Chinese Economic Development and Input-Output Extension[1]

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ABSTRACT

There are three parts in this paper. In the first part we summarily introduce the application of input-output analysis in China, including construction of national and regional input-output tables, input-output tables for special sectors and enterprise input-output table, and their application in China. Particularly, on the basis of input-output model in 1990 the National Bureau of Statistics made a suggestion to the State Council of China for increasing additional 40 billion RMB yuan of the investment in capital construction, the proposal was accepted by the Chinese government.

In the second part we discuss extended input-output model with assets. The main characteristic of the model is that it allows us to examine all holding assets used in production, not only machinery and buildings but also the labor force (or human capital), land, etc., and their requirements are specified for each sector. Thus extended input-output model with assets provides a better alternative to capital stock matrices in the standard Systems of National Accounts (SNA). In this paper we will comprehensively introduce its methods and applications. We specify term of holding and using of assets, extended input-output table with assets and its main characteristics, method of calculation of total input coefficient with input of fixed assets, total holding coefficient of assets, dynamic extended input-output model, etc.

In the final part we introduce the application of extended input-output model with assets in China. Particularly, the model was successfully applied in yearly grain output prediction of China 1980-2004. Since 1980 this approach has been used in China. Every year at the beginning of May we send annual report of yearly national grain output prediction to the governmental agencies and

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top leaders of China. From 1980 to 2003 the main results are as follows:

First, predicted bumper, average and poor harvests are correct every year;

Second, the lead-time of prediction is more than half a year. Since 70% of China grain is reaped in fall and harvest is ended in November, such prior forecasting report at the end of April helps responsible governmental agencies with enough time to arrange grain consumption, storage, imports and exports.

Third, forecasting is accurate (under 3% error) for 19 years out of 23. Error rates for 8 years are lower than 1%, for 6 years are between 1-2%, for 5 years are between 2-3%, for 2 years are between 3-5%, and for 2 years are between 5-8%. Overall, average error rate over 23 years is only 1.9% compared to statistical reports from sample surveys.

Therefore, this forecasting has supported some important policy decisions. The top leaders of China, relevant departments of Chinese government, such as State Grain Administration, Ministry of Agriculture, Research Department of State Council, National Development and Reform Commission, and others paid much attention and gave excellent evaluation to the prediction.

Keywords: Chinese economic development; extended IO table with assets; total input coefficient with input of fixed assets; direct and total holding coefficient of asset; yearly grain output prediction

1. Constructing and Using Input-Output Tables in China

In China study on input-output analysis began in 1960. There were two research groups studying on input-output analysis: one was in the Department of Operations Research, Institute of Mathematics, Chinese Academy of Sciences. The other was in the Institute of Economics, Chinese Academy of Social Sciences. During the period of “Cultural Revolution” (1966-1976) all scientific methods of management, including input-output techniques, methods of operations research, econometrics and others were criticized as capitalist and revisionist rubbish. It was hard time for us. In 1972 we made a suggestion to the National Planning Commission (NPC) for constructing a national input-output table to improve the planning work of China. The proposal was accepted by the NPC. In 1974 under the support of NPC, National Bureau of Statistics and National Bureau of Information, Chen Xikang and others, constructed the first experimental input-output table of the national economy of China for 1973. Since reform and opening to the outside world (1978-present) great changes have taken place in China. Input-output analysis has been applied not only in macroeconomic analysis, but also in microeconomic management.

With the rapid spread of input-output technique in China, it is necessary to exchange experience and search together for solutions to the problems in theory and applications. In 1987 the China Input-Output Society was founded. Up to the present there were 6 conferences. The first conference was convened in 1988 in Nanchang, Jiangxi Province. The second one was in 1991 in Baotou, Inner Mongolia. The third one was in 1994 in Yinchuan, Ningxia Province. The fourth one was in 1997 in Changchun, Jilin Province. The fifth one was convened in 2001 in Xining, Qinghai Province. The sixth conference was convened in October, 2004 in Kunming, Yunan Province. The number of participants of each conference was 80-130. Under the assistance of National Bureau of Statistics (NBS) proceedings for the first 5 conferences have been published.

Besides, the China Input-Output Society spent nearly one and a half year collecting over one hundred papers on input-output application in China from the beginning of 2003. After several rounds of strict examination, finally 35 papers were selected in the book entitled “Selected Papers on Analytical Purposes of I-O Techniques in China”, edited by Xu Xianchun and Liu Qiyun, This book was published in May 2004.

1.1. Constructing National Input-Output Table

The national input-output tables constructed to date are listed in Table 1 (Chen 1989, Karen and Chen, 1991).

The 1973 input-output table is in physical units, while 1979, 1981, 1983 and 1992 tables are available in both physical and value units. The physical input-output table plays very important role in China. It is because before 1978 the most targets of the annual plan and five-year plan, such as iron, steel, coal, oil, electricity, grain, cotton, etc., were given in physical units. After 1978 in order to measure the amounts of generation of pollution, pollution abatement and natural resource use, physical input-output table and value-physical table is also very useful. Before 1987 all value input-output tables are in Material Balance System (MBS). It means only material production is included in the first quadrant (intersectorial flow part) of input-output table. Since 1987 all input-output tables are constructed according to the System of National Accounts (SNA) of United Nations.

In 1987 the State Council of the People's Republic of China decided that every 5 years (1987, 1992, 1997, 2002 and so on) China would do special input-output survey to construct national and regional input-output tables. Since 1987 the NBS constructs input-output table regularly.

1.2. Constructing Regional and Interregional Input-Output Tables

Between 1979 and 1986, 25 of China's 29 provinces, autonomous regions, and municipalities constructed regional input-output tables (Liu and Wu, 1991). Shanxi is the first region to compile regional input-output tables for 1979. Heilongjiang and Shanghai constructed their tables for 1981. Tianjin and Henan constructed their tables for 1982. Liaoning, Guizhou, Gansu and Hunan compiled the tables for 1983. Hebei, Jilin, Zheijing, Sichuan, Fujian and Xinjiang Uygur Autonomous region compiled their tables for 1984. Beijing, Jiangsu, Anhui, Jiangxi, Hubei, Guangdong, Guangxi Zhuang Autonomous region, Shaanxi, Qinghai, and Ningxia Hui Autonomous region constructed their tables for 1985. Beside provincial tables, many cities and counties, for example, Wuhan, Dalian, Xi'an, Chongqing and Harbin constructed their regional tables. The techniques to construct regional tables are flexible and varied. For example, the staff of Shanxi, Heilongjiang, Liaoning provinces and Wuhan city constructed their tables, using "Direct Decomposition Method" on the basis of special surveys, in which all large and median-sized enterprises and part of small enterprises were included. The staff of Tianjin city and

Guangdong province constructed the tables by “UV Technique” recommended by the Statistics Bureau of United Nations.

In 1987, 1992 and 1997 the NBS of China constructed national input-output tables under general and special surveys. All provinces, autonomous regions, and municipalities except Tibet and Hainan constructed their regional input-output tables. The sector classification and the scale of regional tables are the same as national input-output tables.

Besides regional input-output tables, some institutions and scholars also did some work in constructing interregional input-output table. For example, Information Center of Jiangsu Province, etc. constructed Jiangsu interregional table for 1985, in which national economy of Jiangsu is divided into two parts: South and North. The southern part has a developed economy and northern part has a less developed economy. The table is used to analyze the effect of an additional investment in the North on Jiangsu economy. Development Research Center under State Council of China constructed interregional table of China with 3 regions and 10 sectors for 1987 and other years. State Information Center of China constructed interregional table with 8 economic zones: North-East Zone (Liaoning, Jilin and Heilongjiang), Beijing-Tianjin Zone (Beijing and Tianjin), Northern Coastal Zone (Hebei and Shandong), Central Coastal Zone (Jiangsu, Shanghai and Zhejiang), Southern Coastal Zone (Fujian, Guangdong and Hainan), Central Zone (Shanxi, Henan, Anhui, Hubei, Hunan and Jiangxi), North-West Zone (Inner Mongolia, Shaanxi, Ningxia, Gansu, Qinghai and Xinjiang) and South-West Zone (Sichuan, Chongqing, Guangxi, Yunnan, Guizhou and Tibet) for 1997. The table was constructed on the basis of 1997 regional input-output tables and used gravity model to determine the interregional coefficient under the transportation statistical data (Zhang and Zhao, 2004). Under the organization of the Institute of Developing Economies of Japan the State Information Center, together with USA and other 8 Asian countries and regions, compiled the linked international I-O tables for 1985, 1990 and 1995, they are constructing the table for 2000.

1.3. Constructing Input-Output Tables for Special Sectors

In addition to general tables for all sectors we have compiled input-output tables for special sectors, such as input-output tables of agricultural sectors for 1982, 1984, 1987, 1992 and 1997, table of mechanical and electronic industry for 1983, table of chemical industry for 1979 and 1985, table of urban water-economy in Beijing for 1982, table of colour television for 1985, table of weapons industry, table of copper industry, table of information industry, table of environment-economy for Tianjin city, Liaoning province and China, table of taxes for 1987, table of energy consumption and greenhouse gas emission for 1992, table of information for China (1987) and for Yueyang county, Hunan Province, table of foreign trade for 1995, table of township and village enterprise for Shanxi Province and China for 1992, 1995, and 1997, table of air pollution input-output table for Beijing, etc.

The 1982 and 1984 input-output table for agricultural sectors was constructed by staff of Institute of systems Science, Chinese Academy of Sciences and others under the support of Rural Development Research Centre of the State Council of China. The tables were classified into a physical table; two value tables (at current prices and 1980 constant price) and an energy table. There are 40 agricultural products in the first part of physical table, 24 agricultural sectors in value table, and 47 agricultural sectors in energy table. In order to construct these tables a special survey was conducted in 120 counties to collect the data not provided by the existing accounting system of China. The energy table is very interesting and was used to calculate the output-input ratio of artificial energy and study the ecological balance in agriculture (Karen and Chen, 1991).

1.4. Constructing Enterprise Input-Output Table

One of the important characteristics of the application of input-output techniques in China is to use the techniques in enterprise planning and cost calculation, and to construct enterprise input-output table.

In 1964 Chen Xikang and Li Bingquan constructed the first enterprise input-output table for Tianjin Chemical Factory. It was a physical table, which includes 25 self-made products and service sectors in the first part and 30 purchased material and energy products in the third part of the table.

In 1965 Li Bingquan and others of the Institute of mathematics, Chinese Academy of Sciences, went to Anshan Iron and Steel Corporation, the biggest iron and Steel Corporation in China, and constructed a physical enterprise input-output table. The table included 55 self-made products, 10 retrieved metallic materials and 8 purchased metallic products. The table served the needs of the analysis of the metal equilibrium and the management of the corporation. For example, the table created a planned internal price system within the corporation and constructed a long-term development program of the corporation (Li, 1991, 2004).

So far, more than 100 large and medium-sized enterprises of China have constructed input-output tables, for example, Huabei Pharmaceutical Factory, Hangzhou Iron and steel Plant, Shanghai Gaoqiao Chemical Plant, Synthesis Plant under Jilin Chemical Industry Corporation, Qingdao Second Rubber Plant, Tianjin Bicycle Factory, Yanshan Petrochemical General Corporation, Yunan Chemical Plant and so on.

Tong Rencheng and Wang Dong constructed input-output table for Hualin Robber Corporation, one of the large sized robber corporation of China, and made a system of cost calculation and prediction (Tong and Wang, 1992). The input-output table included about 400 products and service. The system is useful to calculate cost of products and to predict profits and gross value output. Since 1991 the manager of the corporation used the system in operational management. Besides, Tong Rencheng and others used input-output method in oil piping enterprise of Liaoning Province (Tong, 2004).

1.5. Some Applications

Chinese economists find that input-output techniques are very useful for economic analysis, planning, management and forecasting. In China input-output analysis is popular for economists, for example, *Input-Output Techniques*, written by Chen Xikang and Li Bingquan， Beijing International Broadcast Press, 1983, had 223 thousand copies. Because of his contribution to input-output technique, Wassily Leontief was the most famous foreign economist of China in the eighties and nineties of the 20th century.

(1) Using input-output techniques to check the equilibrium of the annual plan and the five-year plan. For example, in 1978, 1979 and 1981 we used revised input coefficients of 1973 physical input-output table to check the material balance of the 1979, 1980 and 1991 national economic plan of China (Chen and Xue, 1984). We found that there was serious unbalance in some energy products, particularly electricity, crude oil and coal, and about 15 million tonnes of crude oil in 1975 was burned directly in electricity sector and others instead of coal and fuel oil. We made suggestion to the National Planning Commission for stop burning of crude oil and to increase amount of crude oil export.

(2) Making suggestion on Chinese economic development. At the beginning of 1990 the National Bureau of Statistics used 1987 national input-output table to check the main targets of the annual plan of 1990 and found that total investment of capital construction by government was too small. It made a negative impact on the economic growth of China. Then the National Bureau of Statistics made a suggestion for increasing additional 40 billion RMB yuan of the investment of the capital construction to the State Council of China. The State Council accepted the suggestion. Former Premier Li Peng gave a very nice appraisal on it and the suggestion played an important role in Chinese national economic development of 1990 (Li, Q., 1992).

(3) Using input-output techniques in price reform and studying effect of change in price of some products. The Price Research Centre of the State Council and the Price Research Institute of the National Price Bureau organized the calculation of theoretical prices in 1981, 1983 and 1985. In 1981 it included 1200 categories of products, in which 100 agricultural, 40 mineral, 600 manufactured, 100 light industrial, and 100 textile products (Li, M., 1988). In 1990 and 1991 the Ministry of Finance used input-output model to calculate the effect of raising price in some important products, for example grain, coal, etc. and increasing taxes on government budget and price level. Some people of the Ministry of Railway and others used input-output methods to study the effects of raising price in railway transportation on the national economy. In 1999 the Academy of Mathematics and Systems Science used input-output model to calculate the effect of

change in crude oil price of world market on the GDP and the price level of China.

(4) Studying the effect of China's entry to the WTO on the economic development of China. Professor Li Shantong and her colleagues in the Development Research Center under the State Council used I-O techniques and CGE model to study the effect of China's entry to the WTO on the GDP of China and Guangdong Province. The direct and indirect effect on the growth rate of GDP in the period from 2001 to 2010 is more than 0.5% (Li, Zhai and Liu, 2001)

(5) Studying the effect of Olympic game in 2008 on the economic development of China. Beijing has won the bid for 2008 Olympic Games. The Olympic Game has deep influences on the policy, economy, culture and other aspects of China. Liao Mingqiu, Wei Xiaozhen and others in Beijing Bureau of Statistics and universities, construct China Beijing Olympic Economic Model, using input-output analysis, econometrics and optimization to study the effects.

(6) Using input-output techniques in foreign trade. Chen Xikang, with the collaboration of Lawrence J. Lau, Professor of Department of Economics, Stanford University and others, compiled China's 1995 foreign trade input-output table and studied the effect of Chinese exports on the GDP, employment and gross output. They find that China increases exports to the world market by 1 USD, China's GDP will increase 0.57 USD. China increases exports to United States by 1 USD, China's GDP will increase 0.49 USD (Chen, 2001). Shen Lisheng and Wu Zhenyu studied the effect of imports by method of distribution coefficient on the Chinese economy and reasonability of the structure of foreign trade products (Shen and Wu, 2004)

(7) Using input-output model in environment protection. For example, Tianjin Environment Protection Bureau and Tianjin Statistical Bureau constructed environment protection-economy-input-output tables for 1982, 1985 and 1992. From the tables they found that there was good relationship between economic structure and pollution abatement. Tianjin Environment Protection Bureau used 1987 tables to predict the discharge amount of 4 pollutants (heavy metal, COD, dust and waste residue) of Tianjin City in 1995.

2 Extended Input-Output Model with Assets

In the process of using input-output analysis, in the 1980s we began to study extended input-output model with assets. The main idea of the model is that assets, including fixed assets, inventory, labor, financial assets, and natural resources, play a very important role in production. The common input-output table does not include assets. Assets have to be incorporated into the input-output table and a set of corresponding model has to be established. Since 1980, Chinese input-output researchers have used the extended input-output model in grain output prediction, water conservancy, economic-environmental analysis of township and village enterprises, foreign trade, finance, and other areas.

Many scholars have done work on assets issues. In particular, Leontief proposed a dynamic input-output model using a capital coefficient matrix. He and several researchers at the Harvard Economic Research Project not only studied dynamic models theoretically, but also led empirical work on the construction of matrices of capital coefficients, including fixed capital stocks and inventories by sector (Leontief, Chenery, Clark, Duesenberry, Ferguson, Grosse, A. P., Grosse, R. N., Holzman, Isard, & Kistin, 1953). Following Leontief, many scholars—for example, Ghosh (1964), Alman (1970), Carter (1970), Green (1971), Grossling (1975), Peterson & Schott (1979)—studied issues concerning capital coefficients and labor. In Japan there has been much meaningful research on capital measurement, including an estimation of capital formation matrix every five years since 1970 and an estimation of capital stock matrix in 1955, 1975, and other years (Kuroda & Nomura, 2003). Concerning natural resources, Leontief and his colleagues calculated the production and consumption of six metallic and three energy resources for 2000 and divided developing countries into two groups: developing with major mineral resource endowment and other developing countries (Leontief et al, 1977). The following work is seen as an extension of this research agenda. The common input-output table, however, has up to now not regularly included assets, held or used. In this paper we will introduce an extended input-output model with assets and apply it to prediction of grain output in China.

2.1. Holding and Using of Assets

In 1984, when we constructed input-output table for agriculture to study grain issues in China, we had to face the fact that both cultivated land and capital play a critical role in agricultural production, but the common input-output model did not include land, labor, or any forms of capital assets used in agricultural production. It was therefore necessary for us to extend the normal input-output models to include fixed assets, inventory, labor, land, water, and other assets.

Holding and using assets in production is a prerequisite for production. No production process can proceed without the presence of required quantities of assets, including capital, skilled or unskilled labor, and natural resources. Production scale and economic benefits also depend on the quantity and quality of the available assets. Natural resources play a critical role in some sectors, such as mining and agriculture.

In normal input-output models, the term “input” represents the consumption of various production factors in the process of economic activities. It may be seen from the meaning of “total input” in the input-output table. The total input is equal to the sum of intermediate inputs and primary input, which are consumptions of various materials, energy, services and primary factors.

With assets we refer to holding and using various assets and elements that are used by each sector at a point in time. Assets consist not only of fixed assets (such as machinery and construction), but also of inventories, financial assets, labor force (educated or not, skilled or not), natural resources, intangible assets, and others.

There exists close inter-relationships between factor inputs, assets held and used, and output. First, assets are a *prerequisite* for input and output. Without assets there will be neither input nor output. The quantity and quality of output are directly dependent on the quantity and quality of assets held and used. In particular, modern production requires higher-quality assets.

Second, assets are *related* with output and input. For example, some parts of output are used as fixed capital formation and thus as an increase in stocks in order to improve the quality and quantity of fixed assets. For example, in order to have a more skilled and highly skilled labor force, it is necessary to have more output in the education sector.

Finally, input is dependent on assets used. For example, because modern agriculture uses advanced agricultural machinery and highly skilled managers and workers as assets, its input coefficients, such as oil, electricity, chemical fertilizer, and chemical pesticides, are different from the input coefficients of traditional agriculture.

The input-output model reflects the interdependence between factor inputs (consumption) and outputs in production, but the normal input-output model does not include an asset section; nor does it reflect the inter-relationships between assets and outputs. Because there is no asset section, especially fixed assets and financial assets (other than machinery and construction in the capital stock matrix), the current input-output tables may lead to a misconception that by using the following equations the vector of total output of all sectors can be determined given a final demand vector.

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{1}$$

Where:

x denotes gross output vector

f denotes final demand vector and contains the row sums of the final demand matrix **F**

I and **A** represent identity matrix and direct input coefficient matrix, respectively

In fact, even if **f** has been determined, **x** cannot be obtained if certain quantities of the assets held and used, such as fixed assets, natural resources, and labor, are not assured (Chen, 1990).

The common input-output model shows inter-relationships between input and output; the extended input-output model with assets shows not only relationships between factor input and output, but also relationships between assets and output, and linkages between assets and factor input.

From the point of view of the system of national accounts and statistics, factor input and assets held and used are different types of statistical indicators. Factor input is listed in the category of flows, and assets belong to category of stocks. In common input-output tables, all entries, including intermediate and primary input, intermediate final demand, and output belong to flows. All assets held—for example, natural resources, labor, fixed assets, inventory, and financial assets—are stocks. As Hicks wrote, current activity of production and consumption are called “flow activity”, while the holding of assets is called “stock activity” (Hicks, 1965).

Flows reflect creation, transformation, transaction, or exchange in economic activities within a period of time. Their quantity depends directly on the length of the process. Steel output per year, for instance, is equal to roughly 12 times the output per month. However, stocks are in position or in “holding” at a point in time. The quantity has no direct relation with length of the production period. For example, the number of workers in the steel sector at the beginning of year is roughly equal to that at the end of the year. Generally, stocks are *preconditions* of flows and the intensity and quantity of flows are determined by the status of stocks. Increases in stocks and reproduction of stocks are *dependent* on the flows. There is close and reciprocal relationship between the two.

In summary, the common input-output model shows relationships only between flows; the extended input-output model with assets shows not only linkages between flows, but also between stocks and flows and between stocks themselves.

2.2. Extended Input-Output Model with Assets and Its Main Characteristics[2]

The extended input-output table is shown in Table 2. In order to compile this table it is necessary to have a large quantity of data. Because data in most applications in China are scarce, we more often use some simplified forms of the table. Table 3 is one of the simplified forms.

[TABLES 2 AND 3 ABOUT HERE]

These tables differ from a normal input-output table in two ways. First, the normal input-output table includes only factor input in the vertical direction, whereas the extended

[2] In some previous books and many papers published in China and a few abroad, the model was called input-“occupancy”-output model. The meaning of the term “occupancy” was meant to stand for, in English, “holding and using assets” at a point of time by a sector, where assets include fixed assets, inventory, financial assets, labor, natural resources, and so on.

input-output table with assets includes two sections vertically: factor input section and holding of assets section (Chen, 1990, 1998). The asset matrix $\mathbf{W}^{\mathbf{o}}$ may be very large and consists of following parts:

1). *Fixed assets*. From the table we find not only the total amount of fixed assets, but their specified use by every production sector and the physical contents of the fixed assets (e.g., construction, machinery, transport vehicles, etc.) distributed according to their sector of origin. Therefore, we have a square matrix of fixed assets with *n* orders (some rows of the matrix consist only of zeros);

2). *Inventory*. This is also a square matrix with *n* orders that gives the inventories originating from sector I that are held by sector j;

3). *Financial asset*s. An $\mathrm{n_f} \times \mathrm{n}$ matrix with financial assets held by sector j for each of the $\mathrm{n_f}$ categories (such as currencies; deposits; loans; shares; securities other than shares; advances and trade credits; and other financial assets);

4). An $n_l \times n$ matrix with labor used by sector *j* for each of the n_l schooling categories (such as illiterate; primary school; junior secondary school; senior secondary school; college; and higher level, or according to unskilled, skilled, and highly skilled levels). Labor is usually expressed in physical units.

5). *Natural resources*: land, water, subsoil assets, and so on. Natural resources are also expressed in physical units;

6). *An* $\mathrm{n_i} \times \mathrm{n}$ *matrix with intangible assets held by sector j for each of the* $\mathrm{n_i}$ *categories (such as patents; trade marks; and other intangible assets).*

In the current system of national accounts (SNA) there are capital accounts, financial accounts, and so on. Usually, the total amounts of fixed assets, inventory, financial assets, labor, and natural resources are shown in the related accounts of SNA, but in the current SNA there are no detailed capital data in input-output form by sector of use and origin. In the normal input-output table, fixed capital formation and changes in inventories are column vectors; they are total amounts for all sectors of the economy. We cannot find the figures for fixed capital formation or changes in inventories for every sector of use. This means that the current SNA and the normal input-output table cannot reflect the relationships between output and asset held and used by each sector.

The advantage of the extended input-output model over the SNA model is that it specifies the quantity of asset elements held and used by every production sector and reflects the relationships between output and assets in every sector. This not only supplies more information but creates a very important analytical foundation, for example, to measure the growth of multi-factor or total factor productivity in each sector.

In the extended input-output table, fixed capital formation and changes in inventories are two matrices with *n* orders, respectively. There are three advantages to this:

1) Representing the amounts of fixed capital formation and changes in inventories in every sector. These are important elements for economic analysis and forecasts.

2) Reflecting relations between factor input and assets. There are two relationships: those between fixed capital formation (flow) in final demand and fixed assets in assets held (stock), and those between changes in inventories in final demand (flow) and inventories of assets (stock). The linkages can be shown in following equations, in language form:

Amount of fixed assets at the beginning of next year = Amount of fixed assets at the beginning of current year + fixed capital formation of current year – consumption of fixed capital of current year.

Amount of inventories at the beginning of next year = Amount of inventories at the beginning of current year + net changes in inventories in current year.

3). Capital coefficients play a very important role in dynamic economic analysis. They are the basis of the dynamic input-output model. But it is well known under the present SNA system it is difficult to obtain a capital coefficient matrix. The extended input-output table assists us in data collection, thus allowing us to calculate a capital coefficient matrix, because we find data on fixed assets and inventory in matrix form with *n* orders. If we then compile two extended input-output tables with the same sector classification for two years, we can calculate not only an average capital coefficient matrix, but also a marginal capital coefficient matrix.

4). How to estimate assets is a very important issue. In order to exactly estimate the assets it is necessary to have some special surveys. We used some simple methods to roughly estimate the assets. In current Chinese economic practice, the depreciation of fixed assets is calculated not according to the fixed asset classification, but according to the specific sector that uses the specific asset - a practice that makes general economic sense. Using data of depreciation of fixed assets and depreciation rate by sector, we estimated the approximate value of total fixed assets in every sector (vector of fixed asset value) on the basis of total value of fixed assets of all sectors, which is estimated by the National Bureau of Statistics of China in the national economic accounts. In order to obtain a fixed asset stock matrix we have to disaggregate the value of fixed assets by sector of origin. We used data from the fixed asset formation matrices from previous years to estimate the structure of fixed asset by sectors of origin.

In addition, when we construct an extended input-output table with assets in agriculture we have to disaggregate agricultural fixed assets, labor, irrigated areas, and other factors by agricultural sub-sector (grain, cotton, and others). We used data from surveys on the costs and benefits of major agricultural products of China, organized by the National Development and Planning Commission, National Economic and Trade Commission, the Ministry of Agriculture, the National Bureau of Forestry, the National Bureau of Light Industry, the National Bureau of Tobacco, the General Cooperative of Supply and Marketing of China, and other agencies. The surveys have been conducted in the 1,300 counties of China for more than 60,000 rural households every year since 1980. In these surveys, we can obtain many important figures, such as data on depreciation cost of fixed assets, day labor, cost of farm machinery, irrigation cost, and taxes and benefits per *mu* (.067 hectare) of sown area by major crops, and on the depreciation cost of fixed assets, day labor, material cost, and other factors for livestock products, aquatic products, and forest products.

Horizontally in the extended input-output model with assets, we can write two types of equations:

1) Gross output is the sum of intermediate demand and final demand

$$\sum_{i=1}^{n} W_{ij} + f_i = x_i \qquad (i=1, 2,\ldots, n) \qquad (2)$$

where:

W_{ij} represents intermediate demand of sector *i* by sector *j*

x_i and f_i represent gross output and final demand of sector *i*, respectively

Then we have

$$\sum_{i=1}^{n} a_{ij} x_j + f_i = x_i \qquad (i=1, 2,\ldots, n) \qquad (3)$$

where a_{ij} is direct input coefficient.

2) Gross asset is the sum of intermediate asset and final asset. We denote the asset *held* and used by production sectors the *intermediate* asset; and we denote the asset held and *used* by final demand to be the *final* asset.

$$\sum_{j=1}^{n} W_{ij}^{O} + f_i^{O} = x_i^{O} \qquad (i=1, 2,\ldots, m) \qquad (4)$$

where:

W_{ij}^{O} represents *i*th asset, held and used by sector j, here the upper label "O" indicates asset,

x_i^{O} represents ith gross asset held and used

f_i^{O} represents ith asset, held and used by final demand sector, and f^{O} contains the row sums of the matrix $\mathbf{F^O}$ which is matrix of final asset, held and used by final demand sectors

a_{ij}^{O} represents the direct holding coefficient of ith asset by jth sector

$$a_{ij}^{O} = W_{ij}^{O} / x_j \qquad (i=1, 2, \ldots, m; j=1, 2, \ldots, n) \qquad (5)$$

Then we have

$$\sum_{j=1}^{n} a_{ij}^{O} x_j + f_i^{O} = x_i^{O} \qquad (i=1, 2, \ldots, m) \qquad (6)$$

and

$$\mathbf{A^O x} + \mathbf{f^O} = \mathbf{x^O} \qquad (7)$$

Where

$\mathbf{A^O} = \{a_{ij}^O\}$ indicates direct holding coefficient matrix of asset

$\mathbf{f^O} = \{f_1^O, f_2^O, \cdots, f_m^O\}'$ represents vector of final asset which is held and used by final demand sectors.

On the basis of this extended input-output model we will have some new concepts, models, and calculation formulae—for example, total input coefficient with inputs of fixed assets, total labor consumption coefficient, and total holding coefficients of fixed assets, financial assets, natural resources, and labor.

2.3. Total Input Coefficient with Indirect Input of Fixed Assets

In input-output analysis, the standard static model can be expressed as

$$\mathbf{Ax} + \mathbf{f} = \mathbf{x} \quad (8)$$

Then we have

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \overline{\mathbf{B}}\mathbf{f} = (\mathbf{B} + \mathbf{I})\mathbf{f} \quad (9)$$

where:

$\overline{\mathbf{B}} = (\mathbf{I} - \mathbf{A})^{-1}$ is the matrix of total requirements coefficients, or Leontief's Inverse

$\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1} - \mathbf{I}$ is the matrix of total input coefficients, or matrix of total consumption coefficients, which are equal to the sum of direct input coefficient and total indirect input coefficients. Element (*i*, *j*) of the Leontief inverse $(\mathbf{I} - \mathbf{A})^{-1}$ gives the output in sector *i* that is required to satisfy a one unit final demand in sector *j*. The consumptions or inputs from sector *i* that are required (directly and indirectly) in satisfying this one unit final demand in sector *j* are given by element (*i*, *j*) of the matrix $\mathbf{B} = \mathbf{A}(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + ... = (\mathbf{I} - \mathbf{A})^{-1} - \mathbf{I}$. The difference between Leontief's Inverse and matrix of total consumption coefficients is unity matrix (final demands).

The total consumption matrix is widely used in China, for example, to calculate total electricity consumption of steel and calculate total labor consumption per ton of grain, etc. In the above formula, a question arises concerning the calculation of total input coefficients. The equations in **B** did not include the indirect consumption from the fixed assets. For example, if *j* denotes steel, *i* denotes electricity, in the production of steel, some parts of factory buildings and metallurgical equipment are consumed. The production of these buildings and equipment also consumes electricity, which is obviously an indirect input of electricity to steel, but it is not contained in the total consumption (total input) of electricity to steel in the normal input-output model. Consequently, the total consumption coefficients derived from the above formula are incomplete.

In order to completely include the indirect input of electricity via the fixed assets, a new equation for computing the total input coefficients is developed by extended input-output model with assets as follows (Chen, 1990).

$$b_{ij}^{*} = a_{ij} + \sum_{k=1}^{n} b_{ik}^{*} a_{kj} + \alpha_i d_{ij}^{*} + \sum_{s=1}^{n} b_{is}^{*} \alpha_s d_{sj}^{*} \qquad \text{(i, j=1,2,…,n)} \qquad (10)$$

In above equations, the first item in the right side of the above equations denotes direct electricity consumption coefficient of electricity by steel, the second item denotes indirect electricity consumption via intermediate input, the third one represents direct electricity consumption via fixed assets which is equal to the product of depreciation rate α_i and fixed asset holding coefficient d_{ij}^{*}, and the last one represents indirect electricity consumption via fixed assets. Because we haven't data on actual consumption rate of fixed assets and only have depreciation rate, we made an important assumption that the consumption rate of fixed asset reflects or approximately equals to the depreciation rate of fixed assets. Then we have

$$\mathbf{B}^{*} = \mathbf{A} + \mathbf{B}^{*}\mathbf{A} + \hat{\boldsymbol{\alpha}}\mathbf{D} + \mathbf{B}^{*}\hat{\boldsymbol{\alpha}}\mathbf{D} \qquad (11)$$

Where:

$\mathbf{B}^{*}$ represents a matrix of total input coefficients with the input of fixed assets

$\mathbf{D}$ a matrix of direct holding coefficients of fixed asset. D is the submatrix of direct holding coefficients matrix $\mathbf{A}^{\mathbf{O}}$ that corresponds to the submatrix for fixed assets.

$\hat{\boldsymbol{\alpha}} = \{\alpha_i\}$, represents a diagonal matrix of depreciation rates of fixed assets.

Therefore we can get:

$$\mathbf{B}^*(\mathbf{I}-\mathbf{A}-\hat{\boldsymbol{\alpha}}\mathbf{D}) = \mathbf{A}+\hat{\boldsymbol{\alpha}}\mathbf{D} \qquad (12)$$

We can prove that the matrix $(\mathbf{I}-\mathbf{A}-\hat{\boldsymbol{\alpha}}\mathbf{D})$ is nonsingular and its inverse exists.

Consequently we have

$$\mathbf{B}^* = (\mathbf{I}-\mathbf{A}-\hat{\boldsymbol{\alpha}}\mathbf{D})^{-1} - \mathbf{I} \qquad (13)$$

It means that in above formula the matrix **A** is to be replaced by $\mathbf{A}+\hat{\boldsymbol{\alpha}}\mathbf{D}$, and similarly **B** by $(\mathbf{I}-\mathbf{A}-\hat{\boldsymbol{\alpha}}\mathbf{D})^{-1} - \mathbf{I}$. The total input coefficients $\mathbf{B}^*$ computed from (13) are obviously greater than **B**. For example: Based on the extended input-output table for the urban and rural economies of China in 1987, the total input coefficients of electricity to rice, coal, and metallurgical industries were, respectively, 0.01810, 0.08019, and 0.08626 by use of **B;** and those by use of the new equation $\mathbf{B}^*$ were, respectively, 0.02045, 0.09334, and 0.09475.

What does it imply for the basic accounting equations of input-output table? The new equations of the input-output table will be as follows

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \hat{\boldsymbol{\alpha}}\mathbf{D}\mathbf{x} + \mathbf{f}^* \qquad (14)$$

and we have

$$\mathbf{x} = (\mathbf{I}-\mathbf{A}-\hat{\boldsymbol{\alpha}}\mathbf{D})^{-1}\mathbf{f}^* \qquad (15)$$

Where

$\mathbf{f}^* = \mathbf{f} - \hat{\boldsymbol{\alpha}}\mathbf{D}\mathbf{x}$ represents vector of net final demand, which is equal to the vector of final demand minus vector of depreciation of fixed assets,

Under the following condition that vector of depreciation of fixed assets $\hat{\boldsymbol{\alpha}}\mathbf{D}\mathbf{x}$ reflects or approximately equals to the replacement of fixed assets, then $\mathbf{f}^*$ reflects the vector of net final demand, excluding replacement investment of fixed assets. In this case $\mathbf{f}^*$ would then include the net investments (gross investments minus the investment for replacement of fixed assets). Of course, if data are available with respect to such replacement investments, then we could define vector $\hat{\alpha}$ as diagonal vector of replacement rate of fixed assets. In this case it is assumed that the consumption of fixed assets reflects or approximately equals to the replacement of fixed assets[3].

2.4. Using an Extended Input-Output Model with Assets to Calculate Total Labor Consumption Coefficient and Others

Total labor consumption coefficient is the sum of direct and indirect labor consumption per unit product. It is a very important indicator to express social productivity for each sector. As we know in the common input-output analysis, if the direct labor input coefficients are given by the row vector $\mathbf{l}'$, the ith element of the row vector $\boldsymbol{\mu}' = \mathbf{l}'(\mathbf{I}-\mathbf{A})^{-1}$ gives the total amount of labor that is (directly and indirectly) required to satisfy one unit of final demand in sector i.

The above formula of total labor consumption coefficient does not include labor consumed by fixed assets. To overcome the problem, the new formula by the extended model with assets is $\mathbf{l}'(\mathbf{I}-\mathbf{A}-\hat{\boldsymbol{\alpha}}\mathbf{D})^{-1}$.

Similar results are obtained if the row vector with direct energy coefficients is replaced by a vector with direct energy consumption coefficients, direct service input coefficients, direct water input coefficients, direct input coefficients for employees' compensations, direct input coefficient of net indirect taxes, and others.

The above method could be used in many issues. For example, the traditional method of calculating total service intensities of different industries is $\mathbf{s}'(\mathbf{I}-\mathbf{A})^{-1}$ (Bhowmik, 2003). The new formula to calculate total service intensities is $(\mathbf{I}-\mathbf{A}-\hat{\boldsymbol{\alpha}}\mathbf{D})^{-1}$. The difference between the above two methods is that second one includes the indirect service input, contained in the fixed assets.

2.5. Using the Extended Input-output Model with Assets to Calculate Total Holding Coefficient of

[3] From comments of Dr. Erik Dietzenbacher.

Asset and Others

Direct holding coefficient of asset a_{ij}^{O} is the ratio of ith asset divided by the output of sector *j*. It indicates the holding intensity of ith asset by production sector j.

$$a_{ij}^{O} = W_{ij}^{O} / x_{j} \quad (16)$$

It can be written in matrix form

$$\mathbf{A}^{O} = \mathbf{W}^{O}\hat{\mathbf{x}}^{-1} \quad (17)$$

where:

$\mathbf{W}^{O}$ indicates intermediate asset matrix

The total holding coefficient of asset $\mathbf{B}^{O}$ can be calculated by two methods. The first one is:

$$\mathbf{B}^{O} = \mathbf{A}^{O}(\mathbf{I}-\mathbf{A})^{-1} \quad (18)$$

The second method for calculating the total holding coefficient matrix of asset follows:

$$\mathbf{B}^{O^{*}} = \mathbf{A}^{O}(\mathbf{I}-\mathbf{A}-\hat{\boldsymbol{\alpha}}\mathbf{D})^{-1} \quad (19)$$

The total holding coefficient matrix could be used to calculate total holding intensity of fixed assets, inventory, financial assets, employment, natural assets and others for unit of final demands. For example, we use total holding coefficient matrix of employment to estimate the increase in employment in the People's Republic of China in response to an increase in exports from China to United States.

2.6. *Dynamic Extended Input-output Model with Assets*[4]

Above we introduced the static extended input-output model with assets. In this part we will discuss the dynamic extended input-output model. The Leontief dynamic input-output model can be written as follows (Leontief, Chenery, Clark, Duesenberry, Ferguson, Grosse, A. P., Grosse, R. N., Holzman, Isard, & Kistin, 1953):

[4] We will discuss application of the dynamic extended I-O model in other paper.

$$\mathbf{x} - \mathbf{A}\mathbf{x} - \mathbf{C}\dot{\mathbf{x}} = \tilde{\mathbf{f}} \qquad \text{(in continuous form)} \qquad (20)$$

$$\mathbf{x}(t) - \mathbf{A}\mathbf{x}(t) - \mathbf{C}[\mathbf{x}(t+1) - \mathbf{x}(t)] = \tilde{\mathbf{f}} \qquad \text{(in discrete form)} \qquad (21)$$

where:

C is a matrix of capital coefficient

$\tilde{\mathbf{f}}$ is a column vector of net final demands excluding capital formation

$\dot{\mathbf{x}} = d\mathbf{x} / dt$

The time lag in the above models is one year. These models reflect the relationships between capital demand for increase in outputs in a later period (*t*+1 year) and products use in the current period (*t* year).

Two issues arise:

1) In order to expand production, not only more fixed assets and inventory, but also more labor, particularly skilled labor, are required.

As Schultz has indicated, humans are the determinant factor of production, and in order to develop production it is first required to raise people's cultural, scientific, and technological knowledge. He put forward an important conception of human capital, investment in increasing human capability, and also said that knowledge is the most powerful engine of production. Based on U.S. data, Schultz established that the contribution of human capital to profits is greater than that of physical capital (Schultz, 1961).

In the dynamic extended input-output model with assets, we must take into account the fact that it takes a longer time to train skilled labor than to prepare fixed assets and inventory. Therefore, future demand for labor for expanding production should be linked with current human capital investment. Then, we get a new dynamic extended input-output model reflecting the relationship between human capital demand for increase in outputs in later periods and input for training in the current period. We obtain the following model:

$$\mathbf{x} - \mathbf{A}\mathbf{x} - \mathbf{C}\dot{\mathbf{x}} - \mathbf{H}\dot{\mathbf{x}} = \tilde{\mathbf{f}} \quad (22)$$

where **H** is the matrix of human capital coefficient, which is necessary for increasing unit output in next period, and

$$\mathbf{H} = \mathbf{M}_L \mathbf{L} \quad (23)$$

where **L** is marginal labor force coefficient matrix and $\mathbf{M}_L$ is the input matrix for training the labor force. The discrete form of the above model is:

$$\mathbf{x}(t) - \mathbf{A}\mathbf{x}(t) - (\mathbf{C} + \mathbf{H})[\mathbf{x}(t+1) - \mathbf{x}(t)] = \tilde{\mathbf{f}}(t) \quad (24)$$

This dynamic model shows the functional relationship between uses of products in the current period and the needed skilled labor and capital for an increase in output in the next period. For simplicity’s sake, here we also assumed that the time lag is one year. If the time lag is more than one year, we can obtain a system of high-order-difference differential equations (in continuous form) or a system of high-order-difference equations (in discrete form).

Because most asset elements have time-lag problems similar to that of human capital formation, we can formulate the following dynamic extended input-output model with assets:

$$\mathbf{x} - \mathbf{A}\mathbf{x} - \mathbf{C}^{*}\dot{\mathbf{x}} = \tilde{\mathbf{f}} \qquad \text{(in continuous form)} \qquad (25)$$

$$\mathbf{x}(t) - \mathbf{A}\mathbf{x}(t) - \mathbf{C}^{*}[\mathbf{x}(t+1) - \mathbf{x}(t)] = \tilde{\mathbf{f}} \qquad \text{(in discrete form)} \qquad (26)$$

where $\mathbf{C}^{*}$ is the sum of matrix of marginal capital coefficient **C**, matrix of human capital coefficient **H,** and others.

2) Leontief's dynamic model does not include the requirement to cover consumption of fixed assets.

From Leontief's dynamic model, it can be seen that if production is not expanded—that is, if $\dot{\mathbf{x}}$ =0, or **x**(t+1)-**x**(t)=0—then investment is not needed; in the real world, however, gross capital formation is used not only to expand production, but also for maintenance, i.e. to cover the consumption of existing assets (see Table 4).

[TABLE 4 ABOUT HERE]

From Table 4 we can conclude that in China, Japan, and the United States the ratios of depreciation of fixed assets on gross capital formation are very high: 36.2% in China (1997), 72.4% in Japan (2000), and 70.3% in the United States (1990). In the last two countries, most gross capital formation is to cover the consumption of fixed assets. This ratio tends to increase over time. In Japan, it was 33.0% in 1960, 40.6% in 1980, 52.2% in 1990, and 72.4% in 2000. This should not be ignored. This is for us an additional motivation for extending the Leontief dynamic model as follows:

$$\mathbf{x} - \mathbf{A}\mathbf{x} - \hat{\boldsymbol{\alpha}}\mathbf{A}_{Cap}^{O}\mathbf{x} - \mathbf{C}\dot{\mathbf{x}} = \tilde{\mathbf{f}} \qquad (27)$$

where $\mathbf{A}_{Cap}^{O}$ indicates average capital coefficient matrix, and

$$\mathbf{A}_{Cap}^{O} = \mathbf{W}_{Cap}^{O}\hat{\mathbf{x}}^{-1} \tag{28}$$

where $\mathbf{W}_{Cap}^{O}$ is the matrix of intermediate capital assets. If we assume that the average capital coefficient is equal to the marginal capital coefficient, then $\mathbf{A}_{Cap}^{O}$ equals to **C**, and we have

$$\mathbf{x} - \mathbf{A}\mathbf{x} - \hat{\boldsymbol{\alpha}}\mathbf{C}\mathbf{x} - \mathbf{C}\dot{\mathbf{x}} = \tilde{\mathbf{f}} \tag{29}$$

We could get a dynamic model in discrete form as follows:

$$\mathbf{x}(t) - \mathbf{A}\mathbf{x}(t) - \hat{\boldsymbol{\alpha}}\mathbf{C}\mathbf{x}(t) - \mathbf{C}[\mathbf{x}(t+1) - \mathbf{x}(t)] = \tilde{\mathbf{f}}(t) \tag{30}$$

Because labor eventually retires and this has to be put in a dynamic model, we put forward an extended dynamic input-output model with assets on human capital as follows:

$$\mathbf{x} - \mathbf{A}\mathbf{x} - \hat{\boldsymbol{\alpha}}\mathbf{C}\mathbf{x} - \mathbf{C}\dot{\mathbf{x}} - \hat{\boldsymbol{\alpha}}_{H}\mathbf{H}\mathbf{x} - \mathbf{H}\dot{\mathbf{x}} = \tilde{\mathbf{f}} \tag{31}$$

where $\hat{\boldsymbol{\alpha}}_{H}$ is diagonal matrix of labor retirement coefficients. We have the model in discrete form:

$$\mathbf{x}(t) - \mathbf{A}\mathbf{x}(t) - (\hat{\boldsymbol{\alpha}}\mathbf{C} + \hat{\boldsymbol{\alpha}}_{H}\mathbf{H})\mathbf{x}(t) - (\mathbf{C} + \mathbf{H})[\mathbf{x}(t+1) - \mathbf{x}(t)] = \tilde{\mathbf{f}}(t) \tag{32}$$

Because consumption of most assets must be covered, we have the following dynamic extended input-output model:

$$\mathbf{x} - \mathbf{A}\mathbf{x} - \hat{\boldsymbol{\alpha}}^{*}\mathbf{C}^{*}\mathbf{x} - \mathbf{C}^{*}\dot{\mathbf{x}} = \tilde{\mathbf{f}} \tag{33}$$

where $\mathbf{C}^{*}$ and $\hat{\boldsymbol{\alpha}}^{*}$ are the asset coefficient matrix for all occupied elements and the diagonal matrix of consumption coefficient for all elements, respectively. The discrete form of the above model is:

$$\mathbf{x} - \mathbf{A}\mathbf{x} - \hat{\boldsymbol{\alpha}}^{*}\mathbf{C}^{*}\mathbf{x}(t) - \mathbf{C}^{*}(\mathbf{x}(t+1) - \mathbf{x}(t)) = \tilde{\mathbf{f}}(t) \tag{34}$$

3. Yearly National Grain Output Prediction for China 1980–2004

Up to the present, the extended input-output model with assets has been used in China for grain output prediction (Chen, Pan, Yang, 2001); to study the key sectors of Chinese economic development in urban and rural economies, to calculate the amount of surplus labor (unemployment) in rural areas (Chen, Cao, Xue & Lu, 1992); to predict, from a 1987 base, economic development indicators in Xinjiang in 1990, 1995, and 2000 and to study relations between Xinjiang and other regions of China; to study Shanxi Water Resource (Chen, 2000); to study water conservancy for the nine major river basins in China (Chen, Yang and Xu, 2002); to study Township and Village Enterprises (TVE) in China, in particular their coal and energy utilization and environmental pollution (Yang, 2001). We will focus below on the example of grain production.

3.1. Three Approaches to Predicting Grain Output

Feeding 1.2 billion citizens is a critical issue for China. At the end of 1970s, the former Rural Development Research Center under the State Council requested that the Chinese Academy of Sciences forecast national grain output with two preliminary requirements. First, the prediction lead time should be half a year prior to harvest season so as to plan storage, imports, exports and grain consumption as early as possible. Second, the prediction should be highly accurate, with an error rate lower than 3%.

Three main approaches to predicting cereal output used worldwide are:

a. Meteorological approach, in which the main variables are temperature, sunshine, rainfall, and so on.

b. Statistical dynamic simulation approach to studying relationships between grain yield and effects of environmental factors such as temperature, sunshine and concentration of CO_2 on crop photosynthesis, transpiration, respiration, solid material and seed formation.

c. Remote sensing approach.

These approaches normally have a 5–10% error rate compared to reported output and a two-month prediction lead time. For example, Williams, Joynt & Mecormick (1975) adopted the meteorological approach to predicting Canadian prairie crop district cereal yields at the end of June, two months prior to harvest, with an error rate of 8.8%, 4.7%, and 5.4% for wheat, oats, and barley, respectively. Hayes and Decker (1996) used the Vegetation Condition Index derived from NOAA/AVHRR (National Oceanographic and Atmospheric Administration/Advanced Very High Resolution Radiometer) satellite data since 1982 to estimate maize production in corn belt of the United States of America. The forecasting results from 1985 to 1992 had a lead time of about two months and a 4.9% average error rate over the eight years, of which the rate was below 5% for four years, 5–10% for three years, and higher than 10% for one year. (As we shall see later, however, remote sensing provides the most accurate information about cultivated land which we can use in our own predictions).

These approaches could not, however, satisfy the above two requirements of the Chinese government of prediction lead time and accuracy.

3.2. Systematic Integrated Approach

The above approaches predict grain output mainly by meteorological factors. Up to the present it has been extremely difficult to predict the weather—temperature, sunshine, rainfall, and so on—two to three months away. In the late 1970s we suggested predicting grain output mainly by factor input and assets, held and used, and presented a systematic integrated approach using the key methods of an extended input-output model with assets, nonlinear variable coefficient forecasting equations, and minimum sum of absolute value technique. Our theoretical assumptions were as follows:

Agricultural production is a typical complex system with a multi-level structure. There are complex interrelations between its subsystems and between the system and the external environment, and the characteristics of the system are nonlinear, stochastic, and dynamic.

Grain output is affected by different types of factors: 1) social, economic, and production technology factors, such as agricultural policies, education level of peasants, prices, fertilizers, improved **seed** varieties, irrigation, machinery; 2) natural factors such as meteorological and non-meteorological factors; 3) others. Only when we consider all these factors can we effectively increase the accuracy of prediction of grain output.

The first set of factors, i.e. social, economic, and production technology factors, however, play the critical role in increasing grain output. While the grain output of China in 1952 was 163.9 million tons, in 1998 it was 512.3 million tons. Over 46 years, the changes in China's meteorology were not striking to the same extent. Therefore, the increase in grain output **is more likely to have** been caused mainly by changes in social, economic, and production technology factors. These factors not only determine the long-term trend of grain production but are also a major cause of yearly fluctuations in grain production. There are two periods of significant variation in grain output since 1949: a drastic decline from 1959 to 1961, and a sharp increase from 1981 to 1984, both of which were mainly caused by social, political, and economic factors.

The systematic integrated approach we proposed is based on synthetic method and multi-equations forecasting model. In the approach we use extended input-output model with assets, nonlinear forecasting equations and minimum sum of absolute value technique.

3.3. Extended Input-output Model with Assets on Chinese Agriculture

With the support of the former Rural Development Research Center of the State Council of China, the Chinese Academy of Sciences and National Natural Science Foundation of China, the Institute of Systems Science, we constructed an extended input-output table with assets in agriculture for 1982 (Chen, Hao & Xue, 1991), 1984, 1987 (Chen, Cao, Xue & Lu, 1992), 1992, and 1997. In other years, in order to predict output of grain, cotton, and oil-bearing crops we did some updating calculations on the basis of these extended input-output tables.

The 1997 extended input-output table with assets on agriculture was constructed on the basis of the 1997 national input-output table, compiled by the National Bureau of Statistics. For the purpose of grain output prediction, in our extended input-output table with assets, the agriculture industry was divided into the following 12 sectors: rice, wheat, corn, other grain, oil-bearing crops, cotton, vegetables, other farm crops, forestry, livestock and livestock products, fishery, and other agriculture. In China the term “grain” is the sum of rice, wheat, corn and other grain. Some sectors, including grain, cotton, and oil-bearing crops, and some important agricultural inputs, such as fertilizer and electricity, are measured not only in value, but also in physical units. There are eight items in the asset part: sown area, cultivated land, irrigated area, labor, agricultural fixed assets, total power of agricultural machinery, large and medium tractors, and mini-tractors. The assets part of agriculture in the 1997 extended input-output table with assets is shown in Table 5.

[TABLE 5 ABOUT HERE]

Land and water play a very important role in grain production. The figures for cultivated land prior and including 1995, published by the National Bureau of Statistics (NBS) of China, however, were underestimated and cannot be used in our calculation. To date, we have only reliable figures on cultivated land for 1996 and 2001, published by the NBS on the basis of the remote sensing approach. In our grain output prediction, sown area of crops is a very important indicator. Grain output is a function of the area sown in grain and grain yield. **Therefore, if we had not taken into consideration this asset, our predictions would necessarily been way off the mark.** The main cause of the sudden decline in grain output from 1999 to 2003 is the sharp drop of area sown in grain (see Table 6).

[TABLE 6 ABOUT HERE]

From Table 6 we find that from 1998 to 2003 grain output in China dropped very quickly, from 512.3 million tons to 430.7 million tons, or 15.9%. Areas sown in grain over the same period fell from 113.787 million hectares to 99.410 million hectares, a drop of 12.8%, while grain yield decreased by 3.8%. Thus, the sharp drop in Chinese grain output from 1998 to 2003 was caused mainly by the decline in sown area.

Using data in the asset part of our extended input-output model, we calculate many important indicators, such as consumption of chemical fertilizer and electricity per hectare of sown area, fixed assets per hectare of sown area, ratio of irrigated area to cultivated area, labor per hectare, total power of agricultural machinery per hectare, tractors per hectare, ratio of areas covered by natural disasters to total sown areas, and ratio of total areas affected by natural disasters (natural disasters include flood, drought, wind, hail and frost, etc.) to total areas covered by natural disaster. In particular, we use the extended input-output model with assets to calculate the total income per *mu* of sown area (1 hectare is equal to 15 *mu*) for grain and other important farm crops (see Table 7), net income per workday, and profit rate of capital. Since 1981 China's grain output variation has had a close relationship with the variation of net income of grain. Because the net income status of grain directly influences the quantities of factor inputs and holding of asset in grain production, the net income of the previous year has a significant linear correlation with the grain output of the current year.

[TABLE 7 ABOUT HERE]

According to our calculation and forecasting, the net income per *mu* of grain crops in 2004 will rise quickly and once again to a higher level than 1998. Using systematic integrated approach, in April of 2004, we predicted and reported that grain output would rise and China would have a good harvest in 2004. Using the extended input-output model with assets, the total consumption coefficients of electricity, oil, and chemical fertilizer by grain crops can also be precisely calculated. For example, the direct input of electricity for wheat was 68.1 kilowatts per ton; using traditional formula of **B**, total consumption of electricity for wheat was 235.4 kilowatts per ton; using formula (15), it was 268.6 kilowatts per ton. These results are important for our grain output prediction.

3.4. Nonlinear Forecasting Equation with the Consideration of Diminishing Return

In fact, functional relationships between input and output, and between assets and output, are usually nonlinear. For example, the effect of fertilizer on grain yield follows the law of diminishing return to scale. Figure 1 shows that marginal product and average product per kg of chemical fertilizer sharply decreases with increased consumption of chemical fertilizer per *mu*. To improve forecasting accuracy, it is therefore necessary to construct nonlinear forecasting equations.

[FIGURE 1 ABOUT HERE]

We have so far established 20 forecasting equations on grain yield with a high degree of accuracy. These equations include different variables. Since the effect of fertilizers follows the law of diminishing returns, it is shown as a nonlinear coefficient in the equations, for example:[5]

$$\begin{aligned}\hat{Y} = {} & 62.27441 + 10.41246\mathrm{D} - 61.02954\mathrm{X}_1 + 1.44660\mathrm{X}_2 + \\ & (10.3210) \quad (3.8869) \quad (-3.8095) \quad (6.8073) \\ & + 1.95153[(6.95e^{-0.0391179154X_3} + 1.1) - (1.55^{0.02X_3})]\mathrm{X}_3 + \\ & (18.2190) \\ & + 0.18578\mathrm{X}_4 + \mathrm{CA} \\ & (1.9588) \\ & \mathrm{R}^2 = 0.9945; \quad \mathrm{F} = 1583; \quad \mathrm{N} = 50\,(1952 - 2001)\end{aligned} \tag{35}$$

where:

$\hat{Y}$: estimated grain yield per *mu* annually

D: annual policy dummy variable (*D*= -1 in case of negative agricultural policy such as which resulted in the extensive loss of grain output during 1959–1961)

X_1: ratio of areas covered by natural disasters on total sown areas

X_2: ratio of irrigated area on cultivated area

X_3: chemical fertilizer input per *mu*

X_4: net income of grain per *mu* of the preceding year

CA: adjusted item

The above equation has the higher F value (F = 1583, R^2 = 0.9945) and the reasonable t-test values of fertilizer terms with an exponential form.

The nonlinear items of chemical and traditional fertilizer are calculated from historical data on fertilizer inputs and yield increments, in particular statistically tested the data of yield increments related to the increased chemical fertilizer inputs in some regions of China.

It is found in equation (35) that the t-test value of chemical fertilizer item is 18.2190. If we did not consider the diminishing return, the t-test value would be only 0.4538; in other words, there is no significant linear correlation between China's grain yield and chemical fertilizer input.

[6] Data in parenthesis are values of t-test.

3.5. Minimum Sum of Absolute Value Technique

In regression analysis, the parameter β is normally estimated by the least square (LS) method:

$$\min\ Z = \sum (\hat{Y}_i - Y_i)^2 \qquad (36)$$

The drawback is that the least square treatment will move the fitted curve to some exceptional points, thus reducing forecasting accuracy. One of the modifications is to minimize the sum of absolute value of errors between estimated and actual yields:

$$\min\ Z' = \sum |\hat{Y}_i - Y_i| \qquad (37)$$

Equation (41) can be solved by the linear programming method. The model is as follows:[6]

$$\begin{cases} \min\ \sum (u_i + v_i) \\ \beta_0 + \beta_1 X_{1i} + \cdots + \beta_k X_{ki} - Y_i = u_i - v_i \qquad i = 1,\ 2,\ \cdots,\ \text{n} \\ u_i \geq 0, \quad v_i \geq 0 \end{cases} \qquad (38)$$

Following is the modified result of equation (39) by minimum sum of absolute value approach:

$$\begin{aligned} \hat{Y} &= 67.08731 + 11.22152D - 96.38615X_1 + 1.29494X_2 + \\ &+ 2.01756[(6.95\text{e}^{-0.0391179154\text{X}_3} + 1.1) - (1.55^{0.02\text{X}_3})]\text{X}_3 + 0.19468X_4 + CA \end{aligned} \qquad (39)$$

This equation reduced the average error of grain yield per *mu* from 3.688 kg to 3.551 kg, and the average error rate (average error over average yield) from 2.02% to 1.94%. The technique also marginally improves the accuracy of the grain output prediction.

In order to increase forecasting accuracy, our research team also conducts field studies in the 13 main grain-production provinces in China in March and April of every year. We consult local and national experts and gather their views (using a Delphi method) and collect other related information, do technical and economic analysis, and then modify the results derived from forecasting equations. In particular, we modify the adjusted item *CA* based on data from experimental regions in response to unprecedented factors such as the Household Contract Responsibility Policy System and new improved grain varieties.

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[6] It can be simply proved that $u_i v_i = 0$, if optimal solution exists.

Besides, we use formulae (13) and (19) to calculate total requirements of chemical fertilizer (electricity, diesel oil, etc.) and total requirements of various assets (fixed assets, land, water resource, etc.), respectively. If current qualities of fertilizer and assets are not assured, the predicated amount of grain output will be decreased.

From above description we could find that in systematic integrated approach mainly used three methods: econometrics, extended input-output model with asset and mathematic programming. In the approach extended input-output model is the basis to use other two methods. Particularly, net income per mu of grain crops, which is calculated by the extended input-output model, plays a key role in the grain output prediction. The assets which listed in the extended input-output model are prerequisite and constraints for the grain production. Three methods are used together. As Richard Stone said: “The development of the I/O model seems to be leading in direction which its I/O core is becoming less and less discernible” (Stone, 1984).

3.6. Application and Evaluation

This approach has been successfully used in China since 1980. Every year at the beginning of May, we send a report predicting national grain output to government agencies and top leaders of China. From 1980 to 2003 the main results are as follows: Predicted bumper, average, and poor harvests are correct every year. The prediction lead-time is more than half a year. Since 70% of the grain is reaped in the fall and the harvest is over in November, a forecasting report at the end of April provides government agencies with enough time to arrange for storage, imports, exports and grain consumption. The forecasting accuracy was acceptable (under 3% error) for 19 years out of 23. Over the period, error rates have been below 1% for eight years, 1–2% for six years, 2–3% for five years, 3–5% for two years, and 5–8% for two years. Overall, the average error rate over 23 years is only 1.9% compared to statistical reports from sample surveys.

This forecasting has supported some important policy decisions. Given the predicted bumper harvests of 1996, 1997, and 1998, the Chinese government and the China Agricultural Bank gave financial aid to grain enterprises to expand their storage capacities. The relevant departments of the Chinese government, such as the State Grain Administration, the Ministry of Agriculture, the Research Department of State Council, and the National Development and Reform Commission paid much attention to our predictions. For example, State Grain Administration wrote in the documents: "lead time of prediction is very long", "forecasting is accurate and prediction on the grain situation is correct", "supply very important reference to our Administration and others for policy-making on grain supply and sale, grain imports and exports etc." [7]

9. Conclusions

The holding and using of assets is a prerequisite for production. Production in modern society cannot occur without appropriate quantities of fixed assets, natural resources, labor, and financial assets. The scale of production and the economic benefits derived from the output also partially depend on the quality and quantity of production factors and assets. The output is obtained not only by factor input, but also by assets held and used. The input-output model extended to assets is a very important tool for analyzing the relationships between sectors.

Our contribution has been to formally incorporate assets into the input-output table and establish a corresponding model system to calculate total input coefficient and related indexes, for example, total coefficient of fixed asset. Most important, we have successfully applied this method in predicting China's grain output from 1980 to 2004.

In the 1980s, when we wanted to predict annual grain output in China, we discovered it was necessary to include assets in the input-output model. Since 1987, the model has been used in China to analyze many issues. Most of published papers and books are in Chinese. Therefore most input-output analysts in the world are as yet unaware of this extended input-output model to assets, or its applications.

[7] The work was awarded with the First Prize for Operational Research in Development in the 15th IFORS Triennial Conference in 1999 (Chen, Pan & Yang, 1999). It was also awarded with the Outstanding Science and Technology achievement Prize of the Chinese Academy of Sciences in 2003.

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Table 1. Chinese national input-output tables, 1973–2000

Year	Type of table	Number of sectors/products	Comments
1973	Physical	61	First national table (experimental)
1979	Physical	61	1973 table updated by RAS method
	Value	21	MBS table
1981	Physical	146	MBS table
	Value	26	MBS table
1983	Physical	146	1981 updated physical table by RAS method
	Value	22	1981 updated value table by RAS method

1987	Value	117	First table based on special input-output surveys
1990	Value	33	1987 updated table by RAS method
1992	Physical	151	Tables based on special input-output surveys
	Value	118	
1995	Value	33	1992 updated table by RAS method
1997	Value	124	Table based on special input-output surveys
2000	Value	40	1997 updated table by RAS method

Source: Authors and Karen R. Polenske (Chen, 1989; Polenske & Chen, 1991)

Note: MBS denotes Material Balance System.

Table 2. Extended input-output table with assets

<table>
<tr><th colspan="3" rowspan="2"></th><th colspan="4">Intermediate demand and intermediate asset</th><th colspan="5">Final demand and final asset</th><th rowspan="2">Gross output and gross assets</th></tr>
<tr><th>Sector 1</th><th>Sector 2</th><th>··</th><th>Sector n</th><th>Consum-ption</th><th>Fixed capital formation
1, 2 ··· n</th><th>Changes in inventories
1, 2 ··· n</th><th>Exports</th><th>Imports</th></tr>
<tr><td rowspan="3">FACTOR INPUT</td><td>Inter-mediate input</td><td>Sector 1
……
Sector n</td><td colspan="4">$\mathbf{W}$</td><td colspan="5">$\mathbf{F}$</td><td>$\mathbf{x}$</td></tr>
<tr><td>Primary Input</td><td>Depreciation of fixed assets
Compensation of employees
Net indirect taxes
Operating surplus</td><td colspan="4">$\mathbf{V}$</td><td colspan="5"></td><td></td></tr>
<tr><td colspan="2">Total input</td><td colspan="4">$\mathbf{x}'$</td><td colspan="5"></td><td></td></tr>
<tr><td rowspan="3">HOLDING</td><td>Fixed Assets</td><td>Sector 1
……
Sector n</td><td colspan="4" rowspan="3">$\mathbf{W}^o$</td><td colspan="5" rowspan="3">$\mathbf{F}^o$</td><td rowspan="3">$\mathbf{x}^o$</td></tr>
<tr><td>Inventory</td><td>Sector 1
……
Sector n</td></tr>
<tr><td>Financial Assets</td><td>Currency
Deposits
Loans
Shares
Security other than shares
Advances and trade credits
Others</td></tr>
</table>

A S S E T	Labor	Illiterate Primary Junior secondary school Senior secondary school College Higher level
	Natural Resources	Land Water resource Subsoil assets Forest Others
	Intangible Assets	Patent Trade mark Others

Table 3. A simplified form of the extended IO table with assets

		Intermediate demand	Final demand	Gross outputs
INPUT	Intermediate inputs	$\mathbf{W}$	$\mathbf{F}$	$\mathbf{X}$
	Primary inputs	$\mathbf{V}$		
	Total inputs	$\mathbf{x}'$		
		Intermediate assets	Final assets	Gross assets
ASSET	Fixed assets			
	Circulating assets	$\mathbf{W}^{0}$	$\mathbf{F}^{0}$	$\mathbf{x}^{0}$
	Labor			

Note: In China circulating assets includes financial assets in short term and inventory. The total circulating assets is estimated by the National Bureau of Statistics in the national economic accounts. In statistical yearbook, published by the National Bureau of Statistics yearly, there are also figures of circulating assets of industry by sectors.

Table 4. The proportion of depreciation of fixed assets to gross capital formation in China, Japan and the United States

Unit: 1 billion respective currency units at current prices

	Gross capital formation		Depreciation of fixed assets	Ratio of depreciation on gross fixed asset formation (%)	Ratio of depreciation on gross capital formation (%)
	Total	Gross fixed asset formation			
China					
1981	151.7	118.9	41.1	34.6	27.1
1987	437.3	380.3	120.2	31.6	27.5
1992	963.8	831.7	353.7	42.5	36.7
1997	2,845.7	2,515.4	1,031.2	41.0	36.2
Japan					
1960	5,292.7	4,658.9	1,746.7	37.5	33.0
1970	28,617.5	26,257.9	9,531.2	36.3	33.3
1980	77,846.5	73,943.5	31,640.9	42.8	40.6
1985	88,049.9	86,558.2	44,330.5	51.2	50.3
1990	139,054.0	138,727.0	72,654.0	52.4	52.2
1995	141,782.7	139,721.7	80,800.7	57.8	57.0
2000	130,076.4	129,807.4	94,179.0	72.6	72.4
U.S.					
1970	180.0		106.0		58.9
1980	540.0		365.0		67.6
1990	943.0		663.0		70.3

*Sources: National Bureau of Statistics and State Planning Commission (1984); National Bureau of Statistics (1991,1996, 1999a); Kimio Uno (1989); Japan Statistical Bureau (2003); and OECD (200*3).

Table 5. Asset **holding part** of agriculture in the 1997 extended IO table of China

Items	Crop cultivation										Forestry	Livestock and livestock products	Fishery	Other agri-culture	Total
	Grain crops					Oil-bearing crops	Cotton	Vege-tables	Other farm crops	Sub-total					
	Rice	Wheat	Corn	Other grain	Sub-total										
Total sown area (1,000 ha)	31,765	30,057	23,775	27,315	112,912	12381	4,491	11,288	12,897	153,969					153,969
Area of cultivated land (1,000 ha)	23,059	25,385	21,080	24,345	93,869	11,805	3,638	7,870	12,376	129,558					129,558
Irrigated area (1,000 ha)	15,257	10,020	5,706	4,019	35,002	2,830	3,235	7,435	2,737	51,239					51,239
Labor force (million persons)	40.1	26.0	26.8	15.2	108.1	14.0	12.4	49.9	11.0	195.2	14.4	93.2	31.2	14.4	348.4
Total agricultural fixed assets (billion RMB)	92.8	77.2	49.2	9.5	228.7	18.5	12.6	90.5	28.2	378.5	29.0	191.4	94.9	28.8	722.6
Total power of agricultural machinery (million kW)	49.5	79.6	41.8	13.4	184.4	6.1	5.9	5.5	3.9	205.9	36.7	92.1	52.3	33.2	420.2
Large and medium tractors (1,000 units)	22.7	255.6	219.1	71.4	568.7	18.9	18.3	16.9	12.1	635.0	30.1	14.5	1.5	8.0	689.1
Mini-tractors (1,000 units)	2323	3737	1964	631	8654	288	279	256	185	9663	457	221	23	122	10485

Sources: National Bureau of Statistics (1998, 1999a, 1999b); National Development and Planning Commission, National Economic and Trade Commission, Ministry of Agriculture, National Bureau of Forestry, National Bureau of Light Industry, National Bureau of Tobacco and General Cooperative of Supply and Marketing of China, Ministry of Foreign Trade and Cooperation (eds) (1998). In the last source, there are many important figures per mu of sown area by major crops, for example, data on fixed assets depreciation cost, labor, cost of plows, cost of irrigation, taxes, benefits and others. These data are collected from surveys of 60,000 rural households in 1,300 counties in China.

Note: hectare is abbreviated as ha.

Table 6. Total sown area of farm crops, grain output, and grain yields in China, 1998⁻2003

Year	Total sown area in farm crops (1,000 ha)	of which									Grain Output (million tons)	Grain yields (kg/ha)
		Grain crops	Of which				Oil-bearing crops	Cotton	Vege-tables	Other farm crops		
			Rice	Wheat	Corn	Other grain crops						
1998	155,706	113,787	31,214	29,774	25,239	27,560	12,919	4,459	12,293	12,248	512.295	4502.2
1999	156,373	113,161	31,284	28,855	25,904	27,118	13,906	3,726	13,347	12,233	508.386	4492.6
2000	156,300	108,463	29,962	26,653	23,056	28,792	15,400	4,041	15,237	13,159	462.175	4261.2
2001	155,708	106,080	28,812	24,664	24,282	28,322	14,631	4,810	16,402	13,785	452.637	4266.9
2002	154,636	103,891	28,202	23,908	24,634	27,147	14,766	4,184	17,353	14,442	457.058	4399.4
2003	152,415	99,410	26,508	21,997	24,068	26,837	14,990	5,111	17,954	14,950	430.670	4332.3

Sources: Rural Social and Economic Survey Team of National Statistical Bureau of China (1999, 2000, 2001, 2002, 2003):. The 2003 figures are from Ministry of Agriculture of China.

Note: hectare is abbreviated as ha.

Table 7. Net income per *mu** of grain crops, oil-bearing crops, and cotton, 1998–2003

Unit: RMB per *mu* of sown area

	Grain			Oil-bearing crops		Cotton
	Rice	Wheat	Corn	Peanuts	Rapeseed	
1998	347.77	122.51	245.41	328.72	117.39	581.22
1999	260.50	110.64	157.62	274.66	95.84	292.65
2000	228.62	68.85	140.29	268.54	87.10	547.18
2001	263.75	95.46	216.08	244.66	103.08	402.97
2002	264.49	93.40	204.38	341.93	103.76	609.69
2003	301.77	117.25	235.67	358.20	172.50	844.06
2004 (projection)	369.57	192.35	271.07	371.70	232.20	597.06

Sources: Department of Price, National Development and Reform Commission (2002, 2003, & 2004); National Development and Planning Commission, National Economic and Trade Commission, Ministry of Agriculture, National Bureau of Forestry, National Bureau of Light Industry, National Bureau of Tobacco and General Cooperative of Supply and Marketing of China, Ministry of Foreign Trade and Cooperation (eds) (1998, 1999, 2000, 2001). The 2004 figures are estimated by authors on the basis of surveys in 13 provinces.

Notes: Net income of each crop equals the difference between gross output value and the sum of all costs which include all intermediate input, depreciation of fixed assets, taxes, and other costs of the crop.

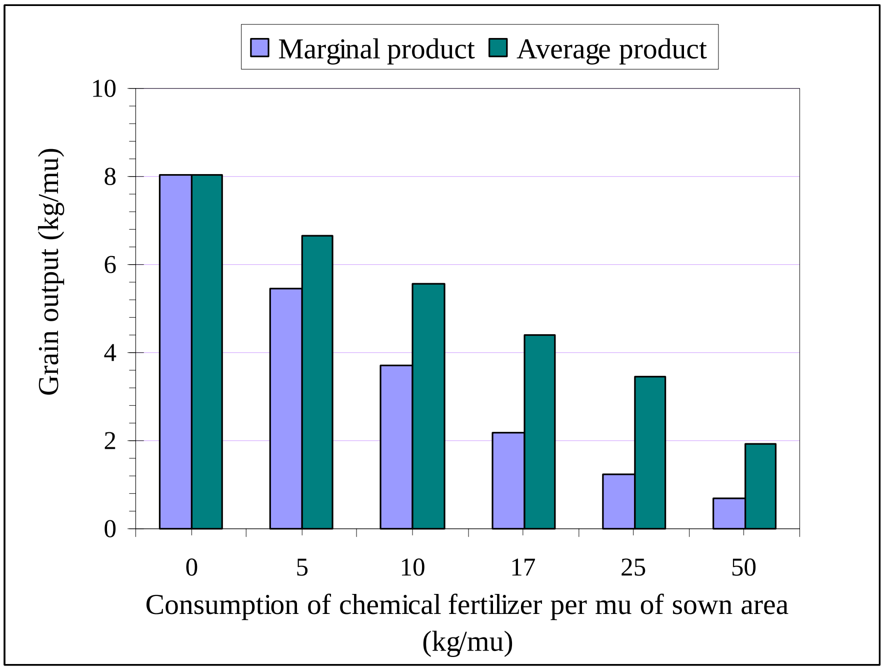

Figure 1. Marginal product and average product per kg of chemical fertilizer in China