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Estimating the Capital Stock of China with Depreciation in IO Tables

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Abstract: As a measure of production factor, capital (K), Capital stock is a key parameter in macroeconomic analysis and policy studies. However, how to account capital stock is a great dispute for the lack of essential data in China. A new method to evaluate the capital stock with optimized depreciation rate is proposed in this paper which makes the sum squared residual minimized between calculated value and authoritative depreciation data from Input-Output (IO) tables, with the capital stock of base year unknown. Formula of the optimized depreciation rate and the base year capital stock can be derived from rigid theory reasoning of the optimization problem to evaluate the capital stock of any year.

Key words: Undetermined coefficients optimizing, perpetual inventory method, input-output table

INTRODUCTION

Capital stock is wildly used as a measure of capital K in massive macroeconomic analysis and policy studies, therefore many countries have issued their official capital stock, in view of its great importance. Perpetual Inventory Method (PIM) for short, proposed by Goldsmith (1951), is the popular approach internationally to evaluate capital stock, on which many OECD countries constructed their official evaluation system of capital stock based on PIM in 70s of last century based. However, we still don't have any official capital stock issued for many reasons. There are many literatures about how to evaluate the capital stock, some of which are studies mainly on totally capital stock of China, such as (Zhang and Zhang, 2003; He, 1992; Haojie, 2008; Zong-Yu, 2010; Yuqing, 2006; Jinxia, 2007) and so on, some of which are those mainly on industry capital stock of China, such as (Wu, 1999; Yong, 2008; Sun and Ren, 2008; Jun, 2009; Junbo and Zheng, 2007; Ren-Jun, 2010; Huang, 2002) and so on and some others are studies mainly on regional capital stock of China, such as (Sun Hui and Hongjin, 2010; Guixin and Guanchun, 2009; Xianxiang *et al.*, 2007) and so on. PIM is also popular in China, but study results are different from each other for the different data, different methods, different statistic criteria, different subjective hypothesis and all that causes which weakens the reliability of analysis results and hampers deep analysis, study and application obviously.

The essence of PIM is to adjust all the capital flows year by year before one year to a consistent meaning according to different price index, different depreciations and so on and summate them as the capital stock of the year. So the capital stock of base year and depreciation rate are crucial bases which is one main reason to different results of literatures of China on capital evaluation. With the hypothesis of constant depreciation rate, we take capital stock of base year and depreciation rate as undetermined coefficients and try to find optimal capital stock of base year and depreciation rate by minimizing the sum squared residual of depreciations between the capital stock expressions represent by those coefficients and samples from IO tables. By solving this optimized problem, we can get actual value of those undetermined coefficients theoretically. With the help of MATLAB Symbolic Toolbox, we can not only reproduce the reasoning process of optimized problem, but also change formal theory expressions to actual numerical values.

We re-evaluate the capital stock of three major industries of China by this undetermined coefficients optimizing method and notice that all the ratios of capital to output met a process of going down firstly and going up afterward, except the first industry which test and verify the necessity of policies about efficiency of capital utilizing and the significance of policy effects.

DATA SOURCE OF PIM

The basic idea of PIM is to represent the capital stock of next term K_{t+1} with all variables of current term: capital stock K_t, depreciation D_t and new investment, I_t as follows:

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$$K_{t+1} = K_t+I_t-D_t \quad (1)$$

Using depreciation rate of current term δ_t instead of depreciation, formula can be rewritten as:

$$K_{t+1} = (1-\delta_t) K_t+I_t \quad (2)$$

Furthermore, it can be written as the following formula under the rate hypothesis of constant depreciation:

$$K_{t+1} = (1-\delta) K_t+I_t \quad (3)$$

Values of different terms calculated by price of the time have no comparability, so we need to adjust investment and capital stock to a same price base, price index of fixed assets adopt usually. Therefore, there are three key data need to collect in our method, new investment, depreciation and price index of fixed assets, in view of capital stock and depreciation rate been regarded as undetermined coefficients.

New investment: There are still bifurcations on how to gain data of new investment of every year in academic field. Some scholars are apt to using accumulation values which need not to consider the problem of depreciation, such as (He, 1992). However, the government has not issued any accumulation data and corresponding price index since 1993 which makes this method very difficult to be applied in cases after 1993. Some scholars like to use new added fix asset, but on one side, just as (Haojie, 2008) concludes that it is a pretty long process to form new added fix asset which is difficult to do price adjustment. On the other side, statistical yearbooks only issue new added fix asset of urban without rural data which misses a great deal data. In consideration of data available, some other scholars think that the investment in fixed assets is a good choice, like (Junbo and Zheng, 2007). Without any better data source, we agree the method to use the investment in fixed assets.

The main sources of the investment in fixed assets are “China Statistical Yearbook” and the website of “China Economic Information Network”, CEI for short. However, the yearbook can only provide industrial investment in fixed assets after 2002 and CEI can only provide data after 1995[1]. We can find some more data from literatures or some other statistical yearbooks. In the work of (Ren-Jun, 2010), the investment of three major industries in fixed assets of 2002 and 2003 differ so much that the coherence of industry investment is destroyed. The “China Agriculture Statistical Yearbook 1999” provides the total investment in fixed assets of agriculture[2] in the whole country from 1990-1997, whose data of 1996 and 1997 differ much from those of CEI. According to the industry classification, the primary industry has the same content to big agriculture before 2003, including Agriculture, Forestry, Animal Husbandry and Fishery. So, we regard the total investment in fixed assets of agriculture in the “China Agriculture Statistical Yearbook 1999” as that of the primary industry from 1990-1996. Using the total investment in fixed assets of the whole country minus that of the primary industry, we get the summary investment in fixed assets value of the secondary industry and the tertiary industry. According to “China investment in Fixed assets statistical yearbook 1950-1995”, we can get the investment proportion of state-owned industries of the whole country which can be used to approximate the investment proportion of the secondary industry and the tertiary industry. Obviously, there are many significant differences between state-owned economy and non state-owned economy, but it is still an acceptable method without any other choice.

Price index for investment in fixed assets: The values of Assets and investment evaluated by current prices of different terms have no comparability for the change of price. Use the price index for investment in fixed assets, price index for short in this paper for the convenient of illustration, can adjust them to a same base year of price so that the values can be compared. National Bureau of Statistics of China has issued the price index since 1990 which is adopted in this work directly. Because all the data are begin with 1990, the study of price index before 1990 is not involved. There are two price indexes, of which one is relative price index representing the price change percentage to that of the last year and the other is absolutely price index representing the price change percentage to that of 1990. We use the absolutely price index to study all the variables in price of 1990.

Industry depreciation: There are mainly tow methods to calculate industry depreciation. One is to transform the problem of depreciation to the problem of depreciation rate by multiplying the capital stock by an estimated or supposed depreciation rate. For the lack of national official depreciation rate, some scholars make use of related international standard of depreciation rate, such as (2008), (Ren-Jun, 2010), etc accepting the international industry depreciation rate, 5%; some scholars try to estimate it by themselves, such as the work of (Junbo and Zheng, 2007) to evaluate depreciation rates of 17 industries, the work of (Jun, 2009) to evaluate depreciation

[1]For the adjustment of national standard of industry classification in 2003, statistical data of some industries can only tracing back to 2003
[2]It refers the big agriculture including agriculture, forestry, animal husbandry and fishery

rates of different types of R&D industry, the work of (Huang, 2002) get the depreciation evaluation of 17% in equipments and 8% in construction. The other one method is to adopt accumulation instead of depreciation, such as the work of (1993), regarding the capital stock as the summation of current capital stock and real net investment of current term, the work of (He, 1992), regarding the capital stock as the summation of current capital stock and current capital accumulation and the work of (Wang and Fan, 2000), regarding the capital stock as the summation of current capital stock and net fix capital formation of current term and so on.

Depreciation data of detailed industries are issued in IO tables and prolonged IO tables. However, IO tables and prolonged IO tables have not been compiled every year[3] for the great complexity, costs and other actual difficulties in our country. According to IO tables since 1990, the depreciations of three major industries are discontinuous and make formula failure to evaluate capital stock of every year with the capital stock of base year unknown.

So it could be a best choice to evaluate capital stock by means depreciation rate with depreciation data from IO tables as beneficial enlightenment. The work of (Junbo and Zheng, 2007) is a good beginning. They suppose a local constant depreciate rate among the years between neighbor IO tables, solve it in PIM equation by replacing capital stock by depreciations from IO tables and get the whole depreciation rate by averaging those solved local rates with some elimination of abnormality. However, actual depreciation rate changes every year with the development of economy and industry itself. So, it is not impossible get infeasible solution by solving the PIM equation among dynamic depreciation rates by constant depreciation hypothesis. The method of average makes error average too which deviate the essence of PIM that initial influence weakens over time. Local calculation and subjective elimination sacrifice the global optimization. Therefore, only optimization depreciation rate in global consideration can satisfy the constant hypothesis of depreciation rate and keep it in an acceptable range.

UNDETERMINED COEFFICIENTS OPTIMIZING AND ITS ALGORITHM

It may not be easy to see the initial influence weakening over time from above formula, but it is obviously in the following form:

$$K_{t+1} = (1-\delta)^t K_1 + \sum_{i=0}^{t-1} (1-\delta)^i I_{t-i} \tag{4}$$

K_1 in the equation is the capital stock of the base year. Obviously, with the multiplier of the t-th power of 1-δ, the influence of initial capital stock weakens sharply over time, till negligible. The higher the depreciation rate is, the faster the attenuation speeds of influence will be. So we can conclude that the error of capital evaluation will weaken over time and will not affect the subsequent analysis in a long time span.

Depreciation rate and capital stock of base year, as premise, can determine the results of capital study much, so literatures only produce many different results of capital stock with different hypotheses of premise. We take them as undetermined variables, in other words, K_1 and δ are known variables without clean value. Then the capital stock of every year is known according to Eq. 4 with all the data of investments and price index of every year collected. According to the relationship of depreciation rate and depreciation as follows, we can calculate all the depreciations of every year, with two undetermined variables of course:

$$D_t = K_t.\delta \tag{5}$$

The error of depreciation between calculation values and samples from IO tables is represented as the following equation:

$$\varepsilon_{t+1} = \left((1-\delta)^t K_1 + \sum_{i=0}^{t-1} (1-\delta)^i I_{t-i} \right) \delta - D_{t+1} \tag{6}$$

Suppose we have totally R samples of deprecations of different year from IO tables, the error sum of square, ER, is written as follows:

$$\begin{aligned} ER &= \sum_{r=1}^{R} \left(\left((1-\delta)^{t_r} K_1 + \sum_{i=0}^{t_r-1} (1-\delta)^i I_{t_r-i} \right) \delta - D_{t_r} \right)^2 \\ &= \sum_{r=1}^{R} \left(\begin{array}{l} \left(\delta(1-\delta)^{t_r} K_1 \right)^2 - 2\delta(1-\delta)^{t_r} K_1 \left(D_{t_r} - \delta \sum_{i=0}^{t_r-1} (1-\delta)^i I_{t_r-i} \right) \\ + \left(D_{t_r} - \delta \sum_{i=0}^{t_r-1} (1-\delta)^i I_{t_r-i} \right)^2 \end{array} \right) \\ &= \left(\sum_{r=1}^{R} \left(\delta(1-\delta)^{t_r} \right)^2 \right) K_1^2 - 2 \sum_{r=1}^{R} \left(\delta(1-\delta)^{t_r} \left(D_{t_r} - \delta \sum_{i=0}^{t_r-1} (1-\delta)^i I_{t_r-i} \right) \right) K_1 \\ &\quad + \sum_{r=1}^{R} \left(D_{t_r} - \delta \sum_{i=0}^{t_r-1} (1-\delta)^i I_{t_r-i} \right)^2 \end{aligned}$$

We can try to find an optimal capital stock of base year K^*_1 and an optimal constant depreciation rate δ* to make the error sum of square minimized globally by solve the optimization problem. It is a traditional optimization

[3]Currently, the formal IO tables are compiled every 5 years which begin with 1987 and the prolonged IO tables are compiled after 3 years the formal IO tables

problem of quadratic function of one variable, with δ regarded as constant. Using the First Order Condition, FOC for short, of ER, we can get the expression of optimal capital stock of base year:

$$K_1^* = \frac{\sum_{r=1}^{R} \delta(1-\delta)^{t_r}\left(D_{t_r} - \delta\sum_{i=0}^{t_r-1}(1-\delta)^i I_{t_r-i}\right)}{\sum_{r=1}^{R}\left(\delta(1-\delta)^{t_r}\right)^2} \quad (7)$$

Replacing K_1 by K^*_1 in the expression of ER, ER becomes a nonlinear function with only one variable, δ that we can use many numerical methods of one variable to get the optimized deprecation rate[4]. (For the complicated expression of ER, we do not try to get the reasoning solution. Anyone interested can reason by oneself.) Replacing the optimized depreciation rate, δ*, in Eq. 7, we can get the optimized capital stock of base year K^*_1. And then, capital stock of every year can be solved according to Eq. 4.

More generally, weighted least square method can be used to get more flexible optimization. Suppose the weight of t term is w_r, where, r = 1, 2,..., R, then:

$$\begin{aligned} ER = &\sum_{r=1}^{R}\left(w_r\left(\delta(1-\delta)^{t_r}\right)^2\right) \\ &K_1^2 - 2\sum_{r=1}^{R}\left(w_r\delta(1-\delta)^{t_r}\left(D_{t_r} - \delta\sum_{i=0}^{t_r-1}(1-\delta)^i I_{t_r-i}\right)\right)K_1 \\ &+\sum_{r=1}^{R}\left(w_r\left(D_{t_r} - \delta\sum_{i=0}^{t_r-1}(1-\delta)^i I_{t_r-i}\right)^2\right) \end{aligned} \quad (8)$$

Therefore, the capital stock of base year is:

$$K_1^* = \frac{\sum_{r=1}^{R}\left(w_r\delta(1-\delta)^{t_r}\left(D_{t_r} - \delta\sum_{i=0}^{t_r-1}(1-\delta)^i I_{t_r-i}\right)\right)}{\sum_{r=1}^{R}\left(w_r\left(\delta(1-\delta)^{t_r}\right)^2\right)} \quad (9)$$

And we may get the optimized depreciation rate δ* and capital stock of every year by some numerical method of one variable with the say way.

EMPIRICAL ANALYSIS

The expression of the function of error sum of square is very complicated with depreciation rate as the only variable, so we are difficult to see the relationship between δ and ER. Therefore, we draw curves of three major industry of china around their optimized depreciation rate shown in Fig. 1 to watch the ER function which looks like quadratic function. The curve of the primary industry looks much flat and low for its low gross and therefore less error. The curve of the whole country looks much sharper because it has a huge gross with all the errors of all the industries.

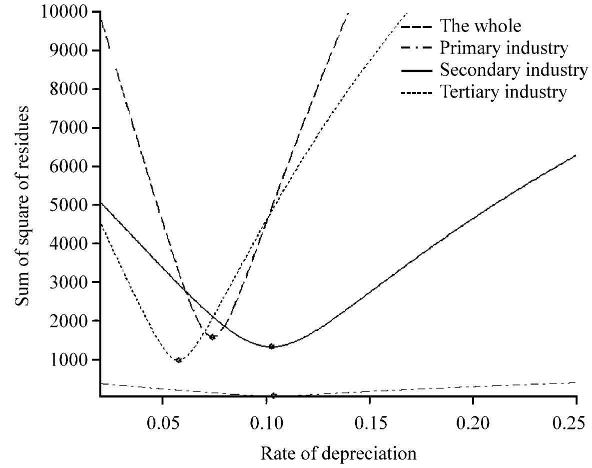

Fig. 1: Error curves respect to depreciation rate of industries of China

Table 1: Optimized depreciation rates of industries of China

The whole (%)	Primary (%)	Secondary (%)	Tertiary (%)
7.39	10.33	10.25	5.74

Finally, we get optimized depreciation rates of three major industries and the whole country of China shown in the following table.

The reliability of results depends on the reliability of source data. The source data of the whole country comparing to industry data are the most integrated and therefore the depreciation rate of 7.98% is pretty believable. The depreciation rates of the secondary industry and the tertiary industry are much closer to former literatures. Only the depreciation rate of 10.33% of primary industry is much higher than our common anticipation. On one side, we have to calculate proportionally for some missing data. On the other side, the standard of statistical industry classification has ever been reversed which makes data incomparable and discontinuous. There are big gaps in all the investments from 1995-1996 and 2002-2003 and even negative increase in the primary industry.

Values of capital stock of every year, calculated according to the optimized variables priced with the same price of 1990.

As we all known, capital stock of the whole country consists of capital stock of the primary industry, secondary industry and tertiary industry. Therefore, the

[4]One may look up any textbook about numerical methods to find a way to sole optimization problems with only one variable

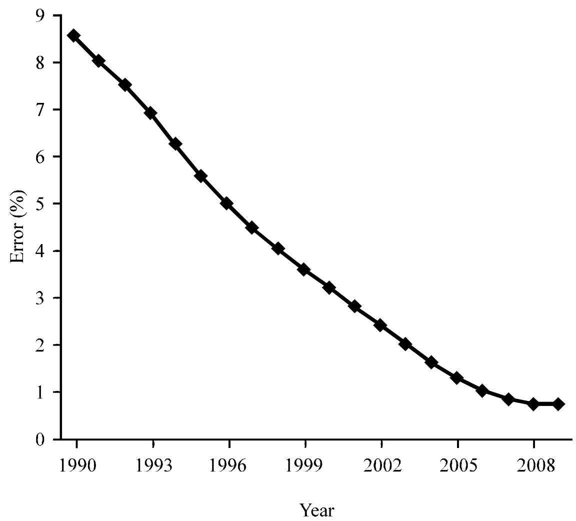

Fig. 2: Line chart of estimating error over time

summation of capital stock of all the three major industries should equal to that of the whole country theoretically. But we see distinct errors in Table 2 which means a deviation from basic theory. As mentioned above, actual depreciation rate changes every year, so no constant depreciation rate can satisfy all the samples which means errors is inevitable. For the case of calculation and analysis, estimation of constant depreciation rate within acceptable range is the basic principle.

From the Eq. 4, we know that the influence initial error will weaken over time. It is proved by the line chart of Fig. 2 clearly. The error decrease over time steadily and fall below 1%.

All the variables are calculated in price of 1990 in this paper, but if needed, one may change the value of absolutely price index according new price year. One may also change the base year by adjust the recursive formula of capital stock.

Generally speaking, according to capital output ratio in 1990 price shown in Fig. 3, the efficiency of capital utilization in China does not meet a steadily increase all the time, but makes a detour: there is a slightly decline in the beginning of 1990s except the primary industry; the efficiency of capital utilization of tertiary industry enters a rising channel soon which drive that of the whole country rising; that of the primary industry ascends very slowly and steadily; however that of the secondary industry is not optimistic for its long time decline till the beginning of 2000s and does not enters its rising channel until 2003; and all the major three industries have met a rising efficiency of capital utilization since 2000. All those mean that the policies to improve capital utilization efficiency are essential and effective.

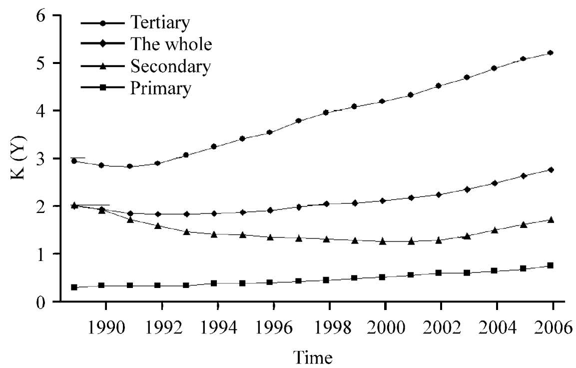

Fig. 3: Capital output ratio trend in price 1990

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CONCLUSION

As a measure of production factor, capital (K), Capital stock is a key parameter in macroeconomic analysis and policy studies. However, scholars have to use some compromise or substitution methods for the lake of data. Because of different hypotheses of premises, different data and different methods, results differ much. As a popular method of capital stock estimation, PIM is dominated in China too. But seldom uses relative authoritative data of depreciation in IO tables as helpful supplement. With the accumulation of IO tables over time, the depreciation rate solved with our method will become more close to the reality according to the character of PIM, weakening over time of initial error. How detailed classification the IO table system provides, how detailed depreciation rate of industry will be estimated with our undetermined coefficients optimizing method which may facilitate detailed analysis of detailed industry classification.

Our optimization method globally minimize the summation of square error between calculated depreciations and sample depreciations from IO tables, with capital stock of base year and depreciation rate as undetermined coefficients. The expression of optimized capital stock of base year can be gained from mathematic reasoning. With the strong function of MATLAB Symbolic Toolbox, we get numerical values of optimal depreciation rate and optimal capital stock of base year, in the empirical analysis of three major industries of China.

The fall of errors of estimation into an acceptable range soon prove the character of PIM which is weakening over time of initial error. We find from changes of capital output ratio that the efficiency of capital utilization in China does not meet a steadily increase all the time, but a detour and therefore proves that the policies to improve capital utilization efficiency are essential and effective.

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