INPUT-OUTPUT MODELS OF SCIENCE AND TECHNOLOGY AND ITS APPLICATION IN EVALUATING PROGRESS OF ENTERPRISE SCIENCE AND TECHNOLOGY①

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ABSTRACT The method of compiling input-output models of science and technology was studied, and the application of input-output techniques in evaluating the progress of enterprise science and technology was discussed. And the models for determining direct, indirect and full contributions of the progress of enterprise science and technology have been set up which can be used to analyse and evaluate the direct, indirect and full benefits of the progress of enterprise science and technology.

Key words input-output techniques input-output models progress of science and technology full economic benefits

1 INTRODUCTION

The progress of sicence and technology (hereafter being abbreviated to PST) is the source of the development of enterprise's production. To analyze and evaluate the PST especially to determine its direct, indirect and full contributions, it is necessary to adopt input-output techniques, of which the basic work is to compile the input-output models of the enterprise's science and technology[1-4].

The input-output models of science and technology can be compiled on the basis of the input-output models of products. According to the input-output table of product and decomposing the total products of various sectors using production function, the input-output table of science and technology, indicating the direct contributions of each sector made by the PST can be obtained. And based on the table, the input-output models of science and technology, and the evaluating of enterprise's scientific and technological progresses can be made.

2 BASIC FORM OF THE INPUT-OUTPUT TABLE OF ENTERPRISE SCIENCE AND TECHNOLOGY

Based on the traditional input-output table of products, adding one row and one column in the first quadrant (or several rows and columns) to reflect the input and output of science and technology, and one row in the third quadrant to reflect the benefits of PST, then the input-output table of science and technology can be obtained. But in fact during its compiling the input row and output column of the first quadrant were omitted consciously for the insufficient of information. The form of the input-output table of enterprise science

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and technology is shown as Table 1.

There are equibalance relations in value terms among the data in Table 1, which can be expressed as follows:

$$\boldsymbol{X}_{n\times n}\boldsymbol{i}_{n\times 1}+\boldsymbol{Y}_{n\times 1}=\boldsymbol{X}_{n\times 1} \quad (1)$$

$$\boldsymbol{i}_{1\times n}\boldsymbol{X}_{n\times n}+\boldsymbol{W}_{1\times n}+\boldsymbol{D}_{1\times n}+\boldsymbol{N}^{(e)}_{1\times n}+\boldsymbol{N}_{1\times n}=\boldsymbol{X}_{1\times n} \quad (2)$$

where $\boldsymbol{i}_{n\times 1}$ is an unit column vector consisting of n elements whose entry is 1; the element $\boldsymbol{X}_{ij}$ in matrix $\boldsymbol{X}_{n\times n}$ refers to the products consumption of sector i in the producing process of sector j; $\boldsymbol{Y}_{n\times 1}$ and $\boldsymbol{X}_{n\times 1}$ respectively are the final product column vector and the total products column vector; $\boldsymbol{W}_{1\times n}$ and $\boldsymbol{D}_{1\times n}$ respectively are the purchased goods row vector and the fixed assets discount row vector; the element $\boldsymbol{N}^{(e)}_j$ of the vector $\boldsymbol{N}^{(e)}_{1\times n}$ is the direct contributions (in value terms) of science and technology in sector j; the element $\boldsymbol{N}_j$ among the vector $\boldsymbol{N}_{1\times n}$ is the difference between the newly created value and the direct contribution of science and technology in sector j, which indicates the contributions made by other factors.

Assuming e_i is the direct contribution value of PST in the unit product of sector i, it is also called as the direct contribution ratio of PST in sector i to its total products. From Table 1, the following equation can be obtained:

$$e_i=\boldsymbol{N}^{(e)}_i/\boldsymbol{X}_i \quad (i=1, \cdots, n) \quad (3)$$

The calculation of e_i can be obtained from equation (3) by determining $\boldsymbol{N}^{(e)}_i$, which can be calculated as follows: firstly figure out the contribution value $\boldsymbol{X}'_i$ of the input factors to the total output of sector i; then, subtract $\boldsymbol{X}'_i$ from the total output value $\boldsymbol{X}_i$ of sector i to get $\boldsymbol{N}^{(e)}_i$. Its specific calculating process can be shown as follows:

Assumed the production function of sector i is:

$$\boldsymbol{X}_i=A_i K_i^{\alpha_i} L_i^{\beta_i} \quad (i=1, \cdots, n) \quad (4)$$

where the capital elasticity to product α_i and the labor elasticity to product β_i can be determined by the regression analysis method. Furthermore,

$$\boldsymbol{X}'_i=K_i^{\alpha_i} I_i^{\beta_i} \quad (i=1, \cdots, n)$$

then $$\boldsymbol{N}^{(e)}_i=\boldsymbol{X}_i-\boldsymbol{X}'_i \quad (i=1, \cdots, n) \quad (5)$$

3 THE INDIRECT AND FULL CONTRIBUTION OF PST

The function of the input-output techniques lies in the fact that it can not only work out the direct contributions of PST, but also can figure out its indirect and full contributions.

$\boldsymbol{N}^{(e)}_i$ and e_i determined by the eqn. (5) and eqn. (3) respectively reflect the direct contribution value and its fraction of PST to the total products in sector i. However, because there are indirect and direct intersectoral eco-

Table 1 The form of input-output Table of science and technology

		Middle products			Final products	Total output
		Sector 1	···	Sector n		
Materials consumption	Sector 1 Sector 2 ⋮ Sector n		$\boldsymbol{X}_{n\times n}$		$\boldsymbol{Y}_{n\times 1}$	$\boldsymbol{X}_{n\times 1}$
	purchased goods		$\boldsymbol{W}_{1\times n}$			
	discount of fixed assets		$\boldsymbol{D}_{1\times n}$			
Net output value	contribution of PST		$\boldsymbol{N}^{(e)}_{1\times n}$			
	else		$\boldsymbol{N}_{1\times n}$			
Total input			$\boldsymbol{X}_{1\times n}$			

nomic connections in the enterprise, moreover among the indirect economic connections, the different kind of indirect connection can be distinguished in accordance with the related degree of its economic connections, that is according to the number of sectors being set apart between two sectors. Therefore e_i has a direct effect on the production of an unit product in sector i as well as an indirect effect on the production of the unit product in the sector j which consumes the products of sector i to maintain its own production and its indirect contribution ratio is $e_i a_{ij}$, in this way, the total indirect contribution ratio of all the producing sectors to sector j is $\sum_{i=1}^{n} e_i a_{ij}$. But this is only the first indirect contribution contained in the unit product of sector j. According to the intersectoral complete economic connections among enterprises, the total indirect contributions of PST contained in the total products of sector j can be determined by the following equation:

$$P_j = \sum_{i=1}^{n} e_i \alpha_{ij} + \sum_{j=1}^{n} P_j \alpha_{ij} \quad (j = 1, \cdots, n) \tag{6}$$

where P_j represents the indirect contribution ratio of PST in the total products of sector j.

The eqn. (6) may be rewritten in matrix form as:

$$\boldsymbol{P} = \boldsymbol{E}A + \boldsymbol{P}A \tag{7}$$

where $\boldsymbol{P}$, $\boldsymbol{E}$ respectively refer to the row vectors whose elements are p_j, e_j; and A is the matrix of the direct consumption coefficient.

Furthermore, the following equation can be obtained from the eqn. (7)

$$\boldsymbol{P} = \boldsymbol{E}[(I-A)^{-1} - I] \tag{8}$$

The full contribution ratio of PST in the total products of sector j is equal to the direct contribution ratio plus the indirect one, that is,

$$f_j = e_i + p_j \quad (j = 1, \cdots, n) \tag{9}$$

The eqn. (9) may be rewritten in the form of matrix as:

$$\boldsymbol{F} = \boldsymbol{E} + \boldsymbol{P} = \boldsymbol{E}(I-A)^{-1} \tag{10}$$

where $\boldsymbol{F}$ represents the rwo vector whose element is f_j.

4 CASE STUDY-ANALYSIS AND EVALUATION OF THE PST IN JINCHUAN CORPORATION INCLUDING ITS SUB-ENTERPRISES

Jinchuan Nonferrous Metals Corporation (being abbreviated to Jinchuan Corporation) is a first-grade national enterprise under the auspices of the China National Nonferrous-Metals Corporation, and it is a super-large-scaled nonferrous metallurgy joint enterprise including mining, mineral processing, smelting and chemistry industry. Based on the related materials, the direct contribution value and direct contribution ratio of PST in the total products of all main subenterprises under Jinchuan Corporation in 1990 can be figured out through eqns. (3) ~ (5) and shown in Table 2.

According to the value-type input-output table of Jinchuan Corporation and the data shown in Table 2, the input-output table of science and technology of Jinchuan Corporation in 1990 is available, see Table 3 which lays a foundation for the complete analysis of

Table 2 The direct contribution values and its ratio of PST in all subenterprises

Index	Longshou mine	No. 2 mine district	Opencast mine	Mineral processing plant	Smeltery plant	Chemical industry plant
$N_i^{(e)}$ /10 000 Yuan	1 369.33	4 143.42	113.63	4 778.19	38 072.44	132.87
e_i /%	31.12	32.02	4.81	18.35	35.29	8.69

the contributions of PST.

On the base of the data shown in Table 3, from the eqn. (8) and (10), the indirect and full contribution ratio of PST of the total products produced by all subenterprises under Jinchuan Corporation in 1990 can be figured out as shown in Table 4.

4.1 *Analyzing and Evaluating the Direct Economic Benefits of* PST *in Subenterprises*

In Table 4, e_j is the direct contribution ratio of PST in the production process of unit product of sector j, which indicates the direct

Table 3 The Input-output Table of science and technology in Jinchuan Corporation (Unit: 10 000 RMB Yuan))

		Middle Products						Final products	Total products
		Longshou mine	No. 2 mine district	Opencast mine	Mineral processing plant	Smeltery plant	Chemical-industry plant		
Materials consumption	Longshou mine				4 277.49			122.51	4 400.00
	No. 2 mine district				11311.12	1 285.96		341.71	12 938.85
	Opencast mine				1 969.07	349.04		44.89	2 363.00
	Mineral processing plant					26 029.97		5.03	26 035.00
	Smeltery plant					2 735.64		105 153.3	107 889.0
	Chemical industry plant					1 051.81	3.74	473.24	1 528.79
Net output value	Purchased goods	861.44	1 721.05	904.85	1 902.09	8 780.91	609.81		
	Discount of fixed assets	855.24	2 130.31	1 004.02	488.99	2 472.76	437.22		
	Contribution of science and technology	1 369.33	4 143.42	113.63	4 770.19	38 072.44	132.87		
	Else	1 313.99	4 944.07	340.50	1 308.05	27 110.47	345.15		
Total output value		4 400	12 938.85	2 363	26 035	107 889	1 528.79		

Table 4 The indirect, direct and full contribution ratios of PST in subenterprises (%)

Index	Longshou mine	No. 2 mine district	Opencast mine	Mineral processing plant	Smeltery plant	Chemical industry plant
e_j	31.12	32.02	4.81	18.35	35.29	8.69
p_j	0.00	0.00	0.00	19.39	10.75	0.02
f_j	31.12	32.02	4.81	37.74	46.04	8.71

economic benefits. From the data shown in Table 4, it may be seen that, among the six subenterprises under Jinchuan Corporation, in terms of the direct economic benefits of PST, smeltery plant comes first. No. 2 mine district second, and opencast mine last.

4.2 *Analyzing and Evaluating the Indirect Economic Benefits of* PST *in All Sub-enterprises*

4.2.1 General Analysis and Evaluation

p_j represents the indirect contributions of PST in the production process of an unit product of sector j, including the indirect contributions of PST of six sectors to the unit product of sector j, it reflects the indirect economic benefits of PST. From the data shown in Table 4, it may be seen that, among the six sub-enterprises, in terms of the indirect economic benefits of PST, mineral processing plant makes the greatest contributions, then comes the smeltery plant. Because the other subenterprises including Longshou mine, No. 2 mine district and opencast mine do not consume the products of other sectors, there is no contribution of PST of other sectors to each of the three subenterprises.

4.2.2 Structural Analysis and Evaluation

The indirect contributions of PST in the production process of an unit product of the mineral processing plant are attributed by the contributions of PST of Longshou mine, No. 2 mine district and opencast mine, whose contribution values are 0.051 1, 0.139 1 and 0.003 7 respectively, and occupying 26.35%, 71.74% and 1.91% respectively of the indirect contributions for unit product of the mineral processing plant. Therefore, among the indirect economical benefits of PST to the production of the mineral processing plant, No. 2 mine district makes the greatest contributions, Longshou mine comes second.

The indirect contributions of PST during the producing process of an unit product of the smeltery plant includes the indirect contributions of PST came from all six sub-enterprises, their contributions fractions are shown in Table 5.

Obviously, the PST of the mineral processing plant makes the greatest indirect contribution to that of the smeltery, No. 2 mine district comes second, and the third is Longshou mine.

4.3 *Analyzing and Evaluating the Full Economic Benefits of* PST *in Various Sub-enterprises*

f_j is the full contribution ratio of PST in the production process of the unit product of sector j, including the direct contribution ratio of PST of both the sector j itself and the other related sectors, indicateing the full economic benefits of PST. From the data shown in Table 4, it may be seen that, among the six sub-enterprises of Jinchuan Corporation, in terms of the full economic benefits of PST, the smeltery plant comes first, the mineral processing plant second, and No. 2 mine district and Longshou mine be next.

Table 5 The indirect contributions to the PST of smeltery plant from six related sub-emterprises

Index	Longshou mine	No. 2 mine district	Opencast mine	Mineral processing plant	Smeltery plant	Chemical industry plant	Total
Contribution value	0.012 7	0.038 3	0.001 1	0.045 4	0.009 1	0.000 9	0.107 5
Contribution fraction/%	11.81	35.63	1.02	42.23	8.47	0.84	100

4.4 *Analyzing and Evaluating the General Economic Benefits of* PST *in Jinchuan Corporation*

4.4.1 Structural Analysis and Evaluation

Among the direct, indirect and full economic benefits of the general PST of Jinchuan Corporation, the contributions of all six sub-enterprises and their fractions are shown in Table 6.

Table 6 The direct, indirect and full contribution to the PST of Jinchuan Corporation from six sub-enterprises and their fractions

Index		Longshou mine	No. 2 mine district	Opencast mine
Direct benefits	Value	0.0088	0.0267	0.0007
	fraction (%)	2.81	8.52	0.22
Indirect benefits	Value	0	0	0
	fraction (%)	0	0	0
Full benefits	Value	0.0088	0.0267	0.0007
	fraction (%)	2.09	6.35	0.17

Index		mineral processing plant	Smeltery plant	Chemical industry plant	Total
Direct benefits	Value	0.031	0.245	0.001	0.313
	fraction (%)	9.830	78.330	0.290	100
Indirect benefits	Value	0.032	0.074	0	0.107
	fraction (%)	30.290	69.710	0	100
Full benefits	Value	0.063	0.320	0.001	0.420
	fraction (%)	15.070	76.110	0.210	100

It can be seen from Table 6 that, the direct contributions of PST to Jinchuan Corporation, made by the smeltery plant comes first, then comes orderly by the mineral processing plant, No. 2 mine district and Longshou mine. And the same order also available for both the indirect contributions of PST and the full contributions of PST.

4.4.2 Gerneral Analysis and Evaluation

Assuming that e, p and f respectively represent the direct, indirect and full contributions of PST in the total output of Jinchuan Corporation, then

$$\begin{cases} e = \sum_{j=1}^{n} e_j x_j / \sum_{j=1}^{n} x_j \\ p = \sum_{j=1}^{n} p_j x_j / \sum_{j=1}^{n} x_j \\ f = \sum_{j=1}^{n} f_j x_j / \sum_{j=1}^{n} x_j \end{cases} \tag{11}$$

Substituting the related data shown in Tables 3 and 4 into the eqn. (11) then the follow figures be yielded:

$e = 31.33\%$, $p = 10.73\%$, $f = 42.06\%$

That is to say, the general direct economic benefits of PST of Jinchuan Corporation in 1990 is 31.33%, the general indirect economic benefits is 10.73%, the full economic benefits is 42.06%.

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