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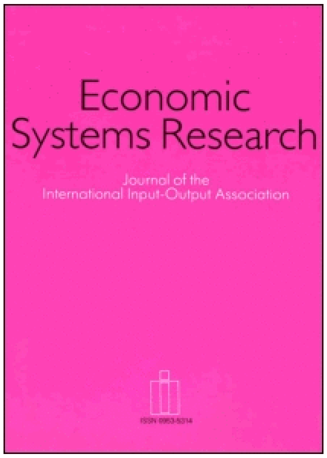

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Estimation of commodity-by-commodity input-output matrices

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Estimation of Commodity-by-Commodity Input–Output Matrices

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ABSTRACT *In this paper we derive a method for the estimation of symmetric input–output tables (SIOTs), which makes it possible to use the commodity technology assumption even when use- and make tables are rectangular. The method also solves the problem of negative coefficients. In the empirical part we derive annual SIOTs in order to evaluate the differences between SIOTs calculated with different methods and the change in technical coefficients over time. Our results, based on data for Sweden, show that the impact of using different technology assumptions is rather large. However, in a factor content of trade application the impact of different technology assumptions does not seem to be very important. Also the size of the changes in the technical coefficients over time is found to be quite large, indicating the importance of calculating SIOTs annually.*

KEY WORDS: Input–output model, commodity technology, product technology, factor content of trade

1. Introduction

Many economic models in applied research are based on input–output (IO) matrices. Basically, there are two kinds of IO-models. In the System of National Accounts (SNA), the make-use model allows industries to produce more than one commodity.[1] In contrast, in the famous Leontief model (or the symmetric IO-table 'SIOT') each industry produces only one commodity and each commodity is produced by only one industry. Furthermore, SIOTs can be divided into two subgroups. They can either be defined as industry-by-industry or commodity-by-commodity. This paper deals only with commodity-by-commodity SIOTs since they show more homogeneous flows than the industry-by-industry tables, which is a requirement in input–output analysis (see for

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example Konijn and Steenge, 1995; Braibant, 2002; ten Raa and Rueda Cantuche, 2003). In commodity-by-commodity tables, the entire use of commodities as intermediate inputs is distributed to the production of a specific commodity, and if an industry produces more than one output, the inputs have to be distributed to specific outputs.

When the United Nations introduced the SNA make-use model, they also proposed two alternative technology assumptions to be used in compiling SIOTs from use- and make tables. These were the industry technology assumption (ITA) and the commodity technology assumption (CTA). Kop Jansen and ten Raa (1990) proved in an axiomatic framework that the CTA is the preferred one with respect to some desirable properties. However, two drawbacks of the CTA are that it often produces negative technical coefficients and that it requires the same number of commodities and industries, i.e. rectangular use- and make tables cannot be used. In this paper we suggest and apply a new method to derive SIOTs from systems of use- and make tables. This method can use the CTA, ITA or a mix of the two technology assumptions. It also deals with the problem of negative technical coefficients and it is able to employ rectangular use- and make tables in the case of the CTA.

In many countries use- and make tables are produced annually, while the SIOTs are produced less frequently. In the case of Sweden, for example, the use- and make tables have been produced on a yearly basis since 1993, but the SIOTs have only been produced for 1995 and 2000 during the same period. The 1995 table was published in 2003 and the 2000 table was published in 2004, all in accordance with a requirement from the European Union (EU). For some research purposes, however, annual SIOTs are needed. An example are studies that are concerned with the development of the factor content of trade over time, where SIOTs are used to capture the intermediate flow of factors of production. If annual official SIOTs are not available, a researcher has to choose between calculating them from use- and make tables himself, or use an official SIOT under the assumption of constant technical coefficients over time.

Is an assumption of constant technical coefficients over time appropriate or is it worthwhile to calculate annual SIOTs? More specifically, is the five-year interval used by Statistics Sweden sufficient to capture the dynamics of the industry structure? One purpose of the empirical part of this paper is to answer these questions by evaluating the size of the changes in the technical coefficients that have occurred over time, based on data from Sweden. To be able to evaluate the changes in technical coefficients over time we need to calculate annual SIOTs. A second purpose of the empirical part is to evaluate the difference between SIOTs computed using different technology assumptions.

In the next section we briefly describe two of the most common technology assumptions in compiling SIOTs from use- and make tables and we also show how one can use a minimization approach to deal with the problems of negatives and of using rectangular use- and make tables. The results are presented and discussed in the third section. In the fourth section, we apply some of our estimated time series of SIOTs in a factor content of trade framework. The concluding section summarizes the main findings.

2. Methods of Input–Output Compilation

In the following, we will show that both the ITA and CTA can be transformed into problems of minimizing the variance of a variable b_{ijk}, which is defined as the quantity of commodity i that is used for producing one unit of commodity j in industry k.[2]

These *b*-coefficients may be called industry-specific technical coefficients and they should not be confused with the ‘ordinary’ technical coefficients a_{ij}, which are defined for the whole economy. That is, if z_{ij} gives the total quantity of commodity i that is used for producing commodity j in the whole economy, then a_{ij} is obtained from dividing z_{ij} by the jth column sum and gives the quantity of commodity i that is used for producing one unit of commodity j in the whole economy.

It is possible to define two relations between use-, make- and SIOTs that always hold. The first relation is that the quantity of commodity i used for producing commodity j in the whole economy must be equal to the sum of the use of commodity i that is distributed to output j in all industries producing output j, i.e.

$$z_{ij_t} \equiv \sum_{k=1}^{K} b_{ijk_t} v_{jk_t} \tag{1}$$

where v_{jk} is the quantity of commodity j that is produced in industry k.

The second relation is that the quantity of commodity i used in industry k must be equal to the sum of the use of commodity i for all commodities produced in industry k, i.e.

$$u_{ik} \equiv \sum_{j=1}^{J} b_{ijk} v_{jk} \tag{2}$$

where u_{ik} is the total quantity of commodity i that is used in industry k.

The implication of equation (1) is that if the *b*-coefficients are known, the SIOT can be calculated from the make table. In general, however, these *b*-coefficients are not known and we have to distribute the different costs of the firms to the different outputs they produce in order to calculate the coefficients. The use- and make tables together with equation (2) give us some more information, but the *b*-coefficients can still not be derived because equation (2) is a system of $I \times K$ equations in $I \times J \times K$ unknown variables. To be able to derive the *b*-coefficients, more assumptions are needed. The two main principles used to solve this problem will be briefly explained in the following two subsections.

2.1. The Industry Technology Assumption

According to the industry technology assumption (ITA), the same industry uses the same mix of inputs for all its outputs, i.e. the *b*-coefficients for a specific input in a specific industry are all equal. Furthermore, since the *b*-coefficients are all equal, their variance is equal to zero. This means that the *b*-coefficients can be calculated using a minimization problem where, for every combination of inputs and industries, we minimize the variance of the *b*-coefficients for different outputs using equation (2) as a constraint.

2.2. The Commodity Technology Assumption

According to the commodity technology assumption (CTA), the same mix of inputs is used for producing a specific product in all industries that are producing that product.

The implication of this is that the *b*-coefficients for a specific input in the production of a specific output are the same in all industries, and therefore the same as the economy-wide technical coefficient a_{ij}, i.e.

$$b_{ijk} = a_{ij} \tag{3}$$

Using equation (3) together with equation (2) implies that the number of unknowns is equal to the number of equations if the number of industries is equal to the number of products, i.e. if the use- and make tables are square. If this is the case it is possible to calculate a SIOT using the CTA.

If the CTA holds, the variance of all the *b*-coefficients for a specific input in the production of a specific output will always be equal to zero. This means that the *b*-coefficients, even in this case, can be calculated using a minimization problem where, for every combination of inputs and outputs, one minimizes the variance of the coefficients for different industries using equation (2) as a constraint.

2.3. The Proposed Method

Since the *b*-coefficients in both the CTA and in the ITA have a variance of zero, they can be calculated using a minimization problem using equation (2) as a constraint. By imposing an additional constraint in the minimization problem, i.e. stating that all the industry specific technical coefficients have to be non-negative, we will also have a natural solution to the problem of negatives in the case of the CTA. However, if such a constraint is added, it will in some cases no longer be possible to reach the value of zero for the objective function. Consequently, the CTA will no longer hold with equality, but the squared deviations in the technical coefficients from their mean will still be minimized.

The minimization approach will have two additional advantages besides dealing with the problem of negatives. First, in the case of the CTA, we will be able to use this method even if the number of industries differs from the number of commodities. Consequently we will no longer have a requirement of using square use- and make matrices. Secondly, it will be possible to mix the CTA and ITA and calculate a SIOT that is a combination of the two assumptions. By relaxing the assumption that one of these variances is equal to zero and instead minimizing a weighted sum of them we are able to accomplish this. The relative importance put on each assumption will determine the relative size of the weights in the objective function. However, we do not place any restriction on the sum of the weights, since the value of the objective function is not evaluated here, only the resulting *b*-coefficients.

In the case of the ITA, the minimization problem can be carried out on every combination of inputs and industries separately. However, in the case of the CTA, or if we want to calculate a mixed model, we have to calculate the minimization problem for all industries and outputs simultaneously, meaning that we can only divide the problem into different inputs.[3] The general setting for our method is to solve the following i number of minimization problems, where we minimize the sum of the different variances, i.e.

$$\text{Minimize } \left(\mu \sum_{j=1}^{J} \text{var}(b_{ij}) + \omega \sum_{k=1}^{K} \text{var}(b_{ik}) \right)$$

$$\text{subject to } b_{ijk} \geq 0 \text{ and } u_{ik} = \sum_{j=1}^{J} b_{ijk} v_{jk} \tag{4}$$

where $\text{var}(b_{ij})$ is the variance of the b_{ijk}-coefficients in the production of commodity j for the use of input i in all the industries k that produce j; $\text{var}(b_{ik})$ is the variance of the b_{ijk}-coefficients in industry k for the use of input i for all the outputs j that are produced in industry k; μ is the weight for the CTA; and ω is the weight for the ITA. Note, however, that it is only the b-coefficients for those industries that produce output j that are to be included in the calculation of the variances and that the other b-coefficients are excluded.

2.4. Which Assumption to Use

Over the years there has been a dispute concerning which of the two assumptions to use.[4] The ITA, on the one hand, is commonly used in practice (e.g. by Statistics Sweden) but often criticized,[5] since it is inconsistent with input–output analysis.[6] The CTA, on the other hand, has a drawback since it often produces negative coefficients.[7] Rueda Cantuche (2004, Chapter 4) reviews the literature concerning the problem of negative technical coefficients and finds that there are basically three reasons for their appearance. (i) There exist different technologies producing the same product. An example is electricity produced from hydropower, which certainly does not use the same inputs as electricity produced in nuclear- or coal power plants. (ii) The classification of commodities is heterogeneous with respect to how the commodities are produced. (iii) There are measurement errors in the use- and make matrices.

In what follows, we will focus on measuring the differences in the technical coefficients, when using different technology assumptions. For a theoretical discussion of the pros and cons between the different assumptions in the construction of SIOTs, see Kop Jansen and ten Raa (1990) and ten Raa and Rueda Cantuche (2003).

3. Results

In this section both the change over time in technical coefficients and the difference between different technology assumptions are investigated. The estimation of commodity-by-commodity IO-matrices in this study is based on data collected from Statistics Sweden, containing use- and make tables at current basic prices. We use four different models; the ITA, CTA, MIX (a mixed model with equal weights on the CTA and ITA) and MIC (a mixed model with a very small weight on the ITA). When comparing the ITA tables (calculated with our data for the years 1995 and 2000) with the official IO-tables for those years (which are also calculated according to the ITA), we find a large difference for the numbers in the 50–52 row. The reason for this difference is that trade margins are included in this row in the official table. Since we have no information about the size of the trade margins used in the official table, we have calculated them as the difference between the 50–52 row in our calculated ITA-tables and the official tables for 1995 and 2000 respectively. For the years in between, trade margins were interpolated. These vectors of trade margins were then added to the 50–52 row in all the SIOTs calculated, regardless of the technology assumption. After this manipulation, there are still some small differences between the ITA-tables that we have computed and the official tables. These are probably due to differences between the use- and make-tables that Statistics Sweden used in their official calculations and the tables that we received from them.[8]

When comparing the different SIOTs, we have used two different measures. The first measure is the sum of the deviations in technical coefficients, in absolute values, divided by the sum of the coefficients, i.e.

$$\frac{\sum_{i,j} \left| a_{ij} - a^*_{ij} \right|}{\sum_{i,j} 0.5(a_{ij} + a^*_{ij})} \tag{5}$$

The second measure is the average percentage deviation in the technical coefficients, i.e.

$$\text{mean}\left[\frac{\left| a_{ij} - a^*_{ij} \right|}{0.5(a_{ij} + a^*_{ij})} \right] \tag{6}$$

The rationale for using both measures is that we get information whether the results are driven by the small or by the large coefficients. The first measure, i.e. in equation (5), will capture the deviations of large coefficients since small coefficients have almost no impact on the sum of the deviations. The second measure is much more sensitive to the small coefficients, since a small deviation, in absolute value, has a larger percentage deviation when compared to large coefficients.

3.1. Changes in Technical Coefficients over Time

In order to investigate the change over time in technical coefficients, we compare the deviation between one year and the next year for our four models. The results are presented in Table 1. The first number in each cell is lower than the second for all models except the CTA. This indicates that the small elements change the most in the ITA, MIC and MIX models. In the CTA model, however, it seems that the large elements change the most over time. The second number in each cell, i.e. the average percentage deviation in the technical coefficients, is about 20% for each model for each year. Furthermore, we find that the deviations from one year to the next are almost as large as the deviation over the whole period. This indicates that there are lots of changes back and forth in the coefficients rather than an ongoing trend. Our conclusion is that the change over time in technical coefficients is so large that it is worthwhile to compute yearly SIOTs.

Table 1. The percentage change over time in technical coefficients

	Model			
Years	CTA	MIC	MIX	ITA
1995–1996	15	11	9	10
	19	19	20	18
1996–1997	47	17	9	8
	20	20	17	14
1997–1998	20	11	9	8
	19	19	18	15
1998–1999	51	19	10	10
	20	20	19	16
1999–2000	38	16	9	10
	23	22	21	18
2000–2001	34	18	10	10
	19	19	19	17
1995–2001	54	33	25	25
	40	39	40	36

Notes: The first number in each cell is the deviation calculated by equation (5); the second number is the deviation calculated by equation (6). The weights used in the models are: CTA: $\omega = 0$, $\mu = 2500$; MIC: $\omega = 0.01$, $\mu = 2500$; MIX: $\omega = 2500$, $\mu = 2500$; ITA: $\omega = 2500$, $\mu = 0$.

3.2. Comparisons of Different Technology Assumptions

In Table 2, the differences between the four models are evaluated using data from 1995. Similar results are obtained for the other years in the study. The deviation between the ITA and CTA is around 50%, indicating that the technology assumption matters a lot for the size of the technical coefficients. It is notable that the MIC model differs significantly from the CTA, despite the fact that the weight on the ITA component is very small. There are a few, but large, coefficients that differ between the two, since the first measure has a difference of 31% while the second has only 2%.

It may be the case that different technical coefficients are of different importance for the results in different applications. For example, coefficients of energy inputs will probably be important in an environmental analysis while other coefficients may be more important in other applications. Even if Table 2 shows that the technology assumption matters a lot, it does not indicate whether the coefficients that differ are the most important in a certain

Table 2. The percentage deviations between different technical assumptions in 1995

	CTA	MIC	MIX
MIC	31		
	2		
MIX	43	14	
	49	47	
ITA	46	19	7
	52	51	29

application. In general, we expect the coefficients in industries with a large share of secondary products to be more affected by the technology assumptions than coefficients in industries that only produce their main commodity (see Guo *et al.*, 2002).

Maybe it is the case that only a few of the technical coefficients change a lot due to different assumptions about technology, but these coefficients are of great importance in a specific analysis. It may also be the case that a large number of the technical coefficients in a SIOT are influenced greatly by the technology assumption used, while the most important ones are not. To evaluate the impact of the technology assumptions in a specific application one must therefore perform a sensitivity analysis in that particular application. In the next section we will perform such a sensitivity analysis in a factor content of trade framework.

4. Applications

In order to investigate one aspect of the significance of different technology assumptions, we apply some of the estimated SIOTs in a factor content of trade framework. Data on imports and exports are taken from the foreign trade statistics, data on factor inputs are taken from the database RAMS (register-based labor force statistics) and the financial statistics, all maintained by Statistics Sweden. The theoretical model is further described and also used empirically in Widell (2005).

In this specific application we use information from the whole intermediate part of the SIOT (except sectors 11, 12 and 95) and not a subset of it.[9] According to the Heckscher–Ohlin–Vanek (HOV) theorem we can think of trade as the international exchange of the services of factors of traded goods. The HOV-theorem shows that, if trade is balanced, countries will have an embodied net export of factors in which they have an abundant relative endowment and a net import of factors in which they have a scarce relative endowment, where abundance and scarcity are defined in terms of a factor-price-weighted average of all resources. To show the different impacts of differently specified SIOTs, we calculate the human capital content of trade in high skilled labor in Sweden for the period 1995–2000. The following equation will be used in the calculation,

$$z_{ft} = \frac{\sum_{i=1}^{I} x_{it}\alpha_{ift}}{\sum_{i=1}^{I} m_{it}\alpha_{ift}} \tag{7}$$

where x_{it} and m_{it} are the share of the ith industry in the total exports, respectively imports, at time t; α_{ift} is the total (i.e. direct plus indirect) use of factor f per unit of final demand in industry i at time t. Note that α_{ift} is an element of the total factor input requirements matrix, i.e. the direct inputs multiplied by the Leontief inverse, and they are not to be confused with the technical coefficients a_{ij}. Hence, z_{ft} gives the average requirements of factor f, weighted by trade shares, per thousand Swedish kronor of exports, compared to the average requirements of the imports. This gives us information about the difference in export- and import structure with respect to a particular factor's intensity in products

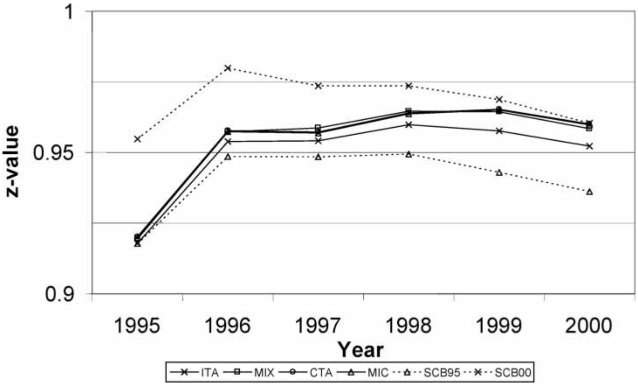

Figure 1. Factor content of skilled labor in Swedish trade for the period 1995–2000 using different SIOTs. *Notes*: All curves are calculated according to equation (7). The technological coefficients based on ITA, CTA, MIC and MIX are calculated according to equation (4). The curves SCB95 and SCB00 are based on technological coefficients calculated from the official 1995 and 2000 SIOTs respectively.

and services, regardless of the trade balance. The production factor used in the calculations is skilled labor, which is measured as labor with at least a post-secondary education.

In Figure 1, we compare six different z_{ft}-curves calculated using identical trade- and factor input requirements data, but using different SIOTs. When examining this figure, we avoid interpreting the development of z_{ft} over time in economic terms (see Widell, 2005, for an economic interpretation). Instead, the intention here is to evaluate the performance of our annually compiled SIOTs and compare them with the assumption of constant cost-shares over time, i.e. the curves calculated with official SIOTs. As we can see, all four of the z_{ft}-curves compiled with annual SIOTs behave similar to each other. However, in 1995 all curves compiled from SIOTs calculated by using data from 1995 give similar results, but the curve compiled from the official SIOT from 2000 differs. In the year 2000 it is the other way around, since the calculations based on the official 1995 SIOT differ from the curves compiled from data from 2000. We can also see that between 1996 and 1999 the curves based on the assumption of constant cost-shares over time are decreasing and those compiled with annual SIOTs are increasing. In this application, it seems more important to compile SIOTs annually, than which method to use in the compilation of annual SIOTs.

5. Conclusions and Further Developments

When we compare the technical coefficients from SIOTs using different technology weights we find rather large deviations indicating that it is important which technology assumption to use. We also find rather large deviations in the technical coefficients over time, indicating that it is important to compute annual SIOTs. However, only studying the deviation in technical coefficients may not be the best way to evaluate differences, as different a_{ij} may be more or less important in different applications. For the application chosen in this study, it seems that the impact from different compilation methods of the SIOTs has less influence on the results compared to the use of annual SIOTs versus constant SIOTs. This result indicates that it is more important to produce SIOTs annually than what compilation method to choose. However, this is only one application and it will be interesting to see whether this also holds for other applications.

We have shown that SIOTs calculated from different technology assumptions differ from each other. The ITA and CTA are only two extreme solutions to all the infinitely many SIOTs that are consistent with the use- and make matrices. It may be the case that SIOTs should not be calculated from use- and make matrices at all. The aggregation of firm level data into use- and make matrices is in fact a loss of information. It would probably be more efficient to base the analysis directly on firm level data.[10] In most cases though, these data are not available outside the statistical office and the alternatives are either to use the official SIOT or to calculate a SIOT from the official use- and make matrices in basic prices. Since the method proposed in this article gives an easy-to-use method of calculating a lot of different SIOTs consistent with use- and make tables, it gives a good opportunity for making sensitivity analyses over the choice of SIOTs in applied research.

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Notes

[1] This model was introduced by the United Nations in 1968.

[2] The same variable is used by Rueda Cantuche (2004, Chapter 4). We have chosen a slightly different derivation of the technological assumptions since our purpose is to prove that it is possible to rewrite them into problems of minimizing the variance of this particular variable.

[3] Since every equation in the constraint consist of j coefficients, it has to be solved for all j outputs simultaneously, and to calculate the variance over k we have to solve for all industries simultaneously.

[4] For a review of the relevant literature see Guo *et al.* (2002) or Rueda Cantuche (2004, Chapter 2) and the references therein.

[5] See for example Kop Jansen and ten Raa (1990) and Almon (2000).

[6] It is inconsistent with the assumption of homogeneous production, which is one of the most important assumptions in input–output analysis (see e.g. Viet, 1994, or Konijn and Steenge, 1995).

[7] See for example Eurostat (2002, Chapter 11.3) and Guo *et al.* (2002).

[8] The share of the elements in our table that differ from the official table is about 9%. These elements had a mean percentage deviation from the official table of about 2%. This leads to an average error for the whole table of about 0.15%.

[9] The reason for excluding ISIC rev.3 sectors 12 (extraction of uranium and thorium ores) and 95 (private households with employed personnel) is that there is no activity in those sectors, which makes the IO-table uninvertable. Sector 11 (oil and natural gas extraction) is excluded due to non-representative factor input requirements.

[10] An interesting example of such a method is given in Rueda Cantuche (2004, Chapter 6).

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