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Measuring the Regional Capital Services of R&D in China: 1998-2012

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Abstract

R&D expenditure has been identified as part of 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. 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 helps to the literature by exploring the parameters in estimation of R&D assets in China. Then the calculation results of regional capital services on R&D from 1998-2012 are finally obtained.

Key words: Capital service; R&D; Productive capital stock; Regional

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INTRODUCTION

New growth theory suggests that technological progress is the ultimate source and the continuing momentum of a country's economic development. Quantifying the contribution of R&D investment to production and growth has been amongthe important issues of economics. With the latest revision 2008 SNA (the United Nations' System of National Accounts) treating R&D as a fixed asset in the achievement of economic growth and introducing the concept of capital services, the measurement of R&D input has become a hot issue in the economic growth studies once again.

The existing research on R&D input measurement has experienced a deepening and perfecting process. People use of current flow or its lag flow of R&D investments to measure the innovation input in the early empirical studies. Because R&D input is a continuous process, measures that simply use periods of R&D spending as the input cannot reflect the accumulation of knowledge capital. The R&D capital is often regarded as the current state of technical knowledge, which is determined by the current and previous R&D investments. Therefore, the scholars began to be used the R&D capital stocks as variables to estimate the production function.

There are still two issues to date. One is the boundary of data used to calculate the R&D capital stock, namely, the statistical scope of R&D capital and whether capital stock is the optimal variable to estimate capital input. The main issue relates to the understanding of the nature of R&D capital. SNA2008 treats the R&D expenditures as fixed capital formation for the first time, this part of "new" capital formation will change the scale of GDP and have a profound impact on capital accounting. Although R&D expenditures have been treated as capital, not all of them belong to capital; the boundary is whether it can bring economic benefits to the owners. In other words, the R&D expenditure that cannot bring economic benefits is still intermediate consumption, rather than capital.

The second issue relates to the measurement methods of capital input. In macroeconomics, for a long time, people used "durable goods stock" to define and measure capital, such as Jorgenson (1963), Jorgenson and Griliches's (1967) growth model, Hall and Jorgenson's (1967) construction of capital accounting framework, and Hulten and Wykoff's (1981a, 1981b) estimation of the capital depreciation rate. Later, many economists realized that it is the capital services flow, rather than the capital stock, which determines output. Namely, the capital input should be the capital services provided by capital goods within a period of time. To this end, the latest revision 2008 SNA specifically adds a new chapter for capital services to introduce how capital input is accounted and recorded in the production process. Related theories and methods come from the OECD Measuring Capital Manual and Measuring Productivity Manual.

Thereafter, many scholars based on the framework of capital services to perform empirical research. Oulton and Srinivasan (2003) established an empirical analysis framework of capital services accounting; Schreyer, Bignon and Dupont (2003) estimated the service flow of material capital in Australia, Canada, France, Germany, Italy, Japan, the UK, and America, including ICT capital from 1980 to 2001; Erumban (2008) compared the differences between EU and American in capital rental price, return rate and capital productivity; Gavin (2009) measured the British capital services from 1950 to 2006; and Robert Inklaar's (2010) empirical estimation of American capital services from 1977 to 2005 found that the choice of return rate has an important effect on the measurement results.

Currently, China only has stock-level R&D capital accounting since the R&D input accounted as capital for a short time. When Wu (2006) studied the productivity of industrial sectors, he used Chinese large- and medium-sized industrial enterprises' panel data to estimate the industrial R&D capital stock; Wang (2009) estimated 28 Chinese manufacturing industries' R&D capital stock from 1998 to 2005; Xiao and Xie (2009) estimated the R&D capital stock of China's 31 provinces during 2000 to 2006 and explored the spatial distribution features; and Wang (2011), based on the U.S. R&D satellite account, introduced and analyzed the R&D capital stock estimation methods of BEA. Overall, these studies are still limited to the stock-level of R&D and to neglect the flow-level, such as R&D capital services.

In the accounting of capital input, at present, China only has capital services studies regarding fixed assets. The measurement of R&D capital has not been involved. Sun and Ren (2005) first reviewed the related theory of capital services and estimated the total factor productivity of China based on the concept of capital services. Subsequently, Sun and Ren (2008) estimated the capital services index in China from 1981 to 2000 at the industry level. Due to the infinite geometric depreciation model that is different from the actual situation, Cai (2009) first applied a hyperbolic function estimating capital services index in China from 1978 to 2007. Cao and Qin (2012) estimated the capital services index of China from 1978 to 2010; compared to the former research, their studies improve on the technical details such as the selection of depreciation rate. However, the calculation results that the productive capital stock is less than the wealth capital stock is contrary to the basic theory of capital services measurement.

In summary, the capital services research of China currently has problems such as a limited perspective and inadequate systematization. In addition, although in the background, R&D has been considered one of the fixed assets in the international standards accounting system, the measurement of R&D capital services in China is still empty. Based on these conditions, this paper takes R&D capital as the research object, using capital services measurement methods, to estimate the Chinese regional R&D capital services from 1998 to 2012 and provide data and a literature basis for studies about quantifying R&D's contribution to economic growth.

1. MEASUREMENT FRAMEWORK OF R&D CAPITAL SERVICES

1.1 Accounting Scope Demarcation

Depending on SNA2008, assets which generate capital services are those non-financial assets contributing to the production process. Specifically, they include fixed assets, inventories, natural resources and contracts, leases and licenses used in production. As a new part of fixed capital formation, R&D expenditures also produce capital services. However, not all R&D expenditures can be considered to be capital; the necessary condition is that the expenditure can bring economic benefits to the owner.

According to the statistical caliber of "Frascati Manual", R&D expenditures are distributed into three types: basic research, applied research and experimental development. If taking market products as the sign of economic benefits, then basic research is obviously distant from the concept of capital, applied research follows, and experimental development is the most likely to be put into market production. Although most of the basic research is similar to public products whose expected returns are indirect, its economic benefits will be embedded in the subsequent products of applied research and experimental development, rather than consumed completely. Therefore, this paper considers that the distinction between basic research and the other two R&D expenditures is mainly reflected in capitalization rates and sets the capitalization rate of basic research as 50% and of applied research as 80%, with experimental development for all transformation.

The contribution of various factors in production is taken into account in the value-added; labor's contribution to production is regarded as the compensation of employees and capital's contribution to production is regarded as capital services. In the production accounting, value-added also includes the consumption of fixed capital and operating surplus, except for the compensation of employees. When all of the capital can be adequately considered, the sum of these two parts (consumption of fixed capital and operating surplus) is exactly the capital services itself. In this way, it seems easy to measure the size of capital services; however, for a particular asset, it is difficult to distinguish the corresponding part from the total capital service expressed as the consumption of fixed capital and operating surplus. Therefore, calculating the capital service of a certain type of asset needs a bottom-up approach.

1.2 The Method of Estimating R&D Capital Services

The so-called bottom-up way of computing capital services is a process that begins with a single type of capital data, calculating the capital service of this type of asset with the PIM method, and then summing the total capital services using user costs as weights. After the capital formation data (*I*) are collected, we need to obtain information on the capital retirement distribution ($Y(t)$) and its age-efficiency profile ($g(t)$) to calculate the productive capital stock ($K^p(t)$). Rates of return (r) and user costs (f) will be used as weights to aggregate the total capital services. The key to calculating capital services is the selection of the following variables:

1.2.1 Age-Efficiency Profile

The age-efficiency profile is used to describe how the efficiency declines for a definite asset over time. The specific form of age-efficiency profile is an empirical question itself, while hyperbolic model and geometric model are relatively common in empirical research. In a hyperbolic model, assets lose little of their productive capacity during the early stages of their service lives but experience rapid loss of productive capacity towards the final stage of their service lives. In a geometric model, on the contrary, assets experience rapid loss of productive capacity during the early stages of their service lives but lose little of their productive capacity towards the final stage of their service lives. At the early stage, it is not difficult to keep technical monopoly, so there will be an unobvious decline in efficiency for R&D products. However, the productive efficiency will drop quickly at the final stage, influenced by technology spillovers and technical substitution. Therefore, the hyperbolic model is more proper for R&D products.

$$g_s^i = \frac{T^i - s}{T^i - b^i s} \quad (1)$$

Equation (1) is the function of the age-efficiency profile in the hyperbolic model. The variable i indicates the type of assets, T^i indicates the asset's service life, and s indicates the age of the asset i ranging from 1 to T^i. Because it is unlikely that all the assets of the same type retire at the same time, T^i is a random variable following the distribution of retirement profile. For the relative efficiency $g^i{}_s$, we have $1 = g_0^i > g_1^i > \ldots\ldots g_T^i > g_{T+1}^i = 0$. Because the efficiency of a new asset has been set to equal one, every $g^i{}_s$ represents the relative efficiency of an s-year-old asset compared to a new asset. Moreover, b denotes an efficiency reduction parameter. According to the service lives of different assets, b equals 0.7 for basic research, 0.6 for applied research and 0.5 for experimental development[1]. According to equation (1), we made three types of R&D assets' age-efficiency profile, shown in Figure 1.

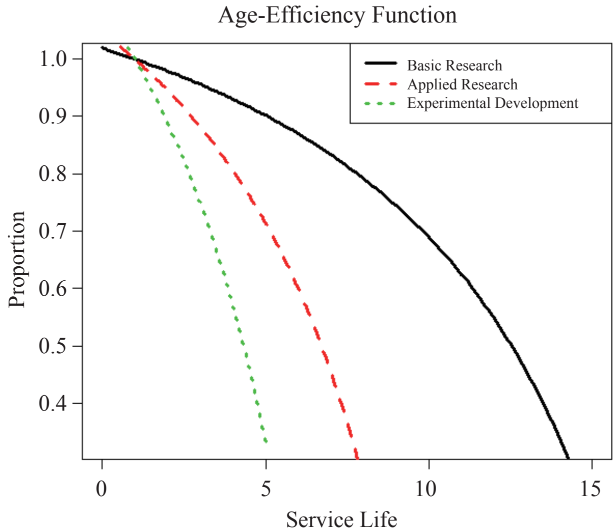

Figure 1
Age-Efficiency Profile for Three R&D Assets

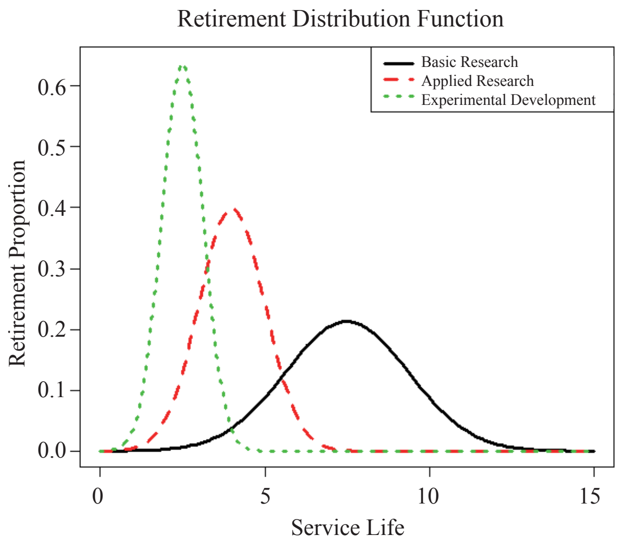

Figure 2
Retirement Distribution for Three R&D Assets

1.2.2 Retirement Distribution

The age-efficiency profile above has been formulated for a distinct asset. When the whole cohort of a type of assets is considered, we need to know the retirement distribution because not all the asset retire at the same time. It is common to choose a bell-shaped distribution and its specific function is displayed as follows:

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

$$Y(t) = [(\frac{1}{s}) \times 2\pi^{-\frac{1}{2}}] \times \exp\ [(-\frac{1}{2})(\frac{t-\overline{T}}{s})^2] \qquad (2)$$

As shown in equation (2), $Y(t)$ denotes the retirement ratio of certain asset type after have been serving for t years, $\overline{T}$ indicates the average service life of this asset type, and s denotes the standard deviation of the service life, which generally equals $\overline{T}/4$. Combining the age-efficiency profile with the retirement function, we obtain the comprehensive efficiency vector $h^i = (1, h_1^i, h_2^i, \ldots\ldots)$.

1.2.3 Productive Capital Stock

Productive capital stock is similar but different from wealth capital stock. Assets' change over time not only reflects the decline in efficiency but also the decline in price. Accordingly, productive capital stock is displayed by an age-efficiency profile whereas wealth capital stock is displayed by an age-price profile. Usually, the productive capital stock is regarded as a volume indicator and the assumption is made that the flow of capital services is in constant proportion to the productive stock of an asset class. Therefore, the rate of change of capital services will equal the rate of change of the productive stock.

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

In equation (3), $K^p{}_t$ indicates the productive capital stock and $h^i{}_t$ denotes the comprehensive efficiency considering the retirement distribution. The principle of measuring productive capital stock is consistent with PIM (Perpetual Inventory Method). Notably, δ means efficiency loss other than the decline in price.

1.2.4 User Costs

User costs constitute the price for the flow of capital services. The total value of capital services is obtained by multiplying the user costs by the flow of capital services. In a perfect market, user costs equal the rental price of capital goods. In fact, many assets are for self-use and we cannot observe the rental price of such assets in an imperfect market. So we user costs to distinguish it.

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

Equation (4) is the expression of user costs derived from the asset pricing model. In the equation, $q^i{}_t$ denotes the purchase price of assets in year t and $q^i{}_{t\text{-}1}$ denotes the price in year *t*-1, *r* indicates the rate of return, and d denotes the depreciation rate. Therefore, user cost is composed of three parts: capital return, capital consumption and capital value changes brought by inflation.

When aggregating the total capital services from different types of assets, we need to consider the selection of the index formula and aggregation weights. It is adapted to use chained superlative indices, among which we choose the Tornqvist index. On the other hand, the aggregation weight of each type of asset is the proportion of its capital return within the gross capital return. As capital return is the product of user cost and capital service, it is necessary to collect information on the user cost of each asset.

1.2.5 Rate of Return

There are for two types of rate of return: endogenous rate of return (calculated using the observed remuneration capital) and exogenous rate of return (such as a specific interest rate). When taking fully into account allthe assets' contribution to production, capital services are the sum of fixed-capital consumption and operating surplus. Thus, the endogenous rate of return can be calculated according to the equation as follows.

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

The left side of the equation is the sum of capital return, which can be obtained from the production account, and r coming from equation (5) is the endogenous rate of return. The exogenous rate of return is directly assigned to equal some specific interest rate, without regard to the equilibrium relation of accounting. No final conclusion has yet been reached in which the rate of return is better. For the endogenous rate of return, all the assets should be associated with the calculation, which means there is no unobservable asset; otherwise, there would be a biased result. Furthermore, the endogenous rate of return will result in an underestimation when there are non-market sectors. For these reasons, this paper uses the exogenous rate of return in the calculations. Referring to the domestic average returns on corporate bonds and banks' long-term loan interest rate within the study period, we assign 10% to the rate of return of R&D capital.

2. EMPIRICAL ANALYSIS

2.1 Data and Parameter Estimation

According to the measurement framework previously discussed, the data and parameters required for estimating the regional R&D capital services of China mainly include: the categorized time series of R&D investment at the regional level, constant-quality price indices, the base year's stock, service lives for different assets and depreciation rates.

(1) Investment data. Strictly speaking, the best variable for calculating investment flows should be capital formation. Due to the lack of related statistics on R&D capital, we substitute the internal expenditure series of capitalized R&D for it. According to the "China Statistical Yearbook on Science and Technology", the internal expenditure of R&D refers to the real expenditure of surveyed units on their own R&D activities (basic research, applied research, experimental development) including the direct expenditure on R&D activities, indirect expenditure

of management and services on R&D activities, and expenditure on capital construction and material processing by others. The capitalization rates of different types of R&D expenditures are set according to the previous context. The data for the calculation come from "China Statistical Yearbook on Science and Technology".

(2) Constant-quality price indices. To avoid the influence of inflation, we adjusted the internal expenditure series of capitalized R&D by the price indices in estimation. R&D price indices have been a difficult problem in innovative economics. Current methods include: a) setting the price indices of R&D expenditures as the weighted average of the index of non-financial enterprise salary and the implicit price index of GNP; b) setting the price indices of R&D expenditures as the weighted average of CPI and the price index of investment in fixed assets; and c) setting the price indices of R&D expenditures as the weighted average of the raw material purchasing price index and the price index of fixed assets investment. Evidently, there is not a unified standard and principle yet. This paper employs the second method, using 0.5 for both the weights of CPI and the price index of fixed assets investment.

(3) R&D capital stock in the base year. As for equation (3), due to the lack of investment data beyond the research period, we must set the productive capital stock of the base year. Because there are for two variables—productive capital stock and wealth capital stock—accordingly, we need two groups of data. The base year stock of R&D is built on the assumption that the average growth rate of capital stock equals that of the R&D expenditure:

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

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

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

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

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

(5) Depreciation rates. There are four methods of BEA's R&D Satellite account to estimate the depreciation rate: production functions, amortization models, patent renewal models and market evaluation models. Each of the four methods has its limits. There is also a popular solution in empirical research: directly setting the R&D depreciation rate as 15%, which are taken from experience. Alternatively, this paper obtains the depreciation rate from the age-price profile. In capital service theory, the depreciation rate reflects the decrease in capital market value along with the increase of capital service years. So it can be expressed in an age-price profile, which can be derived from the age-efficiency profile:

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

The ratio of prices with different capital ages on the left side of the equation reflects the depreciation rate. It can be observed that the depreciation rates are described by the age-efficiency profile (h) and rate of return (r) from the right side of the equation. Once the age-efficiency profile is is established from equation (1) and (2), we can endogenously obtain capital depreciation rates, without resorting to extra information.

2.2 Result Analysis

According to the measurement framework of capital services and the related parameters, we calculated R&D capital services and its index of each region in China during 1998-2012. Table 1 shows the R&D productive capital stock of each region. According to Table 1, the productivity capital stock of R&D was growing during the study period. The total R&D productive capital stock of China increased from 131.17 billion dollars in 1998 to 1842.39 billion dollars in 2012, rising by 14 times at an annual growth rate of 20.8%.

Table 1
The Regional R&D Productive Capital Stock (1998-2012) (Unit: hundred million)

Region	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Beijing	290.7	392.0	421.0	370.1	364.5	395.7	447.0	508.3	569.2	662.2	760.6	1092	1450	1734	2006
Tianjin	29.1	40.3	49.8	46.4	47.3	53.9	70.5	97.5	127.5	154.2	204.8	302.3	409.6	519.6	635.7
Hebei	25.5	38.6	45.5	38.8	46.7	58.0	62.3	79.7	113.8	153.6	195.7	272.3	333.2	380.8	441.2
Shanxi	16.1	22.7	25.3	22.9	24.7	27.3	36.2	44.3	59.1	78.7	98.4	137.2	171.8	205.9	241.6

To be continued

Continued

Region	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Inner Mong	2.6	4.1	5.3	5.7	6.9	9.1	11.9	17.0	25.1	36.4	51.9	85.6	117.1	148.1	178.3
Liaoning	68.5	94.4	105.6	104.3	111.7	130.7	164.5	204.6	236.7	280.5	335.5	435.7	541.2	645.7	722.7
Jilin	25.3	31.0	35.0	35.4	37.4	37.4	44.3	54.6	65.7	78.3	92.7	135.0	156.3	168.4	196.9
Heilonjiang	44.4	56.1	58.4	54.6	50.0	54.2	62.2	78.7	92.3	106.9	139.5	195.4	243.9	267.7	287.0
Shanghai	123.2	164.3	187.9	184.8	198.5	222.2	271.8	341.0	413.4	480.3	546.5	756.8	955.5	1119	1270
Jiangsu	84.0	123.5	145.3	153.5	174.5	215.1	288.4	391.5	531.8	692.1	874.4	1218	1563	1876	2230
Zhejiang	24.2	34.4	45.8	49.9	55.1	74.7	119.0	189.3	267.4	338.4	403.1	631.7	866.5	1046	1245
Anhui	23.0	31.7	41.2	40.3	46.2	55.3	63.5	76.5	100.7	131.4	172.9	245.4	311.0	378.7	478.1
Fujian	17.3	24.9	29.5	30.9	33.4	43.1	57.1	72.6	90.4	110.9	135.1	227.4	322.9	400.0	479.1
Jiangxi	14.1	19.7	22.4	18.8	17.7	23.4	32.6	44.6	60.8	82.2	106.7	148.5	182.8	193.7	207.6
Shandong	62.2	86.9	109.8	117.9	141.5	167.6	216.0	285.8	361.8	462.1	617.7	920.6	1241	1506	1790
Henan	29.6	41.8	52.3	52.6	52.2	55.5	66.6	87.0	118.6	155.0	194.6	286.2	376.3	456.3	536.9
Hubei	57.6	81.3	90.5	80.0	80.0	84.1	93.8	117.0	146.6	180.7	232.9	355.5	475.4	577.0	683.4
Hunan	25.3	34.8	40.7	41.7	41.3	44.3	52.2	64.1	81.0	107.2	147.9	241.5	332.0	411.6	502.6
Guangdong	118.9	171.4	210.7	235.1	245.5	262.5	300.3	364.6	466.7	614.8	773.6	1156	1540	1864	2183
Guangxi	4.8	6.5	10.6	12.0	13.6	16.5	18.2	21.5	27.4	34.5	46.0	75.1	107.9	139.0	170.2
Hainan	2.2	3.2	3.5	3.2	2.9	2.6	2.9	2.9	3.1	3.8	5.4	9.1	12.5	17.3	23.4
Chongqing	11.5	17.0	20.6	18.4	18.7	23.6	33.3	48.0	64.5	83.1	101.0	142.6	188.8	229.6	280.0
Sichuan	80.6	110.4	122.9	117.1	114.8	129.0	142.2	168.8	197.5	243.4	286.4	373.5	477.1	559.3	656.7
Guizhou	6.4	8.8	10.1	9.8	10.6	13.0	15.1	17.9	23.1	26.4	32.3	46.9	59.5	69.7	79.2
Yunnan	12.9	17.5	18.5	15.8	16.6	18.7	21.4	31.5	37.6	43.6	50.0	62.9	79.6	100.5	124.3
Tibet	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.8	1.1	2.1	2.7	2.7	3.2
Shaanxi	80.4	108.1	128.9	120.2	118.0	123.0	140.6	162.7	179.2	207.7	252.9	325.3	393.4	455.0	524.5
Gansu	21.4	26.7	27.7	25.3	25.1	25.8	27.8	33.1	38.8	46.0	55.6	71.8	87.5	100.1	115.9
Qinghai	2.6	3.3	3.8	3.6	3.8	4.3	4.9	5.1	5.7	6.7	7.5	12.2	17.8	22.9	25.6
Ningxia	2.1	2.8	3.6	3.3	3.1	3.3	4.2	5.4	7.4	10.4	12.1	17.5	22.5	27.4	32.8
Xinjiang	4.9	7.0	8.4	8.3	8.1	8.3	10.2	12.1	15.4	18.7	25.3	37.2	49.9	61.8	73.0

As far as regional level and structure are concerned, these regions have a relatively higher productive capital stock of R&D: Beijing (an average of 76.42 billion Yuan), Jiangsu (an average of 70.41 billion Yuan), Guangdong (an average of 70.05 billion Yuan) and Shandong (an average of 53.91 billion Yuan). The regions that have a relatively lower productive capital stock of R&D include Tibet (an average of 0.11 billion Yuan), Hainan (an average of 0.65 billion Yuan), Qinghai (an average of 0.86 billion Yuan), Ningxia (an average of 1.05 billion Yuan), Xinjiang (an average of 2.32 billion Yuan) and Guizhou (an average of 2.86 billion Yuan).

In terms of proportion, the sum of the five regions of Beijing, Guangdong, Jiangsu, Shanghai and Shandong accounted for 52% of the total stock and the sum of the ten regions of Tibet, Hainan, Qinghai, Ningxia, Xinjiang, Guizhou, Inner Mongolia, Guangxi, Yunnan and Gansu accounted for less than 5% of the total stock. This shows that the geographical distribution of R&D productive capital stock is extremely imbalanced.

In terms of growth speed and dynamic development, the average growth rate of the national R&D productive capital stock was 20.8% during the study period. Among them, the regions whose growth rate was more than 25% include Inner Mongolia (35.3%), Zhejiang (32.5%), Guangxi (29.1%), Shandong (27.2%), Fujian (26.8%), Jiangsu (26.4%) and Chongqing (25.6%), whereas the regions whose growth rate was less than 15% include Gansu (12.8%), Heilongjiang (14.2%), Shaanxi (14.3%) and Beijing (14.8%). The fastest-growing provinces contain the regions with a low absolute level (Inner Mongolia) and the slowest-growing provinces include the regions with a high absolute level (Beijing). This finding shows that the dynamic structure may have a certain effect on the regional R&D stock level.

This result can also be expressed through the dynamic changes in regional productive capital stock proportion. In 1998, Beijing's share of the country's total capital stock was 22.2% and this proportion dropped to 10.9% by 2012, a decrease of 11.3 percentage points. Those regions that showed the same trend include Shaanxi (dropped 3.3 percentage points), Sichuan (dropped 2.6 percentage points), Shanghai (dropped 2.5 percentage points), Heilongjiang (dropped 1.8 percentage points) and Liaoning (dropped 1.3 percentage points). In comparison, Jiangsu, Shandong, Zhejiang and Guangdong's capital stock rose by 5.7 percent, 4.9 percent, 4.8 percentage points and 2.8 percentage points, respectively. The R&D capital stocks of the remaining regions remained relatively stable.

In terms of the internal structure of productive capital stock[2], the proportion of experimental development rose from 59% in 1998 to 79% in 2012. The proportion of basic research increased from 4.6% in 1998 to 9.1% in 2001 and then gradually decreased to 6.1% in 2012. The proportion of applied research almost steady declined throughout the whole study period, dropping from 36% to 15%. Wealth capital stock has the the exact same structural changes as productive capital stock, but gets more smoothness in tendency.

Table 2 shows the measured results of R&D wealth capital stock of each region in China during 1998-2012. According to Table 2, during the study period, the national R&D wealth capital stock rose from 104.61 billion Yuan in 1998 to 1.065 trillion Yuan in 2012, increasing by approximately 10 times and at an average annual growth rate of 18%.

Table 2
The Regional R&D Wealth Capital Stock (1998-2012) (Unit: hundred million)

Region	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Beijing	229.7	238.8	214.1	186.8	198.8	229.0	261.3	298.2	335.0	393.7	450.7	664.6	864.1	1024.5	1178.9
Tianjin	24.8	25.4	26.8	24.8	27.1	32.0	42.3	58.9	76.0	91.9	126.2	183.0	239.1	302.5	368.8
Hebei	22.1	24.5	24.5	21.7	27.7	33.2	37.2	51.6	73.6	96.3	120.0	160.5	185.2	214.5	253.2
Shanxi	13.9	14.5	13.5	12.2	14.0	16.1	22.1	26.5	35.4	46.6	59.4	83.2	99.3	118.9	138.8
Inner Mong	2.3	2.7	3.0	3.3	4.1	5.5	7.4	10.7	15.7	22.8	32.2	51.8	67.3	85.3	102.4
Liaoning	56.0	58.5	54.7	54.7	61.5	76.9	99.2	122.6	139.8	166.5	199.3	254.8	308.4	371.6	414.9
Jilin	17.5	17.8	17.3	16.8	20.2	21.5	26.7	33.0	39.1	46.1	54.7	81.2	89.4	98.1	117.1
Heilonjiang	31.4	31.7	27.6	25.7	25.4	31.4	36.7	47.3	55.7	65.8	87.0	119.6	142.9	152.4	163.9
Shanghai	95.4	99.9	98.6	96.7	111.2	132.0	164.6	203.7	244.6	284.4	329.5	458.1	550.1	643.6	731.3
Jiangsu	71.2	78.5	77.8	84.0	100.0	129.1	176.1	237.5	318.2	412.8	522.1	719.0	891.9	1073.7	1284.0
Zhejiang	20.4	21.9	25.5	27.4	31.2	46.0	75.0	116.2	158.9	200.0	239.2	379.4	498.5	600.1	718.3
Anhui	18.9	20.2	23.1	22.4	28.0	33.8	39.2	48.4	63.5	80.0	102.9	145.1	178.2	219.2	280.3
Fujian	13.8	15.7	16.2	17.2	19.3	26.6	35.6	44.7	55.5	67.9	83.6	139.4	184.8	227.4	273.5
Jiangxi	10.9	11.6	11.0	9.0	10.0	14.7	20.1	27.7	37.8	50.8	65.3	87.5	101.2	106.9	117.6
Shandong	50.4	55.2	61.2	65.2	82.9	101.1	132.3	173.9	219.0	281.1	380.6	551.9	709.6	859.7	1027.3
Henan	24.4	26.0	27.7	28.0	28.9	32.1	39.1	51.1	70.2	92.0	115.6	169.9	214.8	261.3	308.4
Hubei	48.7	51.4	47.6	42.5	45.2	49.1	55.9	70.2	87.0	107.6	140.3	213.4	275.8	334.3	396.6
Hunan	20.1	21.7	21.5	21.8	22.6	26.0	31.7	38.9	48.4	64.8	90.2	147.2	193.8	238.9	292.2
Guangdong	89.3	106.3	112.9	123.1	133.8	152.3	179.6	219.5	283.6	377.0	475.1	696.3	876.1	1061.9	1251.3
Guangxi	3.8	3.9	6.1	6.8	7.8	9.7	10.6	12.8	16.6	20.9	28.3	45.8	63.5	81.5	99.5
Hainan	1.5	2.0	1.8	1.5	1.4	1.5	1.8	1.7	1.9	2.4	3.4	5.7	7.6	10.5	14.1
Chongqing	10.0	11.0	11.2	9.8	10.9	14.7	21.0	30.5	39.8	50.0	61.2	86.0	109.1	133.1	163.9
Sichuan	66.2	68.3	63.4	61.9	63.8	76.9	84.4	100.7	116.4	143.8	168.1	223.4	282.0	326.4	381.9
Guizhou	5.3	5.6	5.5	5.5	6.2	7.7	8.9	10.8	14.4	16.0	19.8	28.5	34.4	39.9	45.2
Yunnan	10.8	11.0	9.6	8.3	9.6	11.1	12.5	18.9	21.7	25.5	29.6	38.4	47.8	59.8	73.5
Tibet	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.5	0.7	1.3	1.6	1.6	1.9
Shaanxi	64.2	65.0	66.3	61.2	63.8	69.9	82.0	94.2	103.8	122.6	148.2	191.4	229.0	264.0	304.2
Gansu	15.5	16.0	14.0	12.3	13.0	14.1	15.6	19.4	23.1	27.9	34.1	43.8	51.4	57.7	67.3
Qinghai	1.8	1.9	1.9	1.6	2.0	2.4	2.9	3.1	3.5	4.1	4.6	7.6	10.6	13.4	14.7
Ningxia	1.7	1.8	1.9	1.7	1.7	1.9	2.6	3.2	4.5	6.3	7.4	10.8	13.0	15.9	19.0
Xinjiang	3.9	4.4	4.6	4.3	4.4	4.7	6.1	7.4	9.3	11.2	15.6	22.9	29.5	35.8	42.2

[2] Due to the limited paper length, detailed data can be obtained from the author if necessary.

Comparing the wealth capital stock to the productive capital stock, we can find that they are very similar in the sorted results of absolute level. Regions with relatively high R&D wealth capital stock are still Beijing (an average of 45.12 billion Yuan), Jiangsu (an average of 41.17 billion Yuan), Guangdong (an average of 40.92 billion Yuan) and Shandong (an average of 31.68 billion Yuan). Regions with comparatively low wealth R&D capital stock include Tibet (an average of 70 million Yuan), Hainan (an average of 390 million Yuan), Qinghai (an average of 510 million Yuan), Ningxia (an average of 620 million Yuan) and Xinjiang (an average of 1.38 billion Yuan).

For the growth velocity aspect, the R&D wealth capital stock increased at an annual growth rate of 18% during the research period. There is a very slight difference between wealth capital stock and productive capital stock in the sorted results. Regions whose annual growth rates of R&D wealth capital stock exceed 25% only include Inner Mongolia (31.1%), Zhejiang (28.9%) and Guangxi (26.3%). Regions with annual growth rates less than 15% include Gansu (11.1%), Shaanxi (11.8%), Beijing (12.4%), Heilongjiang (12.5%), Sichuan (13.3%), Jilin (14.5%) and Yunnan (14.7%).

Overall, the productive capital stock of every R&D asset is higher than its wealth capital stock, which is more in line with the theory. Take the example of a light bulb: the productivity of a one-year old bulb (expressed as productive capital stock) is not significantly lower than a new one, but its economic value (expressed as the wealth capital stock) is significantly cheaper than a new bulb. Therefore, the macro-measurement also shows the feature that productive capital stock is higher than asset's wealth capital stock.

In addition, both growth rates of the two capital stocks were fast and stable at the end of the study period, although they had even negative growth rates at the beginning of the study. This is mainly because the average service life of R&D capital is very short and the base year's stock depreciates very quickly. Generally, the impact of the base year on capital stock will weaken by lengthening the study periods. However, due to the limited length of statistic data for Chinese provincial R&D expenditures, it is obvious that we cannot completely ignore the impact of the base year on the study conclusions. Moreover, by the structure of growth, we can find that the growth rate of basic research stock is very high during the early stages and the growth rate of experimental development is very high during the final stages, whereas the growth rate of applied research is uncertain. This means that China's R&D investment has been shifted from basic research towards experimental development. Finally, we combine other information such as depreciation rates to compute a regional R&D capital services index. The results are shown in Table 3.

Table 3
The Regional R&D Capital Services Index (1999-2012)

Region	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Beijing	1.352	1.081	0.901	0.996	1.098	1.131	1.137	1.120	1.163	1.150	1.470	1.327	1.195	1.158
Tianjin	1.392	1.236	0.964	1.049	1.142	1.307	1.396	1.315	1.218	1.339	1.539	1.370	1.278	1.226
Hebei	1.520	1.199	1.085	1.230	1.247	1.242	1.462	1.463	1.355	1.274	2.233	1.363	1.196	1.173
Shanxi	1.407	1.142	0.923	1.082	1.110	1.328	1.233	1.363	1.372	1.274	1.432	1.257	1.202	1.177
Inner Mong	1.557	1.296	1.136	1.212	1.325	1.321	1.428	1.472	1.458	1.426	1.895	1.426	1.289	1.209
Liaoning	1.385	1.121	0.989	1.084	1.172	1.266	1.255	1.159	1.187	1.196	1.385	1.276	1.198	1.119
Jilin	1.229	1.147	1.023	1.079	1.007	1.186	1.233	1.214	1.198	1.189	1.592	1.161	1.083	1.170
Heilonjiang	1.275	1.043	0.945	0.935	1.107	1.151	1.265	1.231	1.204	1.335	1.445	1.261	1.098	1.072
Shanghai	1.339	1.150	0.999	1.084	1.125	1.223	1.258	1.220	1.162	1.155	1.505	1.300	1.178	1.137
Jiangsu	1.484	1.178	1.061	1.143	1.234	1.364	1.359	1.360	1.301	1.264	1.477	1.322	1.219	1.192
Zhejiang	1.439	1.335	1.108	1.109	1.366	1.597	1.606	1.418	1.268	1.200	1.703	1.408	1.217	1.192
Anhui	1.381	1.315	1.084	1.158	1.213	1.250	1.302	1.344	1.409	1.384	1.646	1.323	1.233	1.265
Fujian	1.437	1.191	1.079	1.094	1.295	1.325	1.271	1.246	1.226	1.242	2.258	1.527	1.272	1.211
Jiangxi	1.431	1.148	0.832	1.192	1.322	1.422	1.383	1.374	1.353	1.303	1.902	1.384	1.121	1.099
Shandong	1.401	1.269	1.095	1.215	1.200	1.291	1.322	1.266	1.278	1.338	1.675	1.405	1.229	1.193
Henan	1.431	1.258	1.008	0.994	1.069	1.199	1.316	1.367	1.308	1.263	1.554	1.353	1.230	1.182
Hubei	1.412	1.117	0.930	1.010	1.076	1.133	1.250	1.265	1.232	1.293	1.681	1.358	1.220	1.185
Hunan	1.379	1.180	1.035	0.997	1.101	1.194	1.232	1.264	1.332	1.382	1.743	1.394	1.242	1.221
Guangdong	1.444	1.255	1.136	1.077	1.074	1.151	1.216	1.281	1.317	1.272	1.737	1.411	1.236	1.174

To be continued

Continued

Region	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Guangxi	1.369	1.643	1.136	1.137	1.212	1.116	1.189	1.280	1.271	1.335	1.767	1.464	1.292	1.226
Hainan	1.474	1.105	0.928	0.968	0.947	1.119	1.021	1.115	1.217	1.706	1.837	1.375	1.412	1.359
Chongqing	1.491	1.223	0.924	1.108	1.281	1.433	1.454	1.349	1.288	1.232	1.582	1.382	1.222	1.220
Sichuan	1.375	1.117	0.965	0.999	1.131	1.110	1.189	1.170	1.243	1.176	1.317	1.278	1.172	1.180
Guizhou	1.409	1.144	1.022	1.095	1.247	1.173	1.186	1.301	1.152	1.228	1.513	1.284	1.177	1.140
Yunnan	1.351	1.069	0.926	1.069	1.132	1.154	1.607	1.200	1.165	1.163	1.263	1.265	1.261	1.241
Tibet	1.227	1.225	0.975	1.378	0.980	1.107	1.016	1.668	1.347	1.243	2.271	1.328	1.008	1.204
Shaanxi	1.351	1.197	0.932	0.989	1.047	1.145	1.158	1.113	1.160	1.220	1.290	1.209	1.157	1.153
Gansu	1.254	1.045	0.933	1.006	1.032	1.078	1.193	1.176	1.192	1.207	1.315	1.230	1.147	1.160
Qinghai	1.307	1.179	0.948	1.169	1.127	1.148	1.131	1.130	1.168	1.144	1.853	1.499	1.292	1.121
Ningxia	1.338	1.251	0.931	0.949	1.070	1.285	1.268	1.381	1.430	1.221	1.556	1.325	1.227	1.200
Xinjiang	1.420	1.207	1.003	0.984	1.049	1.246	1.196	1.263	1.223	1.357	1.513	1.370	1.249	1.183

CONCLUSIONS

Accounting R&D input as a part of fixed capital formation within GDP, its impact is no less than a "technology revolution" in statistics. However, due to the differences in marketing effectiveness and databases among countries and other reasons, there are still many technical details that require improvement. This paper treats R&D assets as the research object, consulting the concept and scope of capital services explained by SNA2008, makes full use of the existing data and applies the PIM approach to calculate the regional R&D capital services of China for the first time.

The conclusions of this paper indicate the following. First, according to the statistical caliber of the "Frascati Handbook", we demarcate the accounting scope of three R&D assets: basic research, applied research and experimental development. According to the nature of R&D assets, we consider that the hyperbolic model is an appropriate choice for the estimation of R&D assets' productive efficiency. In the measurement process, we use an age-efficiency profile to deduce an age-price profile and calculate the related depreciation parameters, which, to some extent, would avoid the measurement bias brought by subjective setting. Because estimating capital services is a relatively new research field in China, this article's conclusions can provide some support for the studies regarding quantifying the contribution of capital to economic growth.

Second, based on the results of empirical estimates, we find that China's R&D capital services have experienced a rapid growth process from 1998 to 2012 and the regional distribution is extremely unbalanced. Moreover, there is a trend of transferring capital services from basic and applied research to experimental development in expenditure structure. Currently, China's economic and social development is at an important point. China should further increase R&D investment, strengthen IPR (intellectual property rights) protection, provide a favorable policy environment for enhancing the country's capability of independent innovation and provide a lasting power for the steady economic development of the economy.

Finally, the result that the productive capital stock is significantly higher than the wealth capital stock indicates that measurement based on the geometric model would underestimate R&D capital services. In addition, because R&D statistical work in China started later, certain parameters in the calculation, such as asset prices and service lives, still have restrictions in application. Therefore, we need to improve the R&D statistical system further based on the international statistical standards and work to perfect R&D data by referencing advanced R&D statistical methods.

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