

and since from (7) and (25) $\mathbf{q}_I = \mathbf{M}_I'\mathbf{i} = \hat{\mathbf{q}}\mathbf{D}_I'\mathbf{i}$ therefore from $\mathbf{q}_C = \mathbf{q}$ - $\mathbf{q}_I$

$$\mathbf{q}_C = \mathbf{q} - \left(\mathbf{D}_I'\mathbf{i}\right)\mathbf{q} \qquad (27)$$

Substituting for $\mathbf{q}_C$ in (26) from (27)

$$\mathbf{g} = \mathbf{C}_C^{-1}\left[\mathbf{q} - \left(\widehat{\mathbf{D}_I'\mathbf{i}}\right)\mathbf{q}\right] + \mathbf{D}_I\mathbf{q} \qquad (28)$$

which yields an expression for **g** that can be substituted into the basic equation for a commodity x commodity table (12):

$$\mathbf{q} = \mathbf{B}\left\{\mathbf{C}_C^{-1}\left[\mathbf{q} - \left(\widehat{\mathbf{D}_I'\mathbf{i}}\right)\mathbf{q}\right] + \mathbf{D}_I\mathbf{q}\right\} + \mathbf{f} \qquad (29)$$

Letting $\mathbf{R} = \mathbf{C}_C^{-1}\left[\mathbf{I} - \left(\widehat{\mathbf{D}_I'\mathbf{i}}\right)\mathbf{q}\right] + \mathbf{D}_I$ yields

$$\mathbf{q} = \mathbf{BRq} + \mathbf{f} \qquad (30)$$

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7 This method is reported in CSO (1973), Armstrong (1975) and as Method 1 in Miller and Blair (1985, pp189-192). SNA 1968 (UN, 1968) also reports this method.

and therefore from (4)

$$\mathbf{A}_R = \mathbf{BR} \qquad (31)$$

where the subscript R denotes the employment of the 'R' matrix HTA variant. And similarly for an industry x industry matrix[8]

$$\mathbf{E}_R = \mathbf{RB}. \qquad (32)$$

These variants of the HTA satisfy Armstrong's "...test of an acceptable hybrid solution .." (Armstrong, 1975, p 76)[9] since if $\mathbf{M}_C = 0$ then $\mathbf{A}_R = \mathbf{A}_I$ and $\mathbf{E}_R = \mathbf{E}_I$, and if $\mathbf{M}_I = 0$ then $\mathbf{A}_R = \mathbf{A}_C$ and $\mathbf{E}_R = \mathbf{E}_C$.

*The '**H**' Matrix Method*[10]

Whereas the '**R**' matrix method assumes that by-product, and other non-principal product, production maintain the same proportions of industry production as commodity output varies, the '**H**' matrix method assumes that by-product, and other non-principal product, production is linked to the outputs of the producing industries, i.e.,

$$\mathbf{q}_I = \mathbf{M}_I'\mathbf{i} = \mathbf{C}_I\mathbf{g} \qquad (33)$$

and hence

$$\mathbf{M}_I\mathbf{i} = \hat{\mathbf{g}}\mathbf{C}_I'\mathbf{i} = \left(\widehat{\mathbf{C}_I'\mathbf{i}}\right)\mathbf{g} = \mathbf{g}_I. \qquad (34)$$

We can also define

$$\mathbf{g}_C = \mathbf{D}_C\mathbf{q}_C. \qquad (35)$$

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8 From (28)

$$\mathbf{q} = \mathbf{H}^{-1}\mathbf{g}$$

and substituting for **q** in (30) gives

$$\mathbf{H}^{-1}\mathbf{g} = \mathbf{BHH}^{-1}\mathbf{g} + \mathbf{f}$$
$$\mathbf{g} = \mathbf{HBg} + \mathbf{Hf}$$

9 Armstrong (1975, pp 72-76) produces two variants of the HTA that satisfy this test (the variant employed by the CSO being the first of them) and argues that the solutions proposed by the UN and Gigantes fail this test. He further warns against the tendency to employ the **C** and **D** matrices as ".. output structure assumptions when it is intended that they should be acting as weights on input structures.." (p 76, emphasis added).

10 This method is reported in Gigantes (1970) and as Method 2 in Miller and Blair (1985, p 192-195)

Equations (34) and (35) can be combined to produce an expression for **g**

$$\begin{aligned}\mathbf{g} = \mathbf{g}_C + \mathbf{g}_I &= \mathbf{D}_C\mathbf{q}_C + \widehat{\left(\mathbf{C}_I'\mathbf{i}\right)}\mathbf{g} \\ &= \mathbf{D}_C\left(\mathbf{q} - \mathbf{q}_I\right) + \widehat{\left(\mathbf{C}_I'\mathbf{i}\right)}\mathbf{g} = \mathbf{D}_C\left(\mathbf{q} - \mathbf{C}_I\mathbf{g}\right) + \widehat{\left(\mathbf{C}_I'\mathbf{i}\right)}\mathbf{g}\end{aligned}$$

$$\mathbf{g} + \mathbf{D}_C\mathbf{C}_I\mathbf{g} - \widehat{\left(\mathbf{C}_I'\mathbf{i}\right)}\mathbf{g} = \mathbf{D}_C\mathbf{q} \tag{36}$$

$$\begin{aligned}\mathbf{g} &= \left[\mathbf{I} + \mathbf{D}_C\mathbf{C}_I - \widehat{\left(\mathbf{C}_I'\mathbf{i}\right)}\right]^{-1}\mathbf{D}_C\mathbf{q} \\ &= \mathbf{H}\mathbf{q}\end{aligned}$$

where

$$\mathbf{H} = \left[\mathbf{I} + \mathbf{D}_C\mathbf{C}_I - \widehat{\left(\mathbf{C}_I'\mathbf{i}\right)}\right]^{-1}\mathbf{D}_C. \tag{37}$$

This expression was derived by Gigantes (1970, p 274, Equation 7) and is repeated in Armstrong (1975, p 75, Equation 5.4.15) and Miller and Blair (1985, p 194, Equation 5-1-17).[11]

As with the '**R**' matrix method, this expression can be substituted into (10) to give

$$\mathbf{q} = \mathbf{B}\mathbf{H}\mathbf{q} + \mathbf{f} \tag{38}$$

and hence

$$\mathbf{A}_H = \mathbf{B}\mathbf{H}. \tag{39}$$

where H indicates the use of the 'H' matrix HTA variant. Using (36) to substitute for **q** in (38) produces

$$\begin{aligned}\mathbf{H}^{-1}\mathbf{g} &= \mathbf{B}\mathbf{H}\mathbf{H}^{-1}\mathbf{g} + \mathbf{f} \\ \mathbf{g} &= \mathbf{H}\mathbf{B}\mathbf{g} + \mathbf{H}\mathbf{f}\end{aligned} \tag{40}$$

and hence

[11] Miller and Blair (1985) use **T** rather than **H**.

$$\mathbf{E}_H = \mathbf{HB}. \quad (41)$$

Comment on Hybrid Technology Assumptions

One drawback arising from using an HTA is the almost inevitable appearance of negative entries in the symmetric matrices which then require 'correction': typically, no clear statement appears as to the procedures adopted for these 'corrections' by statistical agencies. Armstrong (1975, pp 78-81) briefly discusses this problem in relation to the 1963 tables where the basic procedure was to set negatives equal to zero following the precedent set by Stone *et al* (1963), this appears however to have been supplemented by manual adjustments to the make matrix division in light of evidence from the **B** matrix and subsequent re-balancing of the **A** matrix[12]. This is a common choice of procedure.

Imported Intermediates

Opening the system to trade introduces no substantive difficulties. Trade involves the requirement to identify a third basic matrix: the IMPORT USE matrix, **Z**, which identifies the commodity imports purchased by domestic industries such that z_{ij} defines the quantity of the imported commodity *i* consumed by industry *j*. Thus, the matrix **Z** is analogous to **X** in that both identify commodity absorption by industries but distinguish between intermediate commodities solely according to whether they are imported or domestically produced. Consequently, a matrix of industry input coefficients for imported intermediate inputs can be defined as

$$\mathbf{B}^F = \mathbf{Z}\hat{\mathbf{g}}^{-1} \quad (42)$$

where each element, b_{ij}^F , defines the quantity of imported commodity *i* used up in the production of a unit of industry *j*'s output, and hence $\mathbf{B}^F$ is equivalent to the matrix **B** (see (1)). The derivation of symmetric coefficient matrices is then a matter of substitution, i.e.,

$$\mathbf{A}_C^F = \mathbf{B}^F\mathbf{C}^{-1} \quad (43a)$$

$$\mathbf{E}_C^F = \mathbf{C}^{-1}\mathbf{B}^F \quad (43b)$$

$$\mathbf{A}_I^F = \mathbf{B}^F\mathbf{D} \quad (43c)$$

12 This process was carried out using the matrix of flows which was then converted to a matrix of coefficients (Armstrong, 1975, p 80).

$$\mathbf{E}_I^F = \mathbf{D}\mathbf{B}^F \tag{43d}$$

$$\mathbf{A}_R^F = \mathbf{B}^F\mathbf{R} \tag{43e}$$

$$\mathbf{E}_R^F = \mathbf{R}\mathbf{B}^F \tag{43f}$$

$$\mathbf{A}_H^F = \mathbf{B}^F\mathbf{H} \tag{43g}$$

$$\mathbf{E}_H^F = \mathbf{H}\mathbf{B}^F. \tag{43h}$$

Primary Input Coefficients and Transactions

The vector **y** (see Table 1) identifies value added by industries. Because of the assumptions made about the structure of production relationships it is necessary to adjust **y**. In principle the procedure is identical to that employed for the inter-industry matrices and thus the discussion here is limited.

The primary input vectors are analogous to the inter-industry absorption and imports matrices. Hence a vector, $\mathbf{b}_y$, can be defined that identifies the value added by industries in coefficient form, i.e.,

$$\mathbf{b}_y = \mathbf{y}\hat{\mathbf{g}}^{-1}. \tag{44}$$

A typical element of the vector $\mathbf{b}_y$ defines the proportion of value added to total output. It is then a matter of substituting $\mathbf{b}_y$ for **B** in the formulae previously derived for the inter-industry matrices, i.e.,

$$\mathbf{a}_C^V = \mathbf{b}_y\mathbf{C}^{-1} \tag{36a}$$

$$\mathbf{e}_C^V = \mathbf{i}\mathbf{C}^{-1}\hat{\mathbf{b}}_y \tag{36b}$$

$$\mathbf{a}_I^V = \mathbf{b}\mathbf{D} \tag{36c}$$

$$\mathbf{e}_I^V = \mathbf{i}\mathbf{D}\hat{\mathbf{b}}_y \tag{36d}$$

$$\mathbf{a}_R^V = \mathbf{b}\mathbf{R} \tag{36e}$$

$$\mathbf{e}_R^V = \mathbf{i}\mathbf{R}\hat{\mathbf{b}}_y \tag{36f}$$

$$\mathbf{a}_H^V = \mathbf{bH} \tag{36g}$$

$$\mathbf{e}_H^V = \mathbf{iH}\hat{\mathbf{b}}_y \tag{36h}$$

The only complication is to ensure correct aggregation, i.e., summation by columns. This explains why the formulae for the industry x industry are marginally more complicated.

Furthermore, since the problems created by the appearance of negative entries in the inter-industry matrices when using an HTA have, or should have, been resolved while determining the **R** and **H** matrices for the inter-industry relationships the process is simply one of computation. In addition, Armstrong's 'test of an acceptable HTA' is met since it is solely dependent upon the derivation of the matrices **R** and **H**.

Moreover, since data on primary inputs are also likely to be collected on the basis of their use by industries, these will also need to be adjusted to conform to the technology assumptions and dimensions of the symmetric tables.

This procedure can be adopted for any vector relating to value added, indirect taxes etc., and can be applied directly to the vectors of transaction values reported in the published IO tables, **and** to vectors of the quantities of primary inputs employed by industries derived from other sources, provided only that the industry definitions coincide.

The Structure of the Make Matrix

A non-square Make matrix has important implications. If the objective is to collapse the database from a Make and Use SAM to a IO SAM (as in Dervis, de Melo and Robinson, 1982, and Hertel, 1997), i.e., to generate a symmetric matrix for the production accounts, the options are apparently limited. Specifically, the use of the $\mathbf{C}^{-1}$ matrix in the CTA and HTA versions limits the choice to an ITA assumption. It may be possible to resolve this problem using so-called generalised or pseudo inverses. However, the interpretation is somewhat difficult to disentangle.

Key Point

A SAM with a diagonal Make matrix requires a symmetric IO table for inter-industry transactions. As the above analysis shows, an IOT based SAM is a reduced form of a SUT/Make and Use SAM.

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