Capital Stock Measurement of Research and Development of Chinese Manufacturing Industries

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Capital Stock Measurement of Research and Development of Chinese Manufacturing Industries

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Abstract: The Chinese System of National Accounts 2016 (CSNA2016) revises the accounting boundary and the classification of the gross fixed capital formation. Research and Development (R&D) expenditures that bring economic benefits to their owners are included in the gross fixed capital formation. This paper establishes an R&D expenditure capitalized framework in line with the System of National Accounts 2008 and measures R&D investment and capital stock of 26 Chinese manufacturing industries from 1990 – 2016. This can provide data supporting for analyzing fundamental and key economic issues of intangible assets such as productivity and the return to capital of Chinese manufacturing industries. The results show that ① R&D investment is an exact indicator for R&D capital stock measurement. R&D capital stock of each industry will be overestimated if directly use industrial R&D expenditures as the R&D investment. ②The constructed R&D investment price index is validated by the robustness test, indicating that the urban consumer price index to deflate R&D wage price index is effective. ③ The R&D strength of Chinese industries has been continuously growing. The proportion of the R&D capital stock of the manufacturing industry to the national one has increased from 35.33% in 1990 to 67.75% in 2016. The annual average growth rate of the R&D capital stock in the high-tech manufacturing industry is as high as 20% ~ 22%, which greatly supporting and driving the quality-improving and efficiency-enhancing and transformation and upgrading of China's economy.

Keywords: Research and Development Capitalization; Capital Stock; Manufacturing Industries

1. Introduction

At the end of the 20th century, under the impetus of the reform and opening up policy, China has accelerated its industrialization process and became a "world factory" by virtue of its comparative advantages in resources such as land and labor, and the open market environment. In recent years, the shortage of land and resources, the rise of labor costs, and the lag in technological innovation have led to a serious weakening of the competitive advantages of China's manufacturing industry. "Made in China 2025" is the first ten-year action plan for China to implement the strategy of manufacturing powerhouse. It has designed a plan for the transformation and upgrading of China's manufacturing industry, and promoted "Made in China" to "Intelligent Manufacturing in China". R&D is the main way to advance technology. R&D is a creative activity for increasing the knowledge inventory system and uses knowledge stock to explore and develop new products – including improving the version and quality of existing products, or exploring and developing new and more efficient production processes (European Commission, et al. 2009). By 2016, China's manufacturing R&D expenditures reached 1.06 trillion Yuan, and its proportion of internal expenditure of R&D funds of the whole society[①] increased from 38.50% in 1990 to 67.49% in 2016, indicating that China's manufacturing R&D investment is increasing, but R&D expenditure cannot portray the level of R&D strength in China's manufacturing industry.

In empirical research, as an important indicator to measure the level of R&D innovation accumulation, R&D capital stock can reflect the level of R&D strength of China's manufacturing industry. In 2017, the National Bureau of Statistics of China released a new version of CSNA2016 The new accounting system incorporates R&D, an intellectual property product, into the scope of fixed assets, and adjusts the R&D expenditure accounting method. R&D expenditures that bring economic benefits to the owner are no longer used as intermediate inputs and is included in total domestic production (GDP) as fixed capital formation, which provides the basis for accounting for R&D capital stock accounting.

Since the official agency did not publicly release R&D capital investment data, the early researches on the R&D capital stock measurement of manufacturing industry directly used R&D expenditures of various industries as R&D investment, used the Perpetual Inventory Method (PIM), which is firstly proposed by Professor Yale University Goldsmith (1951) and used to calculate physical capital, to measure the R&D capital stock. For example, Hall and Mairesse (1995) use the PIM method to measure the R&D capital stock of 351 manufacturing companies in France, and explore their relationship with productivity; Higón (2007) uses the PIM method to measure the R&D stock of eight major manufacturing industries in the UK, and explores the impact of R&D spillovers on productivity; Wang J (2009) uses the PIM method to measure the R&D capital stock of 28 manufacturing industries in China in 1998-2005. However, R&D capital does not wear or wear as much as physical capital, and its depreciation occurs as an outdated production process or product. The R&D capital stock accounting method needs to be adjusted.

Addressing the characteristics of a short cycle and fast depreciation of R&D assets, Harvard professor Zvi Griliches (1973) developed the R&D capital stock measurement method. He used the R&D expenditure lagged for i periods as the R&D investment to calculate R&D capital stock (Griliches, 1979; 1980), which has been widely used in R&D capital stock measurement research. Goto A and Suzuki K (1989) use the Griliches method to measure the R&D stock capital in Japan's manufacturing industry, explore the technology spillover effects of R&D in the

[①]The internal expenditure of R&D funds of the whole society includes R&D expenditure internal expenditures of enterprises, institutions of research and development institutions, institutions of higher learning and other enterprises with relatively R&D activities in the national economy.

manufacturing industries, and conclude that the R&D supply industry has positive externalities for the productivity growth of downstream industries. Hu, et al. (2005) uses the Griliches method to measure the R&D capital stock of 29 large and medium-sized manufacturing enterprises in China from 1995 to 1999; Wu Y (2006) uses the Griliches method to calculate the R&D capital stock at China's industrial-level from 1993 to 2002. However, due to the difficulty in estimating the lag period and conversion rate in the Griliches method, in practice, countries generally do not adopt this method.

Based on Goldsmith's PIM method, the Bureau of Economic Analysis (BEA) of the US Department of Commerce established an R&D capital stock accounting method (referred to as the BEA method) different from Griliches. Compared with the Griliches method, the BEA method capitalizes the R&D expenditure and obtains the R&D investment sequence, which is more reasonable at the theoretical level. Secondly, the R&D investment in the middle of the current year is depreciated, indicating that part of the R&D investment in the current period has formed capital stock (Sliker, 2007), which is more operable. BEA built the R&D Capital Satellite Account and conducted in-depth discussions on key issues such as R&D depreciation rate calculation and R&D asset price index construction, providing method guidance for R&D capital stock accounting, and providing detailed R&D capital related data for enterprises and government departments[①].

In 2016, with the latest results of the GDP after R&D capitalization announced by the National Bureau of Statistics of China, relevant experts have conducted in-depth research on issues about China's R&D capitalization accounting. Jiang Y and Sun F (2016) converts R&D expenditure into R&D investment and measures China's R&D capital stock from 1952 to 2014. Gao M (2017) put forward her understanding and suggestions on the capitalization of research and development according to the principle of national economic accounting. Wang Y and Wang C (2018) put forward the capitalization accounting framework for R&D expenditures and used the BEA method to measure the R&D capital stock of eight major industry sectors in China. However, the existing researches on the measurement of R&D capital stock in China’s manufacturing industries still uses the R&D expenditures of various industries as the investment sequence to measure the capital stock, resulting in the calculation results have the following disadvantages: (1) not being internationally comparable, the United States, the European Union, etc. use capitalized R&D investment to calculate capital stock; (2) there is a problem of repeated calculation, because internal expenses of R&D funds include personnel labor costs, and in the measurement of productivity, labor input includes R&D personnel labor costs.

The manufacturing industry plays an important role in the economic development of various

[①] https://www.bea.gov/national/newinnovation.htm。

countries and is the focus and research object of China's R&D capital stock calculation. Based on SNA2008's GDP accounting platform, this paper uses the BEA method to calculate the R&D capital stock of 26 manufacturing industries in China from 1990 to 2016 after the capitalization of R&D expenditures in the manufacturing industries. This helps to understand the R&D strength and international competitiveness of China's manufacturing industry and provides internationally comparable data support for analyzing the productivity and return on capital of intangible assets in the manufacturing industry.

2. Conceptual Framework

The measurement of R&D capital stock is a process of accumulating R&D fixed capital formation (or R&D investment) in each period and deducting the R&D capital consumption in each period. Different from the physical capital stock measurement: R&D expenditures should be capitalized as R&D investment sequences at first. Then R&D investment in each period is accumulated into R&D capital stocks using BEA method rather than PIM, measuring R&D initial capital stock, R&D asset price index and its depreciation rate (Figure 1).

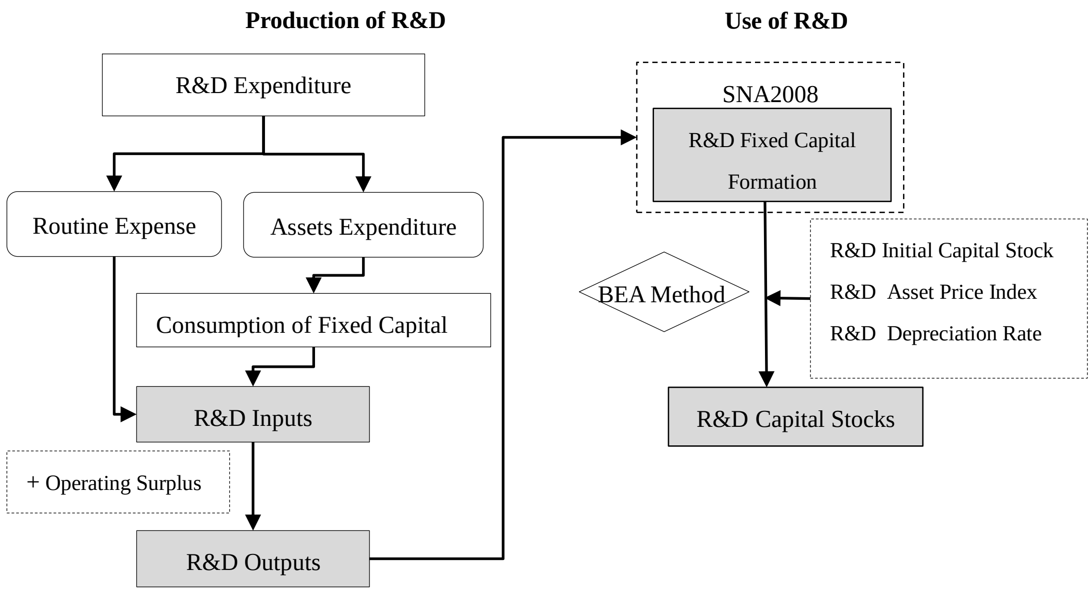

Figure 1 R&D Capital Stock Measurement Framework

2.1 Capitalization Process of the Intramural Expenditure on R&D

The main concepts involved in the capitalization process of R&D expenditure include **the** intramural expenditure on R&D, R&D input, R&D output, and R&D fixed capital formation. The intramural expenditure on R&D is the actual expenditure of the unit investigated used for its internal R&D activities in the reporting year; based on the accrual basis, R&D expenditure recorded by the cash basis are converted R&D input; R&D output represents the value of R&D

outcome; R&D output used is considered R&D fixed capital formation.

The process of converting R&D expenditures into R&D outputs is called the production of R&D, which describes how R&D outputs are produced, involving the calculation of R&D inputs and R&D outputs. According to the accrual basis, the R&D Routine Expense[①] is directly recorded as R&D input; After the R&D Assets Expenditure is converted into fixed capital consumption (representing the value of fixed assets consumed in the current R&D activities), and then it is included in R&D input. The key to converting R&D inputs into R&D output is the calculation of the operating surplus. However, the R&D activities that the enterprise serves for itself do not have market prices, so there is no operating surplus; the output of R&D activities entrusted by the enterprise shows its market price in terms of sales revenue, contract revenue, commission income, and service fee. These are actually included in the R&D expenditure statistics (Gao M, 2017). In actual operation, it is difficult to obtain the market price of R&D products, and it is generally estimated at the total cost of production.

The process of converting the R&D output into an R&D investment is called the use of R&D. SNA2008 incorporates R&D as a type of intellectual property product into fixed assets, thereby enabling R&D output to be used as fixed capital formation. In the process of converting the R&D output into R&D investment, it is necessary to pay attention to:

First, the R&D products used by enterprises are partly derived from their own R&D output, and some R&D products are purchased from outside. However, the self-produced R&D products are far more than the R&D products purchased. For example, in 2009, the proportion of self-produced R&D products of Australian enterprises was 90% (Eurostat, 2014). Corresponding to the intramural expenditure on R&D, the external expenditure on R&D is the fee paid to the entrusting unit or the domestic cooperation unit to carry out R&D activities, and it can be approximated as the surrogate indicators for purchase R&D products. The external expenditure on R&D accounts for only 5% of the total expenditure on R&D, which is not enough to affect the R&D investment level of various industries. Therefore, the R&D investment measured in this paper does not include R&D products purchased from outside.

Second, SNA2008 states that R&D output is generally considered to be capital formation unless the activity clearly does not bring any economic benefits to its owner, in which case it is treated as an intermediate consumption. However, from the perspective of national practice, all

[①] According to the China Statistical Yearbook on Science and Technology, R&D expenditure is divided into routine expense and assets expenditure according to the expenditure purposes. Among them, the routine expense is the labor costs for personnel who carry out R&D activities, as well as various management expenses and materials expenses; assets expenditures are the expenses for the construction, purchase, installation, alteration and expansion of fixed assets for the R&D activities, as well as the actual expenditures for equipment technological transformation and maintenance.

R&D output is generally capitalized as fixed capital formation, including expenses incurred by unsuccessful R&D activities and non-market R&D activities (Gao M, 2017). All R&D output is capitalized as R&D investments in this paper. The reasons are as follows: unsuccessful R&D activities cannot directly create value, but producers will learn from them and improve the production of R&D, so the unsuccessful R&D activity has potential benefits. It is difficult to distinguish between successful and unsuccessful R&D activities on data. Further, it can be considered that most of the R&D expenditures in the manufacturing industry are capitalized, for they are dominated by market-based R&D activities.

2.2 The Measurement Method of R&D Capital Stock

Stocks related to the total level of R&D assets at a point in time, which is the result of accumulating R&D investments and deducting capital consumption over the years. The variables involved in the R&D capital stock measurement include the R&D initial capital stock, the R&D asset price index, and the R&D asset depreciation rate.

2.2.1 The basic method of R&D capital stock measurement

The BEA method is one attempt at solving this problem. In the BEA method, the depreciation amount of R&D capital includes not only the depreciation of the capital stock in the t-1 period but also the depreciation of the current investment (Sliker, 2007). This result may be expressed by the following equation:

(1) $$A_{it} = (1-\delta) A_{i(t-1)} + \left(1-\frac{1}{2}\delta\right) I_{it}$$

Where A_{it} and $A_{i(t-1)}$ respectively are industry-specific R&D capital stock at the constant price in the t period and t-1 period, I_{it} is the real R&D investment in the t period, δ is the R&D capital depreciation rate.

2.2.2 Measurement method of the initial R&D capital stock

Measurement of the initial R&D capital stock is derived by the equation (1):

$A_{it} - A_{i(t-1)} = \left(1-\frac{1}{2}\delta\right) I_{it} - \delta A_{i(t-1)}$, dividing $A_{i(t-1)}$ at both sides of the equation:

(2) $$g_{Ai} = \left(1-\frac{1}{2}\delta\right) \cdot I_{it} / A_{i(t-1)} - \delta$$

Where $g_{Ai} = \frac{A_{it} - A_{i(t-1)}}{A_{i(t-1)}}$ is the industry-specific growth rate of R&D capital stock in the t period.

(3) $$A_{i(t-1)} = \left(1-\frac{1}{2}\delta\right) \cdot I_{it} / \left(g_{Ai} + \delta\right)$$

In the Equation (3), R&D investment series, growth rate of R&D capital stock and R&D capital depreciation rate will be needed to measure the initial R&D capital stock. Zvi Griliches

(1980) believes that the capital stock growth rate may be replaced by the investment growth rate under reasonable conditions (Griliches, 1980). The linear regression method is used to estimate the investment growth rate in this paper, as follows:

(4) $$\ln I_{it} = b_i + m_i t + \varepsilon_{it}$$

Where $\ln I_{it}$ is logarithmic investment series, b_i is constant term， m_i is a parameter to be estimated, ε_{it} is random error term, we get $d\ln I_{it}/dt = m_i$, the investment growth rate g_{Ii} can be described by the following equation:

(5) $$g_{Ii} = e^{m_i} - 1 = g_{Ai}$$

2.2.3 The estimation method of R&D asset price index

The R&D Asset Price Index is a deflator used to calculate R&D investment and capital stock at a constant price. Due to the lack of observable R&D market price, this paper uses the weighted Fisher chain price index method to compile the weighted R&D input price index as the R&D asset price index, as shown in equation (6). The choice of this method is based on two points: First, the weighted Fisher chain price index has the best effect on the theoretical and test properties, for it satisfies the inverse test of the elements, and can deal with the zero value in the data set (Diewert, 1992). Second, the R&D investment was transformed from the intramural expenditure on R&D, and the price index constructed using the intramural expenditure on R&D classified by use was consistent with the capitalization process of R&D.

(6) $$P_{st}^{F} = \sqrt{P_{st}^{L} \times P_{st}^{P}} = \sqrt{\left(\sum_{m=1}^{M} \frac{p_{mt}}{p_{ms}} \times w_{ms}\right) \times \left(\frac{1}{\sum_{m=1}^{M} \frac{p_{ms}}{p_{mt}} \times w_{mt}}\right)}$$

Where P_{st}^{L} is the Laspeyres price index weighted by the number of base periods, P_{st}^{P} is the Paasche price index weighted by the number of current periods. p_{mt} is the price of the m-th type of production input elements that are invested in the R&D production process in the t period, $w_{mt} = p_{mt} q_{mt} \big/ \sum_{m=1}^{M} p_{mt} q_{mt}$, the proportion of expenditure on the m-th type of production input elements investment as a percentage of total expenditure in the R&D production process.

2.2.4 The estimation method of industry-specific R&D depreciation rate

The R&D depreciation rate is the ratio of R&D capital consumption to R&D capital stock. In theory, the R&D depreciation rate varies from industry to industry for the different R&D asset structures in various industries. The Production Function Approach is a method for estimating the R&D capital depreciation rate at the industry level (Li, 2016). The R&D capital depreciation rate is related to the industry investment growth rate in this method. The more stable the industry growth rate is, the lower the R&D depreciation rate is; the industry with a large change in growth rate has a higher depreciation rate. However, this method has high requirements for data quality and is not suitable for the estimation of R&D depreciation rate in China's manufacturing industry. Referring to China's official statistical practices, this paper assumes that the R&D capital depreciation rates are the same for each industry, and estimates the industry R&D capital depreciation rate using the residual value of asset retirement and asset service life expectancy, as shown in equation (7):

$$\delta_k = 1 - \left(d_k\right)^{\frac{1}{L_k}} \quad (7)$$

δ_k, d_k and L_k respectively are the asset depreciation rate, the residual value rate, and the service life expectancy, and the residual value rate is the ratio of the residual value of the asset to the total value of the asset when it is decommissioned.

3. Practical Implementation and Data

R&D investment series is the basis and key data for measuring R&D capital stock. The size of R&D investment over the years determines the size of R&D capital stock. From Figure 1, we should reasonably estimate the missing data on the intramural expenditure on R&D at the industry level, then calculate the fixed capital consumption based on the R&D assets expenditure of each industry, and calculate the R&D output according to the accrual basis. Further, all R&D output is treated as R&D fixed capital formation and capitalized, and R&D investment series at large and medium-sized manufacturing is measured from 1990 to 2016.

3.1 Estimation of the Missing Value

There is a lack of the intramural expenditure on R&D in various manufacturing industries in China, and the industry classification is inconsistent over the time. The specific performance is as follows: the time series is short, and only the intramural expenditure on R&D in the manufacturing industry from 2000 to 2016 can be obtained. The classified data is not enough, only the intramural expenditure on R&D from 2009 to 2015 is classified according to the expenditure purposes; the national economic industry classification standards are not uniform, and the number of manufacturing categories in different years is inconsistent.

(1) Estimation of the intramural expenditure on R&D for large and medium-sized manufacturing industries from 1990 to 1999. This paper uses indicators that are highly correlated with R&D expenditure internal expenditures—the total amount of science and technology funds

used by large and medium-sized industrial enterprises and intramural expenditure on technical development funds to estimate the missing value.

(2) Estimation of R&D assets expenditures for large and medium-sized manufacturing industries from 1990 to 2008. This paper estimates the R&D assets expenditures of large and medium-sized manufacturing enterprises from 1990 to 2008 by using the industry structure ratio of R&D assets expenditures of manufacturing enterprises in 2009. The empirical results show that the proportion of capital expenditures to the intramural expenditure on R&D in various industries has not changed significantly with time.

(3) Unification of industry classification. According to industry classification for national economic activities (GB/T4754-2011), industry classification for national economic activities (GB/T4754-2002), industry classification for national economic activities (GB/T4754-1994) and industry classification for national economic activities (GB/T4754-1984), industry classification for national economic activities (GB/T4754-2011) is the benchmark for the division and merger of major manufacturing industries over the years to ensure the consistency of industry sector.

3.2 Estimation of R&D Output by Industry

Figure 1 structures the calculation process of R&D output. The R&D asset price index constructed to convert the nominal value of intramural expenditure on R&D into the corresponding volume value; R&D assets expenditure deflated the investment price index in fixed asset is converted to the consumption of fixed capital by the PIM method; Finally, we calculate R&D inputs, which equals R&D outputs based on the input cost method recommended by SNA2008. The measurement process is as shown in equation (8).

$$\begin{aligned}&\frac{\text{Intramural Expenditure on R\&D}}{\text{R\&D Asset Price Index}}-\frac{\text{Assets Expenditure}}{\text{Investment Price Index in Fixed Assets}}+\text{Consumption of fixed capital}\\&=\text{R\&D Input}\\&=\text{R\&D Output}\end{aligned} \quad (8)$$

3.2.1The measurement of the R&D asset price index

Equation (6) shows the weighted Fisher chain price index method for calculating the R&D asset price index. The R&D asset price index can be obtained by a weighted average of the price index corresponding to the intermediate input cost, labor cost and fixed asset cost, for R&D expenditure, consists of routine expense and assets expenditure, and the weight is the cost share of each type of R&D expenditure. The intermediate input cost is the actual cost of non-asset materials used by R&D producing and deflated by the industrial producer price index. The labor costs are deflated by the urban consumer price index. The fixed asset costs are deflated by the fixed asset investment price index.

3.2.2 The measurement of the industry-specific consumption of fixed capital

The industry-specific consumption of fixed capital equals the product of the fixed capital stock generated by R&D assets expenditure and the corresponding depreciation rate.

The PIM is one attempt at measuring fixed capital stock:

(9) $$A_{it}^{NT} = I_{it}^{NT} + \left(1 - \delta^{NT}\right) A_{i(t-1)}^{NT}$$

Where A_{it}^{NT} is the capital stock generated by R&D capital expenditure at the end of period t; I_{it}^{NT} is a constant-price physical capital investment series, its data is the R&D assets expenditure, which is deflated by the fixed asset investment price index sequence (1990=100); δ^{NT} is depreciation rates of R&D assets expenditure, according to Wang Y and Wang C (2018), the depreciation rates is 11.33%.

Further, the initial capital stock can be calculated by the equation (10):

(10) $$A_{i(t-1)}^{NT} = I_{it}^{NT} \Big/ \left(g_{Ai}^{NT} + \delta^{NT}\right)$$

Where g_{Ai}^{NT} is the growth rate of R&D assets expenditure.

4. Results

Equation (3) shows that the initial capital stock of R&D equals to R&D investment in the initial year divided by the sum of investment growth rate and R&D asset depreciation rate. The R&D investment growth rate of each manufacturing industry is calculated by the linear regression method shown in (4). The depreciation rate of R&D assets is calculated according to formula (7) with the estimation of residual rate and service life expectation. According to National Bureau of Statistics of China, the service life expectancy of R&D assets is 10 years, and the residual value rate is 10%, then the calculated R&D depreciation rate is 20.6% (Wang Y and Wang C, 2018). According to the Equation (1), this paper measures the R&D capital stock in China's manufacturing industry from 1990 to 2016, and the results are shown in Appendix 2.

R&D capital stock in China's manufacturing industry is gradually expanding. During the period of 1990-2016, it increased from 11.73 billion yuan in 1990 to 931.49 billion yuan in 2016 (1990 = 100), with an average annual growth rate of 18.32%; the proportion of China's manufacturing R&D capital stock to the total social capital stock increased from 35.33% in 1990 to 67.75% in 2016; China's manufacturing industry is becoming the main force of China's research and development and application area of R&D achievements, which can be seen in Figure 2.

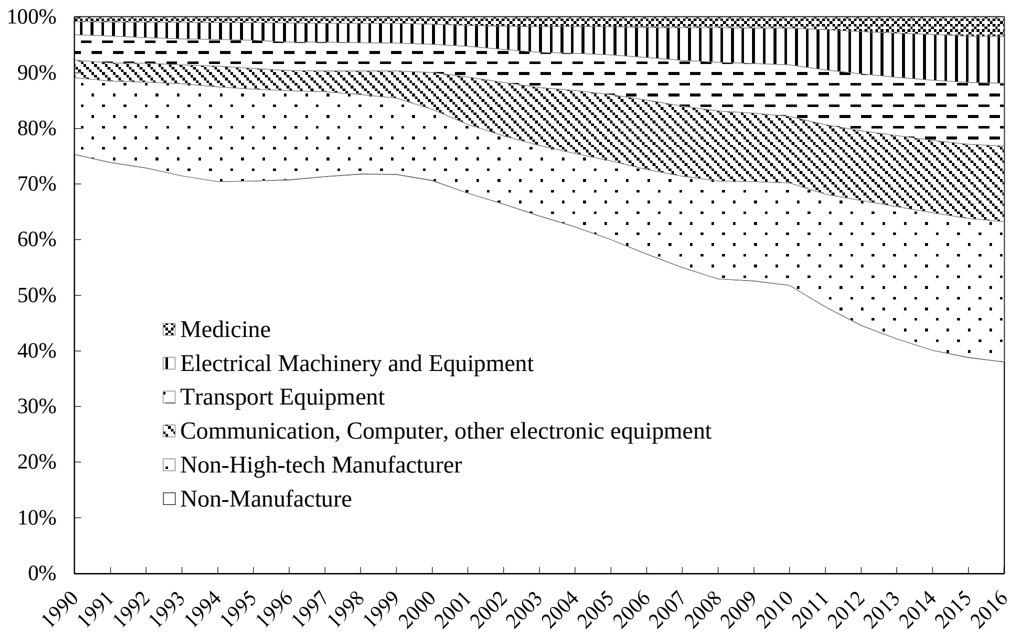

Figure 2 Changes in the R&D capital stock of each industry as a percentage of the total social R&D capital stock, 1990-2016

The average annual growth rate of R&D capital stock in high-tech manufacturing industry is as high as 20%~22%, including manufacture of medicines, manufacture of transport equipment, manufacture of electrical machinery and equipment, and manufacture of communication, computer and other electronic equipment and so on, which plays an important role in improving the quality and efficiency of China's economy. In addition, the R&D capital stock of other manufacturing industries is growing at an average annual growth rate of more than 20%, such as manufacture and processing of non-ferrous metals, manufacture of metal products, manufacture of articles for culture, education and sport activity……, With the implementation of the "Public Entrepreneurship, Innovation", which further stimulated the enthusiasm of enterprises to carry out R&D activities, and the role of enterprises in the growth of R&D capital stock in the whole society was further enhanced.

The industry distribution structure of R&D capital stock in high-tech manufacturing has changed significantly: the proportion of manufacture of communication, computer, and other electronic equipment to the manufacturing industry increased from 2.72% in 1990 to 11.54% in 2016. As an information industry, the improvement of R&D capability thereof will penetrate into the production of all industries through the industrial chain, which will promote the industrial upgrading process for the manufacturing industry and the whole industry. The proportion of manufacture of transport equipment increased from 3.90% in 1990 to 9.59% in 2016, leading the transportation modernization with information technology. The proportion of manufacture of electrical machinery and equipment increased from 2.00% in 1990 to 7.17% in 2016. However, it still relies mainly on the introduction of advanced technologies from developed countries, and its independent research and development innovation level are still at a low level. T The proportion of manufacture of medicines increased only from 0.71% in 1990 to 2.91% in 2016, for China's rigid review process and long approval time has seriously affected efficiency and progress of R&D in China's manufacture of medicines.

5. Conclusion and Further Steps

Based on the actual needs of China's transformation of economic development mode, "Made in China 2025", which responds to a new round of scientific and technological revolution and industrial transformation, proposes a series of major strategic tasks and major policy initiatives focusing on key fields such as innovation-driven, intelligent transformation, strengthening foundation, high-end equipment and others to accelerate the transformation and upgrading of the manufacturing industry and strive to move China from a manufacturer of quantity to one of quality by 2025. In this context, from the perspective of national economic accounting, this paper uses the BEA method to measure the R&D capital stock of 26 manufacturing industries in China from 1990 to 2016, in order to provide substantial support for further exploring the contribution of manufacturing technological progress and innovation to economic development and growth.

5.1 Explanation on the Measurement Results of R&D Capital Stock

R&D investment is an accurate indicator affecting R&D capital stock measurements. Direct use of R&D expenditures in various industries as R&D investment will overestimate R&D investment in various industries and then overestimate the R&D capital stock. This paper explores the capitalized accounting framework for R&D expenditures in the manufacturing industry and calculates the R&D investment sequences of 26 manufacturing industries in China for accuracy analysis for the first time. Data analysis shows that China's R&D innovation capability of manufacturing industry has experienced stages from startup, improving greatly and improving steadily. Manufacture of transport equipment, manufacture of electrical machinery and equipment, as well as manufacture of communication, computer, and other electronic equipment are China's leading high-tech manufacturing industries that have the largest R&D investment.

The constructed R&D investment price index passed the robustness test, which proves that the use of the urban consumer price index as the price deflator for R&D wages is effective. The constant price R&D investment data is the basis and key data for measuring the R&D capital stock. Therefore, the R&D investment price index becomes a key variable affecting the R&D capital stock. In this paper, the weighted Fisher's chain price index method is used to obtain the R&D investment price index by weighting the average price of industrial producers' purchase price index, urban consumer price index and fixed asset investment price index, which is easy to understand and meet the characteristics of factor inverse test. Further, this paper uses the GDP price deflator as a control index to explore the impact of different R&D investment price indices on the R&D investment series. The results show that the difference between the two types of price indices exceeds 10%, but the calculated difference between the two R&D investment sequences is maintained within 5%. This explains that the two types of price indices constructed will not cause significant differences on the R&D investment measurement results. It can be considered that the urban consumer price index is effective as the R&D wage index.

Current status of R&D capital stock in China's manufacturing industry. ① During the period of 1990-2016, the proportion of China's manufacturing R&D capital stock to the total social capital stock increased from 35.33% in 1990 to 67.75% in 2016, becoming the main application area of China's R&D and R&D achievements. ②As a leading industry with strong R&D strength in the manufacturing industries, high-tech manufacturing, with an annual growth rate of R&D capital stock as high as 20%~22%, plays an important role in improving the quality and efficiency of China's economy. ③ High-tech manufacturing industries such as the manufacture of communication, computer and other electronic equipment, manufacture of transport equipment are replacing the basic industries of specialized equipment and general equipment manufacturing industries, and becoming the leading industries of high-tech manufacturing industries. The proportion of manufacture of communication, computer, and other electronic equipment to the manufacturing industry increased from 2.72% in 1990 to 11.54% in 2016. As an information industry, the improvement of R&D capability thereof will penetrate into the production of all industries through the industrial chain, which will promote the industrial upgrading process for the manufacturing industry and the whole industry.

5.2 Further Steps

The measurement of R&D capital stock in manufacturing industries is helpful for understanding the scale of China's manufacturing R&D capital stock and the industry distribution structure thereof, portraying the level of China's manufacturing R&D strength, and providing data support for further applied research.

(1) Measurement of the return to R&D capital and capital services. The return to R&D capital is an important data for the conversion of R&D input to R&D output. It is an important indicator for measuring the efficiency of China's R&D capital utilization and is the basic data for R&D capital services. Among them, the R&D capital services are the R&D capital flow involved in the production process and are an effective variable for productivity analysis. However, the current research still uses the return to capital of fixed-asset investment in the whole society as a substitute for the return to R&D capital, which underestimates the return to China’s R&D capital.

(2) Analysis of R&D technology spillover effect. R&D's contribution to economic growth is not only in the aspect that to what extent the R&D, as a fixed asset, has improved the GDP, but also in the aspect that explore how R&D output penetrates into all aspects of economic processes, and how R&D investment in high-tech industries affects the output increase in other industries. The specific study of the mechanism of R&D penetration effect requires the input-output model that reflects the relevance of each industry in the national economy.

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Appendix

Appendix 1 R&D investment series at manufacture industry, 1990-2016(1990=100)

Industry	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Processing of Food from Agricultural Products	0.01	0.00	0.01	0.51	0.33	0.55	0.53	0.42	0.64	0.88	1.02	1.31	1.77	1.83
Manufacture of Foods	0.67	1.09	0.92	0.44	1.06	0.32	0.64	0.61	0.65	0.98	1.00	1.16	1.73	2.28
Manufacture of Beverage	0.42	0.44	0.83	0.52	0.50	1.07	0.86	0.96	1.01	1.51	2.23	2.23	2.66	3.28
Manufacture of Tobacco	0.42	0.33	0.80	0.41	0.27	0.31	0.56	0.51	0.65	0.84	0.98	1.00	1.43	1.85
Manufacture of Textile	2.78	3.03	3.72	4.23	3.09	3.45	2.87	2.74	2.52	3.70	3.73	4.36	5.77	6.37
Manufacture of Textile Wearing Apparel, Footwear and Caps	0.08	0.07	0.11	0.11	0.14	0.14	0.25	0.35	0.24	0.42	0.41	0.54	0.55	2.21
Manufacture of Leather, Fur, Feather and Its Products	0.14	0.11	0.24	0.11	0.16	0.17	0.22	0.13	0.15	0.23	0.17	0.11	0.36	0.68
Processing of Timbers, Manufacture of Wood, Bamboo, Rattan, Palm, Straw	0.10	0.09	0.16	0.03	0.07	0.07	0.19	0.12	0.14	0.17	0.14	0.88	0.64	0.67
Manufacture of Furniture	0.07	0.06	0.02	0.05	0.04	0.05	0.02	0.08	0.03	0.11	0.07	0.07	0.09	0.11
Manufacture of Paper and Paper Products	0.92	0.85	0.76	0.67	0.68	0.80	0.69	0.85	1.24	1.29	1.78	2.39	2.88	3.04
Printing, Reproduction of Recording Media	0.10	0.15	0.39	0.23	0.15	0.11	0.17	0.28	0.32	0.50	0.39	0.41	0.65	0.83
Manufacture of Articles for Culture, Education and Sport Activity	0.20	0.21	0.21	0.14	0.32	0.30	0.38	0.39	0.57	0.81	3.81	4.35	0.48	1.42
Processing of Petroleum, Coking, Processing of Nucleus Fuel	0.80	0.96	1.17	1.03	0.95	1.66	2.16	1.87	1.88	2.30	3.66	2.68	2.28	2.67
Manufacture of Chemical Raw Material and Chemical Products	4.84	5.47	5.45	4.07	3.86	5.99	5.43	5.82	6.53	8.62	10.27	11.23	15.28	19.12
Manufacture of Medicines	0.94	1.02	1.13	0.90	1.11	1.48	1.72	2.13	2.46	2.95	5.45	7.77	8.96	11.09
Manufacture of Chemical Fiber	0.53	0.56	0.73	0.98	0.82	0.99	1.38	1.43	1.60	1.99	2.08	1.96	2.40	2.46
Manufacture of Rubber and Plastic	1.16	1.69	1.40	1.65	1.41	1.66	1.70	1.78	2.25	2.43	2.50	3.29	4.51	5.40
Manufacture of Non-metallic Mineral Products	1.96	1.91	2.14	2.17	1.75	2.55	2.41	2.95	2.65	2.94	3.44	3.76	4.35	6.19
Manufacture and Processing of Ferrous Metals	3.16	3.98	4.09	5.45	5.03	3.64	4.55	6.94	6.65	8.96	8.42	10.26	16.90	26.38
Manufacture and Processing of Non-ferrous Metals	1.19	1.03	1.20	1.08	0.87	1.30	1.50	1.29	1.13	1.95	3.90	3.96	5.01	5.53
Manufacture of Metal Products	0.58	0.71	0.75	0.92	0.85	1.31	1.07	1.52	1.26	1.27	1.49	2.10	1.83	2.91

Manufacture of General Purpose Machinery and Measuring Instrument, Machinery	6.58	6.56	7.34	6.01	6.01	6.75	7.52	8.63	7.25	8.91	10.58	12.30	14.62	21.17
Manufacture of Special Purpose Machinery	5.81	5.67	6.52	4.21	4.69	6.00	5.72	5.21	4.53	5.14	5.76	6.09	8.03	13.32
Manufacture of Transport Equipment	5.04	5.70	4.65	4.98	5.17	7.71	7.85	10.03	10.10	12.78	17.90	25.42	33.25	39.63
Manufacture of Electrical Machinery and Equipment	2.62	3.14	3.73	3.92	3.28	4.44	6.30	6.30	7.74	9.99	12.31	15.93	24.84	30.26
Manufacture of Communication, Computer, Other Electronic Equipment	3.66	3.68	3.99	3.70	4.86	4.86	5.03	7.38	11.73	16.49	33.37	48.49	58.15	67.90
Manufacture industry	44.72	48.44	52.39	48.48	47.46	57.62	61.67	70.70	76.08	98.34	133.24	172.50	222.37	278.69

Appendix 1(continued)

Industry	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Processing of Food from Agricultural Products	2.01	3.07	4.46	6.53	8.18	11.43	13.69	24.66	36.67	47.60	55.33	62.65	73.56
Manufacture of Foods	2.39	2.89	3.95	5.11	5.37	9.58	11.31	16.57	23.81	27.33	31.43	38.80	44.88
Manufacture of Beverage	4.31	5.21	6.25	8.46	9.65	11.77	13.64	18.50	23.04	23.86	28.83	27.51	30.87
Manufacture of Tobacco	1.96	3.01	2.22	2.87	2.96	4.02	4.24	4.23	5.97	5.97	6.02	5.97	6.54
Manufacture of Textile	9.38	10.43	11.73	14.15	16.04	21.64	25.31	36.04	37.73	44.02	50.49	61.22	65.06
Manufacture of Textile Wearing Apparel, Footwear and Caps	2.02	2.81	3.06	3.22	3.76	4.76	5.23	7.85	14.90	19.62	21.47	27.16	31.94
Manufacture of Leather, Fur, Feather and Its Products	0.74	0.91	1.04	1.55	1.71	2.63	3.21	4.28	7.77	9.82	11.70	15.56	18.00
Processing of Timbers, Manufacture of Wood, Bamboo, Rattan, Palm, Straw	0.84	1.34	1.09	1.63	1.70	1.76	1.64	3.53	5.05	7.38	9.13	12.38	15.25
Manufacture of Furniture	0.69	0.69	0.87	1.26	1.17	1.78	1.32	2.57	3.81	6.33	7.46	9.40	12.46
Manufacture of Paper and Paper Products	3.26	4.32	5.27	5.72	7.86	10.09	11.35	15.32	21.45	23.80	28.22	33.09	36.99
Printing, Reproduction of Recording Media	0.66	0.81	0.82	1.59	1.48	2.35	2.96	4.96	6.74	8.07	9.20	10.86	13.53
Manufacture of Articles for Culture, Education and Sport Activity	2.50	2.07	3.23	3.59	3.90	5.87	6.63	10.78	15.04	17.96	23.90	29.55	38.98
Processing of Petroleum, Coking, Processing of Nucleus Fuel	3.87	3.80	5.48	6.37	8.39	10.82	12.73	16.43	22.33	26.07	30.66	28.93	35.78
Manufacture of Chemical Raw Material and Chemical Products	25.51	30.47	34.03	46.61	53.63	64.48	74.26	126.89	150.93	186.52	212.44	236.71	252.06
Manufacture of Medicines	10.62	14.21	17.90	21.56	23.98	31.93	35.93	57.28	77.93	97.95	111.89	131.21	146.10
Manufacture of Chemical Fiber	3.11	4.44	6.91	9.05	9.47	10.50	13.02	16.67	17.84	18.52	21.15	23.55	25.21
Manufacture of Rubber and Plastic	6.79	7.80	11.81	13.59	17.06	21.27	26.80	36.56	47.70	55.87	64.65	72.54	83.11

Manufacture of Non-metallic Mineral Products	5.99	7.76	8.63	9.49	13.34	18.90	22.06	34.67	44.71	59.96	69.68	79.49	94.73
Manufacture and Processing of Ferrous Metals	33.54	45.38	56.11	73.28	92.71	97.07	122.91	146.97	181.08	185.02	187.33	169.41	168.57
Manufacture and Processing of Non-ferrous Metals	7.44	12.54	18.65	21.75	25.79	30.69	35.73	51.68	75.72	84.26	94.09	107.42	121.52
Manufacture of Metal Products	3.20	5.50	7.19	10.38	13.04	15.00	18.46	29.34	51.56	63.44	71.38	84.13	97.59
Manufacture of General Purpose Machinery and Measuring Instrument, Machinery	24.25	30.88	42.36	55.12	65.18	83.48	89.60	143.26	168.64	197.37	227.62	246.50	259.46
Manufacture of Special Purpose Machinery	13.56	20.30	26.92	37.05	45.41	64.12	73.17	102.92	122.27	146.70	158.27	173.86	178.62
Manufacture of Transport Equipment	48.94	63.43	78.77	101.32	115.75	151.26	177.84	219.78	261.53	304.26	356.99	412.97	462.94
Manufacture of Electrical Machinery and Equipment	35.29	42.48	57.53	70.74	84.04	106.22	127.41	171.94	199.14	236.32	269.42	312.29	337.51
Manufacture of Communication, Computer, Other Electronic Equipment	86.99	102.14	123.26	137.29	150.86	187.18	206.83	264.51	307.85	365.15	412.18	497.51	558.08
Manufacture industry	339.94	428.74	539.58	669.29	782.45	980.60	1137.32	1568.23	1931.21	2269.17	2570.95	2910.68	3209.36

Notes: capital stock in 100 millions of constant prices (1990=100)

Appendix 2 R&D capital stock at manufacture industry, 1990-2016(1990=100)

Industry	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Processing of Food from Agricultural Products	0.02	0.02	0.02	0.48	0.68	1.04	1.30	1.41	1.69	2.13	2.61	3.25	4.17	4.96
Manufacture of Foods	1.79	2.40	2.72	2.56	2.99	2.65	2.68	2.68	2.71	3.03	3.31	3.67	4.46	5.59
Manufacture of Beverage	1.12	1.28	1.77	1.87	1.94	2.50	2.76	3.05	3.34	4.01	5.19	6.12	7.25	8.70
Manufacture of Tobacco	1.23	1.28	1.73	1.74	1.63	1.57	1.75	1.85	2.05	2.39	2.78	3.10	3.75	4.64
Manufacture of Textile	8.18	9.21	10.65	12.26	12.51	13.03	12.93	12.73	12.37	13.14	13.79	14.86	16.98	19.20
Manufacture of Textile Wearing Apparel, Footwear and Caps	0.19	0.21	0.27	0.31	0.38	0.42	0.56	0.76	0.82	1.03	1.18	1.42	1.63	3.28
Manufacture of Leather, Fur, Feather and Its Products	0.36	0.39	0.52	0.51	0.55	0.59	0.66	0.64	0.64	0.72	0.72	0.67	0.85	1.29
Processing of Timbers, Manufacture of Wood, Bamboo, Rattan, Palm, Straw	0.24	0.27	0.36	0.32	0.32	0.31	0.41	0.44	0.47	0.53	0.55	1.22	1.55	1.83
Manufacture of Furniture	0.16	0.18	0.16	0.17	0.17	0.18	0.16	0.20	0.19	0.25	0.26	0.27	0.30	0.34

Manufacture of Paper and Paper Products	2.50	2.75	2.87	2.89	2.91	3.02	3.03	3.17	3.63	4.04	4.80	5.95	7.31	8.54
Printing, Reproduction of Recording Media	0.28	0.35	0.63	0.71	0.70	0.65	0.67	0.78	0.91	1.17	1.28	1.38	1.68	2.08
Manufacture of Articles for Culture, Education and Sport Activity	0.50	0.59	0.65	0.65	0.80	0.91	1.06	1.19	1.45	1.88	4.91	7.80	6.63	6.54
Processing of Petroleum, Coking, Processing of Nucleus Fuel	2.29	2.68	3.18	3.45	3.59	4.34	5.38	5.96	6.42	7.16	8.97	9.53	9.62	10.04
Manufacture of Chemical Raw Material and Chemical Products	12.98	15.22	16.98	17.14	17.08	18.94	19.92	21.04	22.58	25.67	29.61	33.59	40.39	49.24
Manufacture of Medicines	2.34	2.78	3.22	3.36	3.66	4.23	4.90	5.80	6.81	8.05	11.28	15.93	20.70	26.39
Manufacture of Chemical Fiber	1.47	1.67	1.98	2.45	2.68	3.01	3.63	4.16	4.74	5.55	6.27	6.74	7.51	8.17
Manufacture of Rubber and Plastic	3.11	3.99	4.43	5.00	5.24	5.65	6.02	6.38	7.08	7.81	8.44	9.66	11.72	14.16
Manufacture of Non-metallic Mineral Products	5.46	6.05	6.72	7.28	7.35	8.13	8.63	9.50	9.92	10.52	11.45	12.46	13.80	16.51
Manufacture and Processing of Ferrous Metals	8.31	10.18	11.75	14.22	15.81	15.82	16.65	19.45	21.42	25.05	27.45	31.01	39.79	55.27
Manufacture and Processing of Non-ferrous Metals	2.97	3.28	3.68	3.89	3.87	4.25	4.72	4.91	4.91	5.65	7.99	9.89	12.36	14.78
Manufacture of Metal Products	1.48	1.82	2.12	2.51	2.76	3.36	3.63	4.25	4.51	4.72	5.08	5.92	6.35	7.65
Manufacture of General Purpose Machinery and Measuring Instrument, Machinery	17.98	20.16	22.60	23.34	23.93	25.07	26.66	28.92	29.47	31.41	34.44	38.39	43.61	53.64
Manufacture of Special Purpose Machinery	16.00	17.79	19.99	19.65	19.82	21.13	21.91	22.08	21.60	21.77	22.46	23.31	25.71	32.38
Manufacture of Transport Equipment	12.95	15.39	16.40	17.50	18.53	21.64	24.24	28.25	31.50	36.49	45.04	58.58	76.36	96.22
Manufacture of Electrical Machinery and Equipment	6.64	8.09	9.77	11.28	11.90	13.44	16.32	18.61	21.73	26.23	31.87	39.61	53.75	69.84
Manufacture of Communication, Computer, Other Electronic Equipment	9.03	10.47	11.90	12.77	14.51	15.88	17.13	20.22	26.59	35.92	58.47	89.95	123.62	159.11
Manufacture industry	117.36	136.68	155.58	167.07	175.29	190.93	206.99	227.84	249.24	286.21	346.88	430.30	541.30	679.99
High-tech manufacture	77.91	89.91	100.86	105.04	109.43	120.33	131.07	144.93	160.29	185.54	233.17	299.36	384.14	486.81
Total economy	332.15	372.83	413.69	435.22	448.15	492.34	541.94	615.63	695.93	812.27	973.04	1154.38	1393.81	1659.44

Appendix 2(continued)

Industry	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average annual growth rate %
Processing of Food from Agricultural	5.74	7.32	9.82	13.66	18.19	24.71	31.90	47.47	70.61	98.79	128.11	157.97	191.47	41.63

Products														
Manufacture of Foods	6.59	7.83	9.77	12.34	14.62	20.21	26.20	35.68	49.71	64.00	79.03	97.59	117.78	17.48
Manufacture of Beverage	10.78	13.23	16.12	20.39	24.85	30.30	36.31	45.44	56.76	66.49	78.68	87.18	96.94	18.71
Manufacture of Tobacco	5.45	7.03	7.58	8.60	9.49	11.15	12.65	13.85	16.35	18.34	19.97	21.22	22.72	11.86
Manufacture of Textile	23.67	28.16	32.89	38.82	45.23	55.33	66.66	85.28	101.59	120.19	140.77	166.74	190.82	12.88
Manufacture of Textile Wearing Apparel, Footwear and Caps	4.42	6.03	7.53	8.88	10.42	12.55	14.66	18.68	28.21	40.00	51.03	64.91	80.21	26.19
Manufacture of Leather, Fur, Feather and Its Products	1.69	2.15	2.64	3.49	4.30	5.78	7.47	9.78	14.74	20.52	26.79	35.25	44.15	20.26
Processing of Timbers, Manufacture of Wood, Bamboo, Rattan, Palm, Straw	2.21	2.96	3.33	4.10	4.78	5.38	5.74	7.73	10.67	15.10	20.18	27.13	35.24	21.06
Manufacture of Furniture	0.89	1.32	1.83	2.58	3.10	4.06	4.41	5.81	8.04	12.07	16.28	21.37	28.15	22.04
Manufacture of Paper and Paper Products	9.71	11.59	13.93	16.19	19.91	24.87	29.93	37.52	49.04	60.31	73.22	87.85	102.97	15.37
Printing, Reproduction of Recording Media	2.24	2.50	2.73	3.59	4.18	5.43	6.97	9.99	13.99	18.35	22.83	27.88	34.28	20.34
Manufacture of Articles for Culture, Education and Sport Activity	7.44	7.77	9.07	10.42	11.78	14.62	17.56	23.62	32.25	41.73	54.59	69.87	90.48	22.15
Processing of Petroleum, Coking, Processing of Nucleus Fuel	11.45	12.50	14.85	17.50	21.44	26.73	32.66	40.68	52.35	64.97	79.12	88.80	102.64	15.75
Manufacture of Chemical Raw Material and Chemical Products	62.00	76.58	91.36	114.38	138.97	168.23	200.25	272.91	352.19	447.10	545.73	645.86	739.16	16.82
Manufacture of Medicines	30.49	36.97	45.43	55.43	65.54	80.71	96.34	127.92	171.53	224.12	278.41	338.86	400.24	21.86
Manufacture of Chemical Fiber	9.28	11.36	15.23	20.21	24.55	28.92	34.65	42.48	49.75	56.13	63.56	71.62	79.51	16.58
Manufacture of Rubber and Plastic	17.34	20.77	27.09	33.71	42.09	52.51	65.75	85.03	110.34	137.76	167.43	198.07	231.89	18.03
Manufacture of Non-metallic Mineral Products	18.49	21.65	24.94	28.32	34.46	44.33	55.00	74.80	99.53	132.85	168.04	204.80	247.67	15.81
Manufacture and Processing of Ferrous	74.00	99.49	129.36	168.50	217.02	259.47	316.38	383.16	466.81	536.80	594.46	624.19	647.05	18.23

Metals														
Manufacture and Processing of Non-ferrous Metals	18.42	25.87	37.28	49.13	62.16	76.91	93.15	120.35	163.53	205.49	247.65	293.09	341.83	20.02
Manufacture of Metal Products	8.95	12.04	16.02	22.04	29.20	36.65	45.68	62.61	95.99	133.17	169.82	210.37	254.66	21.90
Manufacture of General Purpose Machinery and Measuring Instrument, Machinery	64.36	78.83	100.62	129.38	161.24	202.98	241.62	320.45	405.84	499.44	600.94	698.49	787.61	15.65
Manufacture of Special Purpose Machinery	37.89	48.30	62.52	82.90	106.59	142.19	178.60	234.20	295.72	366.51	433.12	500.02	557.43	14.63
Manufacture of Transport Equipment	120.33	152.49	191.80	243.25	297.07	371.68	454.79	558.42	678.21	811.69	965.02	1137.05	1318.53	19.46
Manufacture of Electrical Machinery and Equipment	87.14	107.33	136.87	172.18	212.16	263.82	323.87	411.52	505.54	613.58	729.10	859.32	985.38	21.21
Manufacture of Communication, Computer, Other Electronic Equipment	204.43	254.03	312.36	371.29	430.27	509.71	590.43	706.31	837.23	992.64	1158.28	1366.40	1586.06	21.99
Manufacture industry	845.12	1055.95	1322.86	1651.25	2013.62	2479.23	2989.69	3781.75	4736.56	5798.20	6912.24	8101.95	9314.93	18.32
High-tech manufacture	606.64	754.53	940.96	1168.81	1411.85	1739.32	2085.91	2631.74	3246.26	3955.08	4710.61	5546.01	6374.42	18.46
Total economy	1970.27	2335.92	2763.14	3269.38	3821.63	4658.25	5533.82	6499.86	7698.44	9068.50	10482.93	12069.79	13748.65	15.40

Notes: capital stock in 100 millions of constant prices (1990=100)