ESTIMATING CHINA'S AGRICULTURAL CAPITAL STOCK FROM 1952 TO 2012

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Abstract: In this paper, we attempt to estimate China's agricultural capital stock from 1952 to 2012 using the perpetual inventory method (PIM). We then compare between four measurements of agricultural capital stock in China: our estimated agricultural capital stock via PIM, the total power of farm machinery, draft animals used in the agricultural sector, and agricultural tractors used in the sector. Estimating the agricultural production function and calculating the contribution of capital accumulation to agricultural output growth using these measurements of agricultural capital stock demonstrate that our agricultural capital stock estimation provides a better index with which to represent actual agricultural capital stock levels in China.
Keywords: agricultural capital stock, perpetual inventory method, production function
JEL codes: C8, O4, Q14

1. Introduction

Capital stock refers broadly to manufactured durable goods or the non-financial assets used in their production. Estimating capital stock accurately is very important for valuing the contribution of each factor in production. Measuring capital stock in the agricultural sector is much more difficult than measuring it in the non-agricultural sector, especially in developing countries. For this reason, many studies use related indicators to represent agricultural capital stock, such as the mechanical and animal horsepower used in the sector (Hayami and Ruttan, 1970; Lau and Yotopoulos, 1989; McMillan et al., 1989; Lin, 1992), the number of machines used in agricultural production (Ercolani and Wei, 2011), and capital services related to agricultural production (Ulveling and Fletcher, 1970). These indicators can represent agricultural capital stock, but they can lead to an underestimation of it. Moreover, the agricultural capital stock measured using those methods is not comparable to non-agricultural capital stock, which is usually estimated by the perpetual inventory method (PIM). Therefore, many studies have attempted to measure agricultural capital stock using PIM.

Few studies have been conducted on capital accumulation in China's agricultural sector before the nation's economic reforms began. A significant exception is Chow (1993), which estimates China's agricultural capital stock from 1952 to 1985 using data on accumulation.[1] He classifies the accumulation amount into four types of

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[1] According to the *China Statistical Yearbook*, accumulation is defined as the portion of national income used for the reproduction of goods or services, non-productive construction, and increases in productive and non-productive reserves. This indicator continued to be calculated until 1993.

economic unit: state enterprises, urban collective enterprises, rural collective enterprises, and individuals. Then, he distributes the accumulation into five sectors within each type of economic unit. By this method, he quantifies the capital stock in each sector from 1952 to 1985.

However, there are two problems with his method. First, considering the accumulation series as the investment in capital is problematic because it involves China's non-productive accumulation: some of the accumulation would not be devoted to production and should not be classified as investment in capital. Second, the ratios of the distributed percentages in his method are constant. The figures for these ratios came from communication with the State Statistical Bureau and data on composition in newly increased fixed assets. For example, he distributes 77% of the accumulation of fixed assets to industry, 3% to construction, 4.5% to transportation, 2% to commerce, and 4.5% to agriculture for the 1952–1977 period. This setting of constant percentages for such a long period ignores the changes that occurred in the investment distribution.

A large body of research has estimated China's agricultural capital stock since the nation's economic reforms began. Li (2010) divides the 1986–2007 period into three periods—1986–1996, 1997–2002, and 2003–2007—to compile data on fixed asset investments in three industrial sectors. In view of that no data on sectoral investments in fixed assets are available from 1986 to 1996, he calculates the percentages of sectoral investments in capital construction and renovation and reformation for that period, and assumes that these percentages remain the same for other investments because of the lack of data on the distribution of other investments among the three industrial sectors. For the 1997–2002 period, the method used is almost the same as that used for the former period except that data on investments in real estate are available for this period, which he classifies as investments in fixed assets in the tertiary sector. For the 2003–2007 period, data on fixed asset investments in the three industrial sectors can be obtained from the *China Statistical Yearbook*. Combining the data for the three periods, Li obtains the distribution of the fixed asset investments among the three sectors and estimates the capital stock in the sectors from 1986 to 2007.

Another interesting method of estimating China's recent agricultural capital stock is that used in Wu (1999). He adds up government expenditures on agricultural capital construction, the investments in the agricultural fixed assets of collectively owned units, and the individual investments in the purchase of productive fixed assets in rural areas to obtain a series of aggregate fixed asset investments in the agricultural sector from 1981 to 1997. Luo (2013) also estimates China's agricultural capital stock from 1980 to 2011 using Wu's method. Although those works are enlightening, none of their estimates cover the period before the 1980s, and none can be matched with the estimation data in Chow's study (1993) as they use different types of data drawn from different national account systems.

To address these problems, this study estimates the agricultural capital stock in China for the whole period from 1952 to 2012 using data taken from the System of National Account (SNA). Doing so has two significant benefits. First, this study's estimation results for agricultural capital stock are comparable across time periods, as the data are consistent for each year. Second, the estimation results are comparable to those for the

PIM's estimation of non-agricultural capital stock.

The rest of this paper is organized as follows. Section 2 describes the estimation of China's agricultural capital stock. Section 3 compares the estimation results with those of other measurements of the agricultural capital stock in China. Section 4 compares between the results of agricultural production function estimations using different measurements of agricultural capital stock. Section 5 measures the contribution of agricultural capital increase to total agricultural output growth using various measurements of agricultural capital stock. Finally, section 6 concludes the paper.

2. Conceptual and Statistical Considerations

This study uses the PIM, pioneered by Goldsmith (1951), to estimate the agricultural capital stock in China. This method is most widely used to construct capital stock in OECD nations as well as other countries and areas (e.g., Hofman, 1992, 2000; Berlemann and Wesselhöft, 2012). According to the PIM, the net capital stock at the beginning of period *t*, K_t, can be written as a function of the net capital stock at the beginning of the previous period *t*-1, K_{t-1}, the gross investment in the previous period, I_{t-1}, and the capital stock depreciation in the previous period, D_{t-1}:

$$K_t = K_{t-1} + I_{t-1} - D_{t-1}. \quad (1)$$

Assuming geometric depreciation at a constant rate δ, the capital stock can be rewritten as

$$K_t = (1-\delta)K_{t-1} + I_{t-1}, \quad (2)$$

which is

$$K_t = \sum_{i=0}^{\infty}(1-\delta)^i I_{t-(i+1)}. \quad (3)$$

We can choose any period as the initial point to calculate a complete time series as follows:

$$K_t = (1-\delta)^{t-1}\bar{K} + \sum_{i=0}^{t-1}(1-\delta)^i I_{t-(i+1)}, \quad (4)$$

where $\bar{K}$ is the capital stock at the initial time point.

Thus, to construct a capital stock series by PIM, we need (i) a time series of investment, (ii) the value of the initial capital stock when the investment series begins, and (iii) the depreciation rate of the existing capital stock. Next, we will explain the estimation process.

2.1 Investment series

Before selecting the data with which to measure investment in the agricultural sector, it is necessary to consider the different kinds of investment data used in China. China used the Material Product System (MPS) from 1953 to 1993. In this system, "accumulation" was used to record capital stock levels, which were equal to employed national income minus expenditures. Data on accumulation can be found in the earlier *China Statistical Yearbooks* and *The Gross Domestic Product of China 1952-1995*. Chow's studies and most other earlier studies on China's capital stock adopt this indicator. However, the data on accumulation cover only from 1952 to 1993, and they do not use an industrial classification.

In 1993, China abolished national income accounting via MPS and gradually adopted national income accounting based on SNA. By 2002, China has adopted SNA fully. In SNA, total capital formation—the fixed assets acquired minus those disposed and the change in inventory—is recorded to replace accumulation in measuring investment. This consists of total fixed capital formation and inventory increases. The time series of total capital formation before the 1990s are estimated officially and can be traced back to 1952. However, considering inventory as a single type of investment in capital stock is problematic. Thus, total fixed capital formation is the most widely used indicator when estimating China's aggregate capital stock.

Unfortunately, there are no industrial classification data on total fixed capital formation for China. Researchers seeking to estimate sectoral capital stock typically use total investment in fixed assets instead. Investment in fixed assets refers to the values of construction activities and the purchases of fixed assets.[2] Statistics on investments in fixed assets are based on the registration status of three kinds of economic units: state-owned units, collectively owned units, and individuals. Data on fixed asset investments in state-owned units begin in 1952 while data on collectively owned units and individuals begin in 1980. These data can be found in the *China Statistical Yearbooks* and *China Statistical Yearbook on Investment in Fixed Assets*.

The main differences between total fixed capital formation and total investment in fixed assets are as follows. (i) Total investment in fixed assets does not include assets under 500 thousand yuan; however, those assets are included in total fixed capital formation.[3] (ii) Total fixed capital formation includes the net increase in intangible fixed assets but investment in fixed assets does not. (iii) The portion of used fixed assets that is transferred out due to sale, barter business, or the transfer of physical capital is eliminated from fixed capital formation but is reserved in investment in fixed assets. (iv) Finally, investment in fixed assets includes the costs of land transactions but fixed capital formation does not.

We use the data on total fixed capital formation as the investment series in constructing China's agricultural capital stock. However, due to the lack of sectoral data on fixed capital formation, we use the data on fixed asset investments to acquire the distributed percentages of investment among the sectors. Data on fixed capital formation are taken from the *Annual Database of National Bureau of Statistics of China*.

2.2 Agricultural investment

[2] Investments in fixed assets can be classified into four groups: investment in capital construction, investment in innovation, investment in real estate, and others.

[3] It should be noted that this indicator reflecting the statistical caliber for fixed assets changed in 1997, when the criterion for recording fixed asset investments was increased to 500 thousand yuan from 50 thousand yuan.

As mentioned, none of the data on China's total fixed capital formation use a sectoral classification. Thus, we use data on industrial fixed asset investments to calculate the percentage of agricultural investment of total investment. Then, by multiply this percentage by total fixed capital formation, we can obtain an approximate agricultural fixed capital formation for China.

China's National Bureau of Statistics publishes data on fixed asset investments in the agricultural sector from 1995 to 2012 (excluding 1998, 1999, and 2000). We can calculate agriculture's percentages of fixed asset investments for this period directly (except for the three excluded years); for 1952 to 1986, we use agriculture's percentages of capital construction investments instead. The data are taken from *Rural Economy Statistics in China 1949–1986*.

To calculate agriculture's percentages of total fixed asset investments from 1987 to 1994 and in the missing three years (1998, 1999, 2000), we collect data on fixed asset investments in each type of economic unit from 1987 to 2000, which includes fixed asset investments in state-owned units, fixed asset investments in collectively owned units, individual fixed asset investments, and other kinds of fixed asset investments. Individual fixed asset investments can be divided into individual fixed asset investment in urban areas and individual fixed asset investment in rural areas.

Official statistical data are published on agricultural fixed asset investments in state-owned units and collectively owned units but not on individual fixed asset investments or other fixed asset investments. Hence, we extract data on agricultural fixed asset investments from the data on the latter two types.

First, we assume that individual fixed asset investments in urban areas and other fixed asset investments are not devoted to the agricultural sector. This assumption is reasonable given that the probability that such investments are devoted to agricultural production is low in China. As for individual fixed asset investments in rural areas, only the portion of individual investments in the purchase of productive fixed assets is included in agricultural fixed asset investments.

Thus, total agricultural fixed asset investment can be calculated as the sum of agricultural fixed asset investments in state-owned units, agricultural fixed asset investments in collectively owned units, and individual investments in the purchase of productive fixed assets in rural areas. Dividing this sum by the amount of total fixed asset investment produces agriculture's percentages of aggregate fixed asset investment. Details are provided in Table 1. The data are taken from the *China Statistical Yearbook on Investment in Fixed Assets 1950–1995*.

Combining the data generated by the three methods produces agriculture's percentages of fixed asset investments for the entire period from 1952 to 2012 (see Table 2). The first column in Table 2 reports agriculture's percentages of capital construction investment from 1952 to 1986 except from 1966 to 1974. The second column reports agriculture's percentages of fixed asset investments from 1987 to 1998 calculated from Table 1. The third column reports agriculture's percentages of fixed asset investments 1995 to 2012 calculated directly from the data published by China's National Bureau of Statistics.

Table 1. Calculation of Agriculture's Percentages of Total Fixed Asset Investments from 1987 to 2000, 100 million Yuan, %

Year	Fixed asset investments in state-owned units	Agricultural fixed asset investments in state-owned units	Fixed asset investments in collectively owned unites	Agricultural fixed asset investments in collectively owned units	Individual fixed asset investments F+G	Individual fixed asset investments in urban areas
	A	B	C	D	E	F
1987	2448.8	32.8	547.0	44.1	795.9	100.5
1988	3020.0	38.3	711.7	44.9	1022.1	156.9
1989	2808.2	31.1	570.0	46.2	1032.2	140.2
1990	2986.3	34.1	529.5	63.7	1001.2	124.7
1991	3713.8	48.2	697.8	73.9	1182.9	140.3
1992	5498.7	58.4	1359.4	90.4	1222.0	216.5
1993	7925.9	64.3	2317.3	56.6	1476.2	338.5
1994	9615.0	74.2	2758.9	103.7	1970.6	451.3
1995	10898.2	93.0	3289.4	208.1	2560.2	552.4
1996	12056.2	127.8	3660.6	222.6	3211.2	667.1
1997	13091.7	169.7	3850.9	274.9	3429.4	738.3
1998	15369.3	237.1	4192.2	334.5	3744.4	1062.9
1999	15947.8	304.0	4338.6	400.1	4195.7	1416.1
2000	16504.4	357.4	4801.5	376.5	4709.4	1805.1

100 million yuan, %

Year	Individual fixed asset investments in rural areas	Individual investments in purchase of productive fixed assets in rural areas	Other fixed assets investment	Total fixed asset investments A+C+E+I	Agricultural fixed asset investments B+D+H	Agricultural percentages in fixed asset investments K/J
	G	H	I	J	K	L
1987	695.4	92.2	0.0	3791.7	169.1	4.46
1988	865.2	124.0	0.0	4753.8	207.2	4.36
1989	892.0	97.9	0.0	4410.4	175.2	3.97
1990	876.5	99.3	0.0	4517.0	197.2	4.36
1991	1042.6	130.1	0.0	5594.5	252.1	4.51
1992	1005.5	68.0	0.0	8080.1	216.8	2.68
1993	1137.7	122.4	1352.9	13072.3	243.3	1.86
1994	1519.2	203.3	2697.6	17042.1	381.3	2.24
1995	2007.9	298.5	3271.5	20019.3	599.6	2.99
1996	2544.0	293.2	4046.1	22913.5	643.6	2.81
1997	2691.2	285.4	4569.1	24941.1	729.9	2.93
1998	2681.5	279.3	5100.3	28406.2	850.9	3.00
1999	2779.6	N.A.	5372.7	29854.7	N.A.	N.A.
2000	2904.3	N.A.	6902.5	32917.7	N.A.	N.A.

Source: Calculated by the authors.

Table 2. Agriculture's Percentages of Total Fixed Asset Investments

%

Year	Agriculture's percentages of capital construction investment	Agriculture's percentages of fixed asset investments I	Agriculture's percentages of fixed asset investments II	Combination of Series M, N, and O
	M	N	O	P
1952	13.40			13.40
1953	8.60			8.60
1954	4.20			4.20
1955	6.20			6.20
1956	7.70			7.70
1957	8.30			8.30
1958	9.80			9.80
1959	9.40			9.40
1960	11.60			11.60
1961	13.30			13.30
1962	20.20			20.20
1963	23.00			23.00
1964	18.70			18.70
1965	13.90			13.90
1966	N.A.			13.45
1967	N.A.			13.00
1968	N.A.			12.55
1969	N.A.			12.10
1970	N.A.			11.65
1971	N.A.			11.20
1972	N.A.			10.75
1973	N.A.			10.30
1974	N.A.			09.85
1975	9.40			09.40
1976	10.90			10.90
1977	10.90			10.90
1978	10.60			10.60
1979	11.10			11.10
1980	9.30			9.30
1981	6.60			6.60
1982	6.10			6.10
1983	6.00			6.00

1984	5.00			5.00
1985	3.40			3.40
1986	3.30			3.30
1987		4.46		4.46
1988		4.36		4.36
1989		3.97		3.97
1990		4.36		4.36
1991		4.51		4.51
1992		2.68		2.68
1993		1.86		1.86
1994		2.24		2.24
1995		2.99	2.49	2.49
1996		2.81	2.56	2.56
1997		2.93	2.60	2.60
1998		3.00	N.A.	3.00
1999		N.A.	N.A.	2.96
2000		N.A.	N.A.	2.96
2001			2.92	2.92
2002			3.42	3.42
2003			2.97	2.97
2004			2.68	2.68
2005			2.62	2.62
2006			2.50	2.50
2007			2.48	2.48
2008			2.93	2.93
2009			3.07	3.07
2010			3.15	3.15
2011			2.81	2.81
2012			2.93	2.93

Sources: Series *M* is from *Rural Economy Statistics in China 1949–1986*, pp. 380–381, series *N* is calculated in Table 1, and series *O* is calculated using data from the *Annual Database of National Bureau of Statistics of China*.

Notes: (1) The missing values from 1966 to 1974 are calculated as $v_t = v_{t-1} - 0.1 \cdot (v_{1965} - v_{1975}) = v_{t-1} - 0.0045$ for $t = 1966, 1967, \cdots, 1974$. The implicit assumption is that agriculture's percentage of fixed asset investment decreases by the same amount each year during this period.

(2) For the three years of 1995, 1996, and 1997, we adopt the values of series *O* rather than series *N*. However, the differences between the two are not large, which also proves that our calculations for the period from 1987 to 2000 are acceptable.

(3) The value in 1998 is the calculation result from series *N* since it is missing in series *O*. The missing values in 1999 and 2000 are calculated as the average of 1998 and 2001.

2.3 Price indexes

As China has no statistical data on the price indexes of fixed capital formation, the price indexes of fixed asset investments are often used instead. Official data on the price indexes of investments in fixed assets begin in 1990. Thus, price indexes before 1990 can be obtained only through prediction or by using other price indexes instead.

Chow (1993) estimates the price indexes of accumulation from 1952 to 1988 at 1952 prices. Many studies use his results as the price indexes of fixed asset investments. Some studies find that the price index of fixed asset investments was stable until 1978. Thus, they consider price indexes to be equal to 1 from 1952 to 1978 (e.g., Zhang, 2008). Other studies use GDP deflators to eliminate the influence of price changes in fixed asset investments.

However, it is inappropriate to use the price indexes of aggregate fixed assets investment to estimate capital stock in the agricultural sector. Instead, we adopt the price indexes of the means of agricultural production to deflate agricultural fixed capital formation. The price indexes of the means of agricultural production can be calculated as

$$\text{Price index of means of agricultural production in period } t = \frac{\text{Present value of means of agricultural production in period } t \,/\, \text{Quantity index of means of agricultural production in period } t}{\text{Present value of means of agricultural production in period } t_0} \quad (5)$$

The data used are taken from the *China Statistical Yearbook* and *Annual Database of National Bureau of Statistics of China*. Using this method, we can obtain the approximate price indexes of agricultural fixed capital formation. The sixth column in Table 3 reports our results.

2.4 Depreciation rate

The estimation results for capital stock are very sensitive to the setting of the depreciation rate. Some studies assume the depreciation rate in China to be a constant (e.g., Perkins, 1988; Young, 2003). Other studies calculate depreciation rate using the following formula:

$$d_t = (1 - \delta)^t, \quad (6)$$

where d_t represents the marginal efficiency of new capital goods relative to the old ones, and δ is the depreciation rate or replacement rate.

Strictly speaking, δ is not the depreciation rate but the replacement rate of capital; only when the relative efficiency of capital stock geometrically diminishes is the replacement rate equal to the depreciation rate (Jorgenson, 2001; Huang et al., 2002). The estimated ratio of the residual value to the cost of fixed assets in China is usually set to from 3% to 5%. Many studies choose 4%, the median.

Estimating the depreciation rate also requires estimating the useful life of fixed assets. As mentioned, fixed asset investment in China is divided into three categories: investment in construction and installation, investment in the purchase of equipment, tools, and instruments, and others. Most studies assume that investment in other fixed assets is part of investment in construction and installation or investment in equipment, tools, and instruments. Thus, the estimation simply requires determining the useful life for construction and installation and for equipment, tools, and instruments. Bai et al. (2006) estimate that the deprecation rate of construction and installation is 24% and that of equipment, tools, and instruments is 8% by assuming a useful life of 38 years and 12 years, respectively. The weighted average of the depreciation rates of the two types of fixed assets by their relative percentages is regarded as the aggregate depreciation rate of all fixed assets.

However, the estimated results for depreciation rate obtained by this method are much larger than we expected. China adopted a type of scrimping-and-saving pattern of economic development before its economy took off. For this reason, we use official data on the depreciation rate in enterprises as the aggregate depreciation rate. The data are taken from the *China Financial Yearbooks*. However, these data cover only 1952 to 1992. There are no post-1992 data on depreciation rates at the national level, but there are data on depreciation rates in state-owned industrial enterprises at the provincial level. Thus, we calculate the average depreciation rate weighted by the percentages in each province of the fixed assets of state-owned industrial enterprises from 1993 to 1998.[4] We then use a robust regression to predict the missing values for 1999.[5] The fifth column in Table 3 reports the data on the depreciation rates.

2.5 Initial capital stock

There are methodological differences in previous estimations of initial capital stock. Harberger (1978, 1988) proposes the steady state approach for calculating initial capital stock under the assumption of economic equilibrium. That is,

$$g_Y = g_K = \frac{K_t - K_{t-1}}{K_{t-1}} = \frac{I_t}{K_{t-1}} - \delta_t, \tag{7}$$

where g_Y is the GDP growth rate, g_K is the capital stock growth rate in the long term, and δ_t is the depreciation rate at period t. Hence, the initial capital stock at period $t-1$ can be calculated by

$$K_{t-1} = \frac{I_t}{g_Y + \delta_t}. \tag{8}$$

Another method is the disequilibrium approach proposed by Griliches (1980) and refined by De La Fuente and Domenech (2006). They argue that the growth rate of capital stock can be approximated using the investment growth rate. Thus, the initial capital stock at period $t-1$ can be calculated as

$$K_{t-1} \approx \frac{I_t}{g_I + \delta_t}, \tag{9}$$

where g_I is the investment growth rate.

We use the equilibrium approach to estimate the initial capital stock. We do not use the disequilibrium approach because China's investment increased steeply during the early 1950s. The average annual growth rate of total investment from 1953 to 1957 was 23.15%, while the average GDP growth rate during this period was 9.35%. Thus, we choose the GDP growth rate of 9.35% to calculate the initial agricultural capital stock.[6]

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[4] For the period before 1993, we observe that the average depreciation rate for all types of enterprises in each year is about 0.0002 larger than the depreciation rate in industrial enterprises. We thus subtract 0.0002 from the weighed average to obtain more consistent data on the depreciation rate in industrial enterprises.

[5] We adopt $\delta_t = a_o + a_1 \cdot t$ to predict the missing values from 1999 to 2013. *R*-square is 78.89%.

[6] The initial capital stock in the agricultural sector is calculated using the growth rate of the aggregate

2.6 Calculation results

Table 3 reports the estimation results for agricultural capital stock from 1952 to 2012. The second column shows agriculture's percentages of total fixed capital formation. Overall, agriculture's percentages decline, from 13.40% in 1952 to 1.86% in 1993. Since 1993, they have remained at around 2% to 3%. Column three reports the deflator of fixed assets in the agricultural sector; it remained almost constant before the 1980s and then began to rise rapidly. The last column shows the estimation results for agricultural capital stock at 2010 prices.

Table 3. Estimation of Agricultural Capital Stock

100 million yuan, %

Year	Total fixed capital formation at current prices	Agriculture's percentages of total fixed capital formation	Agricultural fixed capital formation at current prices	Depreciation rate of fixed assets	Deflator of fixed assets in agricultural sector (2010=1)	Estimated agricultural capital stock at 2010 prices
1952	80.7	13.40	10.81	2.90	0.1762	459.29
1953	115.3	8.60	9.92	2.90	0.1762	502.25
1954	140.9	4.20	5.92	3.10	0.1763	520.25
1955	145.5	6.20	9.02	3.30	0.1762	554.27
1956	219.6	7.70	16.91	3.30	0.1763	631.91
1957	187.0	8.30	15.52	3.10	0.1762	700.39
1958	333.0	9.80	32.63	3.40	0.1762	861.75
1959	435.7	9.40	40.96	3.40	0.1762	1064.83
1960	473.0	11.60	54.87	3.70	0.1762	1336.76
1961	227.6	13.30	30.27	3.40	0.1762	1463.08
1962	175.1	20.20	35.37	3.20	0.1762	1616.97
1963	215.3	23.00	49.52	3.10	0.1762	1847.81
1964	290.3	18.70	54.29	3.20	0.1763	2096.67
1965	350.1	13.90	48.66	3.20	0.1762	2305.69
1966	406.8	13.45	54.71	3.30	0.1763	2540.04
1967	323.7	13.00	42.08	3.00	0.1763	2702.59
1968	300.2	12.55	37.68	3.00	0.1763	2835.27
1969	406.9	12.10	49.23	3.10	0.1763	3026.72
1970	545.9	11.65	63.60	3.20	0.1762	3290.71
1971	603.0	11.20	67.54	3.20	0.1763	3568.58
1972	622.1	10.75	66.88	3.50	0.1762	3823.14
1973	664.5	10.30	68.44	3.40	0.1762	4081.49
1974	748.1	9.85	73.69	3.50	0.1762	4356.74
1975	880.3	9.40	82.75	3.60	0.1762	4669.40
1976	865.1	10.90	94.30	3.60	0.1762	5036.34

output rather than the growth rate of the agricultural output.

1977	911.1	10.90	99.31	3.70	0.1762	5413.46
1978	1073.9	10.60	113.83	3.70	0.1762	5859.05
1979	1153.1	11.10	127.99	3.70	0.1769	6365.60
1980	1322.4	9.30	122.98	4.10	0.1787	6792.76
1981	1339.3	6.60	88.39	4.10	0.1818	7000.58
1982	1503.2	6.10	91.70	4.10	0.1852	7208.65
1983	1723.3	6.00	103.40	4.20	0.1908	7447.90
1984	2147.0	5.00	107.35	4.40	0.2077	7636.93
1985	2672.0	3.40	90.85	4.70	0.2177	7695.28
1986	3139.7	3.30	103.61	4.90	0.2201	7788.93
1987	3798.7	4.46	169.39	4.90	0.2355	8126.50
1988	4701.9	4.36	204.98	5.00	0.2737	8469.16
1989	4419.4	3.97	175.54	5.00	0.3254	8585.16
1990	4827.8	4.36	210.73	4.80	0.3433	8786.91
1991	6070.3	4.51	273.56	5.50	0.3532	9078.05
1992	8513.7	2.68	228.41	5.50	0.3663	9202.29
1993	13309.2	1.86	247.70	6.43	0.4180	9205.97
1994	17312.7	2.24	387.30	6.50	0.5083	9369.61
1995	20885.0	2.49	519.67	6.24	0.6475	9591.26
1996	24048.1	2.56	616.10	5.64	0.7019	9931.90
1997	25965.0	2.60	674.28	5.10	0.6984	10390.85
1998	28569.0	3.00	855.76	5.76	0.6600	11084.82
1999	30527.3	2.96	902.39	5.62	0.6323	11891.31
2000	33844.4	2.96	1000.45	5.69	0.6266	12810.20
2001	37754.5	2.92	1101.16	5.76	0.6209	13840.60
2002	43632.1	3.42	1491.73	5.82	0.6240	15428.29
2003	53490.7	2.97	1590.57	5.89	0.6328	17031.67
2004	65117.7	2.68	1746.91	5.96	0.6998	18505.90
2005	74232.9	2.62	1943.05	6.02	0.7579	19959.15
2006	87954.1	2.50	2198.84	6.09	0.7693	21599.87
2007	103949.0	2.48	2576.31	6.15	0.8285	23370.13
2008	128084.0	2.93	3753.30	6.22	0.9967	25686.77
2009	156680.0	3.07	4809.85	6.29	0.9718	29017.84
2010	183615.0	3.15	5780.26	6.35	1.0000	32940.96
2011	215682.0	2.81	6064.18	6.42	1.1130	36281.23
2012	241757.0	2.93	7095.01	6.49	1.1753	39959.57

Source: Calculated by the authors.

3. Different Measurements of Agricultural Capital Stock in China

In this section, we compare the agricultural capital stock estimated by PIM with other indicators often used to represent agricultural capital stock in China. The most commonly used indicators are the horsepower of tractors and/or draft animals (e.g., Lin, 1992; Islam and Yokota, 2008) and the number of machines used in the agricultural sector (e.g., Ercolani and Wei, 2011).

To compare between the measurements of agricultural capital stock, we collect data on the total power of farm machinery, draft animals in the agricultural sector, and agricultural tractors covering 1952 to 2012. The total power of farm machinery refers to the total mechanical power of machinery used in farming, forestry, animal husbandry, and fisheries, including plowing, irrigation and drainage, harvesting, transport, plant protection, stock breeding, forestry, and fisheries. Agricultural tractors in use comprise large- and medium-sized agricultural tractors.

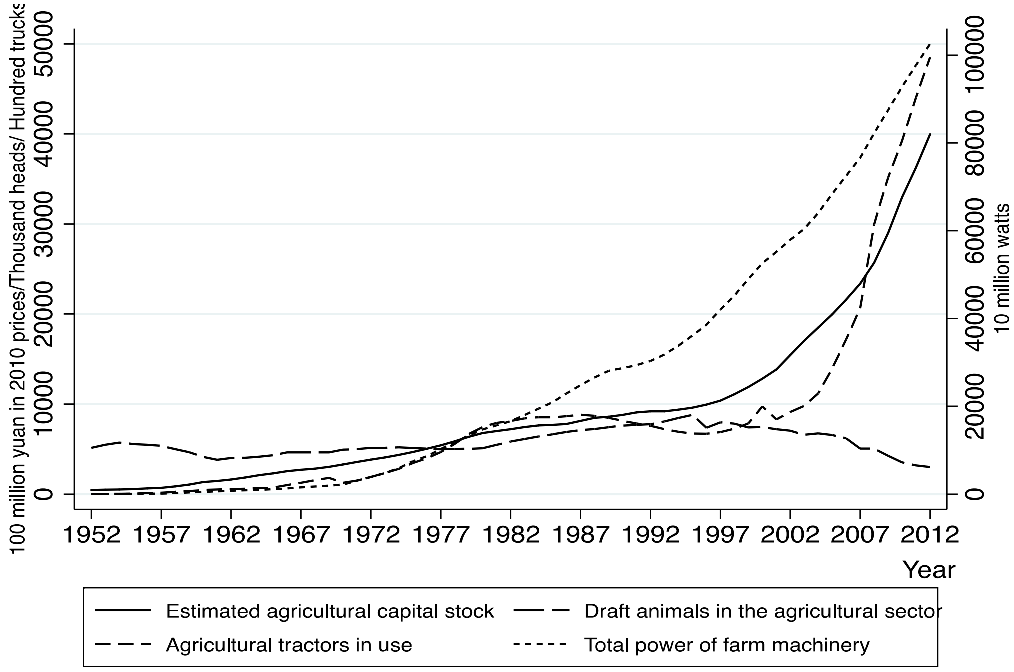

Figure 1. Measurements of Agricultural Capital Stock in China

Source: Drawn by the authors. Data on total power of farm machinery come from *China Statistical Yearbook*.[7] Data on draft animals in the agricultural sector come from *China Rural Statistical Yearbook*.[8] Data on agricultural tractors in use come from *Statistics of China's Rural Economy* and *China Statistical Yearbook*.[9]

[7] Data on the total power of farm machinery are missing for 1953–1956, 1958–1961, 1963, 1964, 1966–1969, 1971, and 1972.

[8] Data of draft animals in the agricultural sector are missing from 1966 to 1969.

[9] Data on agricultural tractors in use are missing from 1966 to 1969. We replace the missing values with figures taken from the *Food and Agriculture Organization Database*.

Figure 1 compares between the agricultural capital stock estimation via PIM and the other three measurements of China's agricultural capital stock. Overall, the estimated trend is consistent with that of the total power of farm machinery and agricultural tractors in use. They all increased from a low level in 1952 and began to accelerate in the late 1990s. Agricultural tractors in use declined in the 1980s but rebounded and began an astonishing acceleration in the 2000s.

By contrast, the difference between the estimated capital stock trend and that of draft animals in the agricultural sector is clear. Draft animals in the agricultural sector increased since the 1960s, reached a peak around 1995, and then began to decline, which shows that modern machinery has been gradually replacing traditional animal labor in China's agricultural production. Thus, it is problematic to use only draft animals to represent China's agricultural capital stock, as a few studies do.

4. Estimates of Agricultural Production Function

Using the four measurements of agricultural capital stock, we estimate the agricultural production function in China as

$$Y_{at} = f(L_{at}, K_{at}, H_{at}) = A_0 e^{\propto t} L_{at}^{\beta} K_{at}^{\gamma} H_{at}^{\delta}, \tag{10}$$

where Y_{at} is agricultural output, L_{at} is the agricultural labor force, K_{at} is agricultural capital stock, and H_{at} is the land used in the agricultural sector.

By taking the natural logarithms, we estimate the production function in this form:

$$\ln Y_{at} = \ln A_0 + \propto t + \beta \ln L_{at} + \gamma \ln K_{at} + \delta \ln H_{at}. \tag{11}$$

Here, we adopt agricultural value added to represent agricultural output, expressed in real yuan deflated to 2010 prices. The agricultural labor force is measured by the employed persons in the agricultural sector.[10] Agricultural capital stock is measured by the estimated capital stock (K_{at}^1), total power of farm machinery (K_{at}^2), draft animals in the agricultural sector (K_{at}^3), and agricultural tractors in use (K_{at}^4). Land used in the agricultural sector is represented by the hectares under cereal production. All of the data (except for agricultural capital stock) are taken from the *China Statistical Yearbooks*. Finally, a time trend, starting in 1978 and equal to zero before 1978, is used to indicate technological progress in the agricultural sector. The estimation spans 1952 to 2012 using all available observations; we drop the observations from 1958 to 1961 in the estimation process.

We adopt augmented Dickey–Fuller statistics and the Phillips–Perron statistic to test the stationarity of the variables. All the variables are non-stationary and integrated of order one, $I(1)$, at the 10% significance level. A cointergrating relationship is also identified. Thus, we estimate the agricultural production function directly. However, the original estimation results of the ordinary least squares exhibit a large degree of residual serial correlation. Accordingly, the generalized least squares (GLS) method is adopted to handle this problem. The estimation results are reported in Table 4.[11]

[10] There is a serious jump problem in the data on total employment and sectoral employment during 1989 and 1990 in China. Thus, we adjust the official data on agricultural employment before 1990. Details can be found in *The Recalculation of the Agricultural Labor Forces in China* by Qi Dong, Tomoaki Murakami, and Yasuhiro Nakashima (2015).

[11] The missing values for draft animals in the agricultural sector from 1966 to 1969 are replaced with the average value of draft animals in 1965 and 1970 during the estimation process.

Table 4. Agricultural Production Function Estimates with GLS *AR (1)*

	Model 1	*Model 2*	*Model 3*	*Model 4*
T_{1978}	0.0469 *** (0.0042)	0.0540*** (0.0033)	0.0751*** (0.0032)	0.0623*** (0.0023)
$\ln(L_{at})$	0.3385*** (0.0786)	-0.0764 (0.0878)	0.8624* (0.4727)	0.4723*** (0.1331)
$\ln(H_{at})$	0.0694 (0.0618)	0.4025*** (0.0488)	0.0193 (0.2241)	0.1544* (0.0809)
$\ln(K_{at}^1)$	0.4167*** (0.0661)			
$\ln(K_{at}^2)$		0.1928*** (0.0430)		
$\ln(K_{at}^3)$			-0.1331 (0.1134)	
$\ln(K_{at}^4)$				0.1477*** (0.0384)
ρ	0.7225	0.3802	0.7731	0.6414
Obs.	51	43	47	51
R^2	0.9999	0.9999	0.9996	0.9999
MSE	0.0308	0.0470	0.0471	0.0406

Notes: (1) K_{at}^1 is our estimated agricultural capital stock, K_{at}^2 is total power of farm machinery, K_{at}^3 is draft animals, and K_{at}^4 is agricultural tractors in use.
(2) GLS accommodates first-order autoregression, *AR (1)*, in the structural residuals.
(3) *** denotes significance at the 1% level, ** denotes significance at the 5% level, and * denotes significance at the 10% level.
(4) Values in parentheses are standard errors.
(5) Observations from 1958 to 1961 are omitted.

It can clearly be seen that the number of draft animals is a poor measurement of agricultural capital stock, whose estimated coefficient is negative. Moreover, the elasticity of agricultural output with respect to labor is quite high, 0.86, using the data on draft animals. The total power of farm machinery is also not a good indicator given that the estimated coefficient of labor is negative and insignificant when we use it.

Comparatively, our estimated agricultural capital stock and agricultural tractors in use are good measurements of China's agricultural capital stock. The estimated elasticities of agricultural output with respect to labor using the two types of measurements do not differ significantly. However, the differences in elasticities with respect to capital and land are obvious. The estimated elasticity of agricultural output with respect to capital is 0.42 using our estimated agricultural capital stock but 0.15 using the number of agricultural tractors in use. These results occur because not only the tractors (agricultural machinery) but also the other types of investments are included in the PIM estimation of agricultural capital stock. Thus, using only the number of agricultural tractors in use to represent agricultural capital stock would underestimate the contribution of agricultural capital to agricultural production.

Using our estimated agricultural capital stock, the elasticity with respect to land is about 0.07. When using the number of agricultural tractors in use, the elasticity with respect to land is about 0.15. As data on arable land in China are missing, we use the hectares under cereal production instead. Arable land in China is declining along with rapid urbanization and labor transfers. However, there is no obvious declining trend in the hectares under cereal production because this partially depends on progress in agricultural technology. Thus, hectares under cereal production are not a good measure of the land used in the agricultural sector.

5. Estimation of the Contribution of Capital Accumulation to Agricultural Output Growth

Based on the estimation results of the agricultural production function above, we estimate the contribution of capital accumulation to agricultural output growth. It is necessary to first determine the elasticity of agricultural output with respect to capital. To this end, we examine the estimation results of agricultural production functions in other studies. Hayami and Ruttan (1985) estimate an inter-country agricultural production function involving 43 countries for 1960, 1970, and 1980. According to their results, the elasticity of agricultural output is around 0.5 with respect to labor, around 0.07 with respect to land, about 0.14 with respect to livestock, and about 0.1 with respect to machinery. If we sum livestock and machinery as agricultural capital stock, the elasticity with respect to capital is about 0.24. Chow (1993) estimates China's agricultural production for 1952 to 1980. His results indicate that the elasticity of agricultural output with respect to labor ranges from 0.23 to 0.64, while the elasticity of agricultural output with respect to capital ranges from 0.21 to 0.56. Excessively high estimates of the elasticity of capital would underestimate the contribution from labor and land while excessively low estimates would underestimate the contribution from capital. We consider 0.35 to be the best option.

Table 5. Contribution of Capital Accumulation to Agricultural Output Growth

%

	K_{at}^1	K_{at}^2	K_{at}^3	K_{at}^4
1953-1957	66.47	N.A.	6.78	368.69
1958-1962	-113.36	N.A.	39.34	-176.69
1963-1967	42.83	N.A.	11.80	68.59
1968-1972	84.37	N.A.	25.74	101.28
1973-1977	87.28	238.75	-8.23	225.19
1978-1982	33.51	56.33	18.52	64.68
1983-1987	10.95	36.72	18.13	7.40
1988-1992	15.88	25.44	11.11	-19.05
1993-1997	11.83	31.80	2.60	-9.40
1998-2002	50.94	41.40	-15.63	36.02
2003-2007	35.19	23.67	-28.26	69.03
2008-2012	51.56	28.09	-50.03	81.84

Source: Calculated by the authors.

Table 5 summarizes the contribution of capital accumulation to agricultural output growth from 1952 to 2012.[12] The contribution of capital accumulation calculated using draft animals became negative in the late 1990s, because the number of draft animals used began to decrease. Employing tractors in use to represent agricultural capital stock results in a widely fluctuating estimate of the contribution of agricultural capital accumulation, which is even negative for the 1988–1997 period due to the steep decrease in tractor use during that time.

Ignoring the abnormal periods, using the total power of farm machinery to represent agricultural capital stock produces a higher contribution from agricultural capital accumulation for 1978 to 1997 than our estimated capital stock produces but a lower contribution from agricultural capital accumulation for the period since 1998. These results are unreasonable. From 1978 to 1997, China's agriculture contributed a large amount of investment to the development of the non-agricultural sector. In the 2000s, the Chinese government has increased investments in the agricultural sector to make up for the influence of the large-scale inter-sectoral labor transfers. Thus, we consider a lower contribution from agricultural capital accumulation from 1978 to 1998 and a higher contribution from agricultural capital accumulation to be more reasonable in China. Thus, our estimated data are better at explaining China's agricultural capital accumulation.

6. Conclusion

Though Chow (1993) sheds light on agricultural capital accumulation in China for the period before its economic reforms and much research has measured China's agricultural capital stock for the period after they began, the trajectory of China's agricultural capital accumulation since 1952 remains unclear. This study attempts to address that issue.

Using data on fixed capital formation and PIM, we estimate a continuous and consistent series of agricultural capital stock in China for the whole period from 1952 to 2012. By estimating an agricultural production function and calculating the contribution of capital accumulation to agricultural output growth, we prove that our estimated data on agricultural capital stock are superior to other indicators often used to represent China's agricultural capital stock.

Two points about our estimates need to be noted, however. First, the initial capital stock in the agricultural sector is not set to zero, as it is in Chow (1993). In 1952, more than half of China's GDP represents agricultural value added. It is hard to imagine that such a large sector had no capital stock. Furthermore, Minami (2014) estimates agricultural capital stock in Manchuria from 1932 to 1944, finding that it accounted for about one-third of the agricultural value added. Though agriculture was more developed in Manchuria than in other areas in China at that period and thus cannot be said to represent China's average level of agricultural capital stock, assuming that the initial agricultural capital stock in 1952 was zero is risky.

[12] The growth accounting equation is $\frac{\dot{Y}_{at}}{Y_{at}} = \beta\frac{\dot{L}_{at}}{L_{at}} + \gamma\frac{\dot{K}_{at}}{K_{at}} + \delta\frac{\dot{H}_{at}}{H_{at}} + \frac{\dot{T}_a}{T_a}$, where T_a is the total factor productivity in the agricultural sector. Note that the average growth rate is calculated as $\dot{X}/X = (X_t - X_{t-1})/[(X_t + X_{t-1})/2]$.

Second, using the percentages of the agricultural sector in fixed asset investments to represent the percentages of the agricultural sector in fixed capital formation might be questionable. Especially for the period from 1952 to 1986, we use the percentages of the agricultural sector in capital construction investment to represent its percentages in fixed capital formation. Before China's economic reforms began, the wage rate in China's agricultural sector remained at subsistence levels. Thus, the probability that peasants invested significantly in agricultural production is low; government investment in the agricultural sector was the dominant kind. Also during this period, a large amount of the investment in the agricultural sector flowed through the People's Communes in order to promote them. Therefore, using the percentages of the agricultural sector in capital construction investment to represent the percentages of the agricultural sector in fixed capital formation is reasonable and acceptable for that period.

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