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Measuring the Capital Services of R&D in China

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Abstract

R&D expenditure has been recognized as part of capital formation in SNA2008 for the first time. This part of the "new" capital formation changes the size of GDP, and also has a profound impact on capital accounting. Furthermore, with the concept of capital services introduced in SNA2008, there are some changes in capital accounting itself. In China, the R&D capitalization accounting is facing a lot of problems both in technique and data. By using the framework established in the two OECD manuals, our paper contributes to the literature by exploring the parameters in estimation of R&D assets in China. Then the calculation results of capital services on R&D from 1995-2011 are finally obtained.

Key words: Capital services; R&D; Productive capital stock; Age-efficiency profile

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1. INTRODUCTION AND REVIEWS

As the contribution of research and development (R&D) to production and growth is an important issue in development economics, measuring R&D input in production is the premise of this subject. People used the present and lagged input of R&D expenditures to measure the innovation input in initial empirical research. With much more knowledge of the capital property of R&D, researchers are beginning to estimate the knowledge production function using R&D capital stock as a variety. There are two problems: one is to determine the scope of R&D capital, the other is whether the capital stock is the best variable to estimate capital input.

The first problem is related to the knowledge of the capital property of R&D. R&D expenditure has been recognized as part of fixed capital formation in SNA2008 for the first time. This part of the new capital formation changes the size of GDP, also has a profound impact on capital accounting. America and Japan are the first two countries that adjust their historical data of GDP in 2013. Though R&D has been recognized as part of capital, it doesn't mean all kinds of R&D expenditure are capital. It will be classified as capital on condition that it can bring economic benefits to the owner. In other words, if R&D expenditure can't bring economic benefits, it still belongs to intermediate input.

The second problem refers to the measurement of capital input. People used "durable goods stock" to define and measure capital stock during a long time in macroeconomics. R&D capital stock was calculated in the same way. Then many economists realize that it's the capital service flow that determines production instead of the capital stock. So it's more reasonable to define capital input as the amount of capital service provided by the capital goods during a period of time. Therefore, the chapter of capital service is specially introduced into SNA2008 to present the accounting and recording of the capital input as capital flow, with methods and theory from the two OECD manuals.

China only accounts the R&D capital based on stock level by now, since it is not long before R&D was recognized as capital. For example, applying the panel data of middle and large sized enterprises in China, Wu (2006) has measured the industrial R&D capital stock with the base year of 1993; Wang J. (2009) has estimated the R&D capital stock of 28 manufacturing industrials in China from 1998 to 2005; Xiao and Xie (2009) have estimated the R&D capital stock in 31 provinces from 2000 to 2006 and found the space distribution characters; Wang M. X. (2011) has analyzed the method of BEA to measure R&D capital stock, based on the American R&D satellite account. On the whole, these researches are all focusing on R&D capital stock, with no regard to R&D capital service flow.

By now, on the account of capital input flow, China only measures fixed capital without R&D capital. For example, Sun and Ren (2005) firstly review the theory on capital services and calculate total factor productivity of China. Then in 2008 they have estimated the capital service indices on industry level from 1981 to 2000. Since there are some differences between the infinite geometric depreciation model and the actual use of capital, Cai (2009) firstly applies age-efficiency profile to the calculation of the capital service indices of China from 1978 to 2007 on aggregation level. Cao, Qin and Qi (2012) also estimate the capital service indices of China from 1978 to 2010. With contrast to the researches before, their study has some improvement in technical details, such as how to choose the depreciation rate, but the calculation result that productive stock is smaller than the net capital wealth contradicts the basic theory of capital measurement.

To sum up, research on the measurement of capital service in China is of small amount with limited view and there has not been a perfect system of the measuring method by now. Meanwhile, with R&D expenditure recognized as fixed capital by international standard accounting system, there is still no measurement of capital services based on the new capital demarcation. Therefore, we focus on R&D capital and use method of measuring capital service to estimate R&D capital input in China from 1995 to 2011.

2. THE FRAMEWORK OF MEASURING THE CAPITAL SERVICES ON R&D

The value-added represents the contribution of various factors to production. The contribution of labor is regarded as compensation of employee, and the contribution of capital is treated as capital services. Except for compensation of employee, the value-added includes consumption of fixed capital and operating surplus. They two make up capital services, with full consideration of the contribution made by all the capital to production.

2.1 The Accounting Scope of R&D

According to SNA2008, the assets that provide capital services are non-financial assets that make contributions to production, including fixed assets, inventories, natural resources and agreement related to production. As a new part of fixed capital formation, R&D provides capital

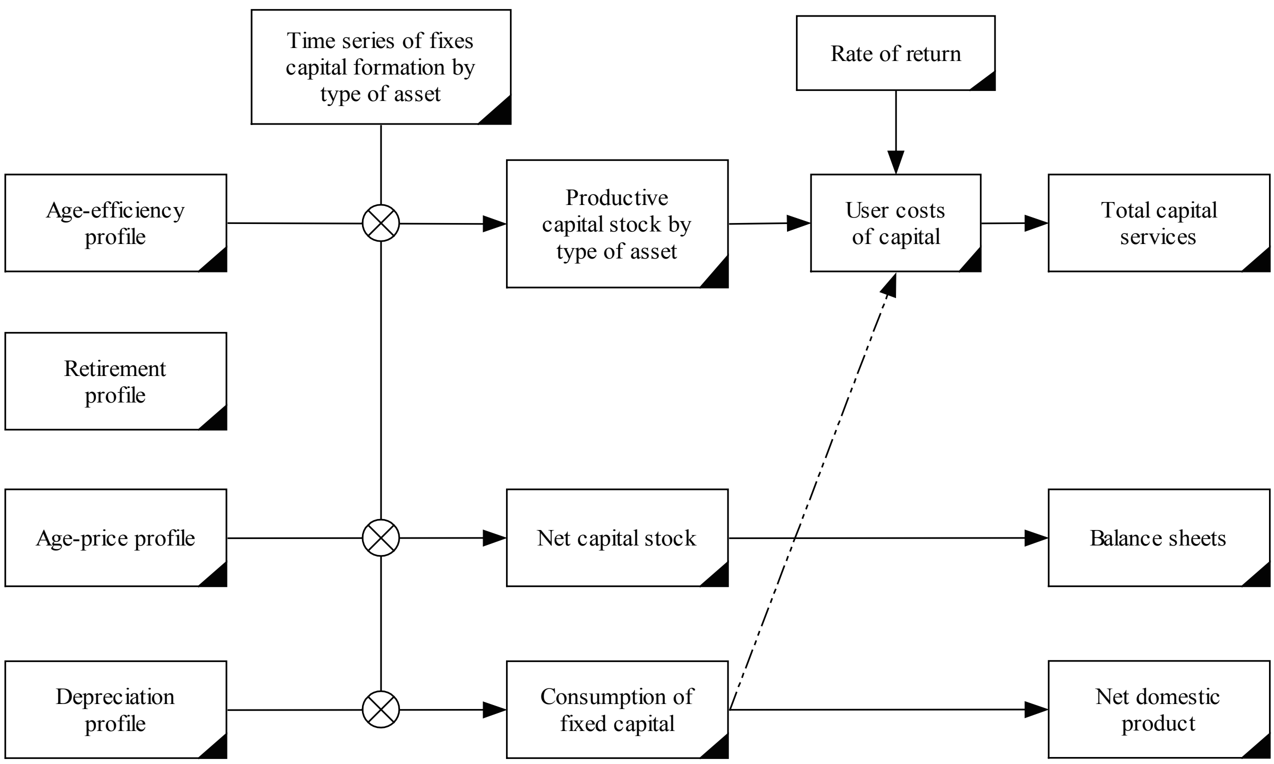

Figure 1
Measurement Framework of Capital Services

services. However, R&D expenditure is recognized as capital on condition that it can bring economic benefits.

R&D consists of basic research, applied research and experimental development under the statistical caliber of Frascati manual. If the activity can produce market product, we believe it brings economic benefit. Obviously, experimental development is most likely to produce market product, applied research second, and basic research is less of a possibility. Most basic research is like charity activity with little expected returns. But its products are the up-stream products of applied research and experimental development. Thus its benefits are embedded in later products. Hence we believe basic research differ from the other two activities mostly in the conversion rate of capital. Accordingly, we set the capital conversion rate of basic research is 50%, that of applied research is 80% and that of experimental development is 100%.

2.2 The Measuring Routine of R&D

Figure 1 shows the basic procedure of capital service calculation. Once capital formation data (I) are collected, we need to get information on capital retirement function (Y(t)) and its age-efficiency profile (g(t)) to calculate an intermediate production, that is productive capital stock ($K^p(t)$). Productive capital stock obtained, rate of return (r) and user costs (f) will be used as aggregation weights to measure capital services. And user costs are calculated on the basis of depreciation model and age-price profile. Since there is a one-to-one correspondence between age-price profile and age-efficiency profile, the key to calculate capital services is the selection of the following parameters and variables:

2.2.1 Age-Efficiency Profile

Age-efficiency profile is used to describe how the efficiency of a single asset declines over time. Its specific from is an empirical issue. And hyperbolic model and geometric model are relatively common in practice. The productive efficiency of assets declines rapidly at the very beginning but slowly in the later stage in geometric model. However it is just the opposite in hyperbolic curve model. It is not difficult to hold a techniques monopoly for R&D products at the very beginning with unobvious decline of efficiency. But the productive efficiency will drop quickly in the later stage influenced by technology spillovers and substitution of new technology. Therefore the hyperbolic curve model is more proper for R&D products.

$$g_s^i = \frac{T^i - s}{T^i - b^i s} \tag{1}$$

Formula (1) is the functional form of the hyperbolic model of age-efficiency profile. And i denotes asset type; T^i indicates the maximum service life of the asset i; s indicates the age of the asset i ranging from 1 to T^i. Since it is impossible for the assets to retire at the same time, T^i is a random variable following retirement function distribution. g_s^i satisfies the inequality $1=g_0^i>g_1^i>\ldots\ldots g_T^i>g_{T+1}^i=0$ Since the efficiency of a new asset is 1, g_s^i indicates the relative efficiency of assets at different ages compared to new assets. Besides, b denotes efficiency reduction factor. According to the service lives of different assets, b equals to 0.7 for basic research, 0.6 for applied research and 0.5 for experimental development[1].

2.2.2 Retirement Function

Age-efficiency profile defines the functional form of a single asset. Since not all the assets retire at the same time, we need to know the retirement distribution. It is common to choose bell-shaped distribution and its specific functional form is displayed as follows:

$$Y(t) = [(\frac{1}{s}) \times 2\pi^{-\frac{1}{2}}] \times EXP[(-\frac{1}{2})(\frac{t-\bar{T}}{s})^2] \tag{2}$$

As shown in formula (2), Y(t) denotes the retirement ratio of some asset after it has been serving for t years; $\bar{T}$ indicates the average service life of this asset type; s denotes the standard deviation of the service life and generally it equals to $\bar{T}/4$. We can get the comprehensive efficiency vector $h^i=(1,h_1^i,h_2^i,\ldots\ldots)$ of investment flows with age-efficiency profile and retirement function.

2.2.3 Productive Capital Stock

Productive capital stock is different from wealth capital stock. Not only the decline in asset efficiency but also the decline of asset price presents the change in investment over time. Accordingly, productive capital stock is displayed with age-efficiency profile while wealth capital stock is displayed with age-price profile. Productive capital stock is usually regarded as volume concept and capital service is recognized as a proportion of it. For a single asset, the rate of change of capital services will equal the rate of change of productive capital stock.

$$K_t^p = K_{t-1}^p(1-\delta) + I_t = \sum_{\tau=1}^{\infty} h_\tau^i I_{t-\tau} \tag{3}$$

K_t^p indicates productive capital stock and h_t^i denotes the comprehensive efficiency parameter considering retirement function in formula (3). The measuring principle of productive capital stock is consistent with PIM. What is to note is that δ means efficiency loss other than the decline of price.

2.2.4 User Costs

Productive capital stock is a volume indicator and user cost defines the unit price of it. In a perfect market, user costs equal the rental price of capital goods. In fact, a lot of assets are for self-use, and we can't observe the rental price of this part of assets in an imperfect market. So we use user costs to distinguish from it.

Since it is correlated with the aggregation of different

[1] Generally, the longer the service life, the higher the value of b. The Australian Bureau of Statistics (2000) sets the b value of a database product is 0.5.

assets to calculate the total capital service indices, we should carefully determine the formula form and aggregation weights. It is appropriate to use chained superlative indices, among which we choose Tornqvist index. On the other hand, the aggregation weight of each asset is relative to the share of its capital return in the total capital returns. As capital return is the product of user cost and capital service, it is necessary to get information on the user cost of each asset.

$$f_t^i = q_t^i \times (r_t^i + d_t^i) - (q_t^i - q_{t-1}^i) \tag{4}$$

Formula (4) is the expression of user cost derived by asset pricing formula. In the formula, q_t^i denotes the purchasing price of capital goods in year t and q_{t-1}^i denotes the price in year t-1; r indicates the rate of return of capital goods; d denotes the depreciation rate. Therefore user cost is composed of three parts: capital return, capital consumption and changes in capital value brought by inflation.

2.2.5 Rate of Return

There are two methods to calculate the rate of return: internal rate of return and external rate of return. Taking full account of all the assets' contribution to production, capital services are the sum of consumption of fixed capital and operating surplus. Internal rate of return is calculated according to the following identity.

$$\sum_i f_t^i K_t^i = \sum_i q_t^i \times \left(r_t^i + d_t^i - \frac{q_t^i - q_{t-1}^i}{q_t^i} \right) \times K_t^i \tag{5}$$

The left side of the equation is the sum of capital returns, which can be obtained from national account. And r in equation (5) is the internal rate of return. While external rate of return is directly assigned to be equal to certain interest rate, without regard to the equilibrium relation of the account. No final conclusion has yet been reached on the matter of applying which return in academic research. We assume all the assets are involved when calculating internal rate of return, which means there is no unobservable asset, or we will get a biased result. What's more, we tend to underestimate the internal rate of return since there are non-market sectors. For these reasons, the paper uses external rate of return in calculation. Referring to the average return of corporate bonds of domestic enterprises and long-term loan interest rate of bank, we assign 10% to the rate of return of capital on R&D.

3. EMPIRICAL ANALYSIS OF R&D CAPITAL SERVICES

3.1 Parameter Selection and Data Sources

According to the measurement framework previously discussed, the parameter variables required for estimating China's R&D capital services mainly include: categorized annual investment sequences of R&D expenditure, price index, base-year stock, service lives of assets, depreciation rate and other information.

3.1.1 Investment Data

Strictly speaking, the base data for calculating investment flows should be fixed capital formation data. Due to lack of statistics on R&D capital, in China we substitute the internal expenditure sequences of capitalized R&D for it. According to "China Statistical Yearbook", the internal expenditure of R&D refers to the actual annual expenditure on R&D activities within the researching institutions, excluding that on the productive activities, repayment of loans, and the transferred capital to cooperating institutions or entrusting institutions. The capitalization rates of different types of R&D expenditure are set according to the previous context. The data for calculation come from "China Statistical Yearbook".

3.1.2 Price Index

In order to avoid the influence of inflation upon capital service calculation, we use adjusted data by price indices of investment sequences. R&D price index construction has been a tough problem in innovative economics. Current methods include: a. Set the price index of R&D expenditure as the weighted average of the price indices of non-financial enterprise salary and the implied price index of GNP; b. Set the price index of R&D expenditure as the weighted average of CPI and the price index of fixed assets investment; c. Set the price index of R&D expenditure as the weighted average of the price index of raw material import and the price index of fixed assets investment. Evidently, there is yet no uniform standard and principle. This paper employs the second method, setting 0.5 for both the weights of CPI and the price index of fixed assets investment.

3.1.3 Base-Year Stock

As for formula (3), due to lack of access to investment flows longer than the researching period, we have to set the capital stock of the base year. Since there are two indicators, productive capital stock and wealth capital stock, accordingly we have two groups of data. The base-year stock of R&D is on the assumption that the average growth rate of capital stock equals that of the R&D expenditure, i.e.

$$\frac{K_t - K_{t-1}}{K_{t-1}} = \frac{I_t - I_{t-1}}{I_{t-1}} = v \tag{6}$$

In formula (6), v is the average growth rate of R&D expenditure. When t=1, according to formula (3) and (6), we have

$$K_0 = \frac{1+v}{v+\delta} I_0 \tag{7}$$

δ in formula(7) indicates a decline of 1-h_1 in the relative efficiency in productive capital stock; in wealth capital stock it means a depreciation rate of d_1. Thus, we can calculate the productive capital stock and wealth capital stock of R&D in the base year.

3.1.4 R&D Service Lives

Formula (1) and (2) require the average service lives of the three types of R&D assets. According to Fraumeni (1997)'s estimation, the average service life of computer software (including the self-owned and the purchased) is 5 years; that of copyrighted products is 15 years. In China, it is generally held that the average life of patents is 6 years. This paper holds that the average service life of the three types of R&D assets should be included in the mentioned estimation. On this basis, we set the average life of fundamental research is 15 years, that of application research is 8 years, and that of experimental development is 5 years.

3.1.5 Depreciation Rate

There are four methods in BEA satellite accounts to define depreciation rate: production function method, amortized depreciation model, patent renewal model and market evaluation model. Each of the four methods has its limits. There is a also popular solution in empirical research: directly setting the R&D depreciation rate as 15%, which is from experience. Differently, this paper obtains the depreciation rate from the age-efficiency profile. In the capital service theory, depreciation rate reflects the decreased capital value along with the increase of capital service years. The age-price profile and the age-efficiency profile have one-to-one correspondence, i.e.

$$\frac{p_s^i}{p_0^i} = \frac{(h_s^i + h_{s+1}^i/(1+r) + h_{s+2}^i/(1+r)^2 + \cdots)}{(1 + h_1^i/(1+r) + h_2^i/(1+r)^2 + \cdots)} \tag{8}$$

On the left side of the equation, the price ratios of capitals with different service lives reflect the depreciation rates. From the right side of the equation, it can be seen that the depreciation rates are described by age-efficiency profile (h) and rate of return (r). Once the age-efficiency profile is determined from formula (1) and (2), we can endogenously obtain capital depreciation rates, without resorting to extra data.

3.2 Results

We calculate R&D capital services in China from 1995 to 2011, on the basis of the measuring procedure of capital services and the capital investment related parameters. It is listed the comprehensive efficiency parameter and depreciation rate by age of the three types of R&D capital in Table 1.

Table 1
Comprehensive Age-Efficiency and Depreciation Rates by Asset Type

Age of assets	H1	H2	H3	D1	D2	D3
1	0.999736	0.998650	0.991802	0.102038	0.206970	0.322554
2	0.977379	0.924425	0.700572	0.112189	0.227254	0.351348
3	0.948046	0.742363	0.158891	0.118891	0.227195	0.263422
4	0.901419	0.403225	0.004684	0.124853	0.194026	0.060873
5	0.819399	0.113325	0.000011	0.127918	0.109323	0.001799
6	0.685343	0.013650	-	0.124139	0.031264	-
7	0.504281	0.000613	-	0.109468	0.003794	-
8	0.312762	0.000008	-	0.083834	0.000171	-
9	0.157764	-	-	0.053523	-	-
10	0.062904	-	-	0.027560	-	-
11	0.019358	-	-	0.011151	-	-
12	0.004491	-	-	0.003467	-	-
13	0.000762	-	-	0.000811	-	-
14	0.000089	-	-	0.000138	-	-
15	0.000006	-	-	0.000016	-	-

Remarks: H denotes comprehensive age-efficiency, D denotes depreciation rate, and number 1, 2, 3 denotes basic research, applied research and experimental development.

From Table 1 we can see, the capital efficiency is going down gradually at the beginning stage and declines rapidly in final stage in hyperbolic curve model. Accordingly, the depreciation of capital on R&D changes in the same way because age-efficiency profile and age-price profile are connected by return on assets in this model. Though the two profiles are related which results in the similarity in the above change trend, they are unequal. As a consequence, the productive capital stock and the wealth capital stock is different and the calculation results are listed in Table 2.

Table 2
The Productive and Wealth Capital Stock by R&D Type (unit: hundred million)

Year	K^P1	K^P2	K^P3	K^P	K1	K2	K3	K
1995	67.8	524.7	857.1	1449.5	42.5	270.9	529.1	842.5
1996	76.9	596.0	1107.1	1780.0	46.4	272.0	534.0	852.4
1997	86.6	639.7	1070.1	1796.4	50.8	264.0	453.8	768.7
1998	95.3	601.3	685.0	1381.5	53.4	227.0	351.8	632.3
1999	103.3	463.9	616.9	1184.1	55.3	191.8	359.2	606.3
2000	111.2	320.8	754.8	1186.8	58.4	163.7	447.2	669.3
2001	115.7	278.0	865.8	1259.6	61.2	162.0	577.8	801.0
2002	118.6	298.6	954.5	1371.7	66.0	181.5	555.7	803.2
2003	119.9	338.9	1034.2	1493.0	71.2	208.5	600.9	880.6
2004	126.0	393.6	1158.3	1677.9	80.0	323.3	677.2	1080.6
2005	134.1	430.5	1339.4	1904.0	87.8	260.2	785.5	1133.6
2006	145.1	451.7	1518.6	2115.4	95.6	268.4	886.5	1250.5
2007	155.4	442.7	1709.5	2307.5	101.2	257.4	998.5	1357.1
2008	168.4	436.4	1944.2	2549.0	109.1	254.7	1137.4	1501.2
2009	183.2	453.4	2230.5	2867.1	118.7	271.1	1305.9	1695.8
2010	198.8	490.0	2503.4	3192.2	129.1	297.3	1459.9	1886.3
2011	218.6	532.6	2813.8	3565.0	154.3	322.3	1643.8	2120.3

Remarks: K^P denotes productive capital stock, K denotes wealth capital stock, and number 1, 2, 3 denotes basic research, applied research and experimental development.

The productive capital stock and the wealth capital stock of the three kinds of R&D capital are both increasing year by year as is shown in Table 2. The productive capital stock increases from 144.95 billion in 1995 to 356.5 billion in 2011 and the wealth capital stock increases from 84.25 billion in 1995 to 212.03 billion in 2011. The share of the three kinds R&D capital in the total productive capital stock is changing with time: the proportion of experimental development rises from 59% at the beginning to 79% in 2011; the share of basic research increases from 4.6% to 9.1% in 2011 and later declines gradually to 6.1% in 2011; the proportion of applied research is almost decreasing through the whole study period from 36% to 15%. Besides, the share of the three kinds of R&D capital in wealth capital stock changes in the same way but more smoothly.

In terms of the increment speed, productive capital stock and wealth capital stock both increase more quickly at a steady speed at the later stage but even appear to decrease at the beginning. This is mainly due to the short service lives of R&D capital on average and the fast depreciation of base year's capital stock. Generally speaking, the effect of base-year stock on capital accounting is weakening as the study goes on. Since it is not long before China develop its R&D expenditure accounting, we can't neglect completely the influence of base-year stock on the study conclusion. Besides, the increment speed of the three kinds of R&D capital stock in different stages is distinct from each other: basic research stock rises rapidly at the beginning; experimental development stock increases fast at the later stage; the increment speed of applied research stock changes irregularly in different stages. And it shows the phenomenon that the composition of R&D investment in China is tilting from basic research toward experimental development.

Compared the productive capital stock with the wealth capital stock, we find the productive capital stock of each kind of R&D capital is larger than the wealth capital stock, which is in conformity with the empirical theory. Take bulb for example. The productive efficiency (representative of productive capital stock) of an old bulb declines insignificantly compared to a new bulb. However, the value (representative of wealth capital stock) of an old bulb is notably lower than a new bulb. As a result, the productive capital stock is larger than the wealth capital stock measured in macro view. At last, we can obtain R&D capital service indices on the basis of depreciation rate, rate of return and other information.

Table 3
The R&D Capital Services Indices of China (1996-2011)

Year	Index 1	Index 2	Index 3	Indices	Year	Index 1	Index 2	Index 3	Indices
1996	1.135	1.136	1.292	1.231	2004	1.051	1.161	1.120	1.127
1997	1.126	1.073	0.967	1.012	2005	1.064	1.094	1.156	1.134
1998	1.100	0.940	0.640	0.769	2006	1.082	1.049	1.134	1.111
1999	1.084	0.772	0.901	0.872	2007	1.071	0.980	1.126	1.092
2000	1.077	0.691	1.223	1.052	2008	1.084	0.986	1.137	1.106
2001	1.040	0.867	1.147	1.076	2009	1.088	1.039	1.147	1.125
2002	1.025	1.074	1.102	1.089	2010	1.085	1.081	1.122	1.113
2003	1.011	1.135	1.084	1.089	2011	1.099	1.087	1.124	1.116

Remarks: numbers 1, 2, 3 denote basic research, applied research and experimental development.

CONCLUSION AND SUGGESTION

In macroeconomics, the measurement of R&D input and its contribution to production is always the hot spot in theoretical circle. Although R&D has been recognized as capital in GDP accounting, there are still many technical details to be perfected in practice of R&D capital measurement, owing to many reasons including the differences in the market efficiency and data foundation. Referring to the exposition of capital services in SNA2008, this paper makes full use of the available data to estimate the R&D capital services of China from 1995 to 2011 with PIM method. Since research on the capital service measurement is not mature in China, our paper lays data and literature foundation for study on quantifying the contribution of capital to economic growth.

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