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Measuring agricultural total factor productivity in China: pattern and drivers over the period of 1978-2016

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The Chinese agricultural sector has experienced a substantial increase in total output since dramatic reforms were introduced in 1978. This paper uses the index method to measure agricultural total factor productivity (TFP) for China's crop and livestock industries, based on the gross output model from 1978 to 2016. We construct production accounts for the industries using input-output relationships for the 26 main agricultural commodities and commodity groups, which account for over 90 per cent of the total agricultural inputs and outputs. The results show that China's agricultural TFP grew at a rate of approximately 2.4 per cent a year before 2009, which is comparable to the main OECD countries and is double the world average. TFP growth accounts for approximately 40 per cent of output growth, suggesting that input growth was the main driver of output growth in the past. However, average productivity growth slowed down after 2009 though it has gradually recovered since 2012. The slowdown reflects the emerging challenges to existing farm production practices in Chinese agriculture, suggesting the need for further institutional reform.

Key words: agricultural TFP, China, index method, institutional reform.

1. Introduction

Since implementation of the household responsibility system (HRS) in the agricultural sector in 1978, China has embarked on a series of economy-wide institutional and marketisation reforms. Consequently China has achieved substantial and sustainable economic growth in the last four decades, leading to recognition of an 'economic growth miracle' (Garnaut *et al*. 2018; World Bank 2018). China's real gross domestic product (GDP) increased from US$ 216.5 billion to US$ 9.2 trillion (based on 2005 prices) at an average annual growth rate of 11.3 per cent a year (CNBS 2018; World Bank 2018). Consequently, it became the world's second largest economy in 2011, second only to the United States. As China's economy has continued to grow at a

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much higher pace than the rest of the world, it is expected to overtake the US economy in size and become the largest economy within the next two decades.

Driven by productivity growth, the agricultural and rural sector in China has experienced a substantial increase in total output, as well as changes in the production structure and a large reduction in poverty. Between 1978 and 2017, China's real agricultural output value grew at an annual rate of 5.3 per cent, which is more than double that for the period of 1952 to 1978, when it recorded a rate of 2 per cent a year (CNBS 2018; Huang and Rozelle 2018). With the advancement in production technology and the improvement in technical efficiency, China managed to meet approximately 95 per cent of domestic food demand through its own production using the constrained supply of natural resources (such as arable land and fresh water) in 2015.[1] Along with agricultural output growth and production efficiency improvement, China's rural per-capita income in real terms has quadrupled, and the poverty rate has declined significantly. From 1978 to 2007, the number of people below the extreme poverty line in rural China fell drastically from 250 million to <15 million (Huang and Rozelle 2018).

It is widely believed that institutional reforms, market integration, and technological progress, have played an essential role in contributing to the rapid productivity growth in China's agricultural sector. For example, McMillan *et al.* (1989) and Lin (1992) found that efficiency improvement at the farm household level immediately after the HRS reform accounted for approximately 40 per cent of agricultural output growth between 1979 and 1984. Jin *et al.* (2010) showed that marketisation integration after the early 1990s caused total factor productivity (TFP) of main coarse grain producers (i.e. producers of rice, maize, wheat and soybean) to increase at an average rate of 2 per cent a year between 1995 and 2008, approximately double the world average for the same period of time. Fuglie and Rada (2018) used the Food and Agriculture Organization (FAO) data to measure the TFP of China's agriculture, forestry and fishery sector as a whole and showed that aggregate TFP in China grew at a rate of 2.7 per cent a year during 1978–2013, accounting for 61.4 per cent of its total agricultural output growth since 1978. They attributed this productivity growth to ongoing technological progress and increased public R&D investment.

The aforementioned studies provide useful insights on agricultural productivity growth for particular enterprises or for specific reform periods. Despite the significance of this issue, apart from Fuglie and Rada (2018),[2] only few studies have investigated how agricultural TFP for crop and livestock industries has evolved throughout the post-reform period. In addition, the mechanism of how industry-level agricultural TFP growth is

[1] China has used only 5 per cent of the world's fresh water and 8 per cent of arable land to feed nearly 20 per cent of the world population (Huang and Rozelle 2018).

[2] Fuglie and Rada (2018) targeted at the industry-level TFP estimates but relied on using the FAO data, which do not provide information on price and full inputs.

linked to institutional and marketisation reforms is not clear. This is partly because little effort has been spent on constructing internationally consistent production accounts for China's agriculture sector or to estimate the real factor inputs in agricultural production (Jin *et al.* 2002, 2010).[3] Consequently, most existing studies on policymaking and international comparison have used partial factor productivity measures, such as yield and labour productivity, more widely than the TFP measure (State Council 2018). Nevertheless, as these measures usually cannot efficiently account for total labour usage or the structure of capital and intermediate inputs, research based on these measures may result in inappropriate managment and policy conclusions.

This study applies the index method to measure China's agricultural TFP at the national level using the gross output model for the post-reform period of 1978 - 2016. This involves construction of internationally consistent production accounts using detailed inputs and outputs of 26 main agricultural commodities and commodity groups in the crop and livestock industries. Implicit quantities of agricultural gross output and total input are derived by using nominal values to divide the corresponding price indexes, which are measured by using the Fisher index. The TFP is then calculated by dividing the implicit quantity of total output by total input. In the output and input aggregation process, we adopt proper procedures to consider quality adjustments for various inputs, particularly for land, labour, and some intermediate inputs such as fertilisers and chemicals. Finally, we present agricultural TFP indexes and their growth for the post-reform period and or four sub-periods (i.e. 1978 - 1984, 1985 - 1992, 1993 - 2008, and 2008 - 2016). The sub-periods are classified according to different reforms and policy period, which enable us to analyse the underlying determinants of changes in TFP growth rates.

Our study makes at least three contributions to the literature. First, it is the first to measure aggregate output, input, and TFP for crop and livestock industries in China throughout the whole period 1978 - 2016. This allows us to compare our measurements of China's agricultural TFP with those for the rest of the world. Second, we use the country-wide farm survey data to construct production accounts. This enables us to retrieve micro-founded information on the real input of land, labour, and intermediate inputs underlying the aggregate agricultural production function in China. Third, we consider the change in structure and quality of land, labour, and intermediate input qualities and their potential impact on agricultural TFP measurements and follow a proper procedure to manage them. The newly available agricultural TFP statistics and the subsequent analysis are expected to enrich the body of knowledge about China's agricultural productivity and provide policymakers with useful information and valuable insights to inform their future work.

[3] In most developing countries (like China), the national account statistics on agriculture and rural areas are not separable.

The rest of the paper proceeds as follows. Section 2 briefly discusses the agricultural and rural reforms in China over the past four decades; their possible impact on agricultural productivity; and estimation of China's agricultural TFP. Section 3 presents the index method used in our study and the method used to construct the production account for agriculture. Section 4 discusses the estimated agricultural TFP, its growth, and the underlying changes in input and output structure in China between 1978 and 2016. In particular, we split the whole reform period into four sub-periods; each of which captures different stages of reforms. Section 5 concludes the paper.

2. Background

Agriculture is an important strategic sector in China, since it provides food, fibre, and other primary products to meet the basic requirements of a growing population and to ensure economic development. In 2017, the agricultural sector (including crop, livestock, forestry, and fishery) produced commodities and services with value added of RMB 6.80 trillion yuan (approximately US$ 1.10 trillion), by utilising 134.9 million hectares of arable land and 361.8 million people in the labour force. Although the share of agricultural value added in its GDP declined significantly from 27.9 per cent in 1978 to 8.2 per cent in 2017, real output of the sector has expanded substantially over time with an annual growth rate of 5.3 per cent. Further, major agricultural products, namely: cereals; oil crops; cotton; meat; dairy products; vegetables; and fruits; have increased by 2.2 times, 6.7 times, 2.6 times, 10.1 times, 32.4 times, 14.8 times and 12.1 times, respectively, in 2017 compared to 1978. This rapid increase in agricultural output has enabled China to meet its growing domestic demand for food largely through its own agricultural production (Huang and Yang 2017).

Along with the expansion of agricultural output, two trends have emerged in China's agricultural production. First, rapid urbanisation and industrialisation have fundamentally changed the Chinese food consumption structure. With an increase in per-capita income, the focus of food consumption has shifted from grain products to non-grain products as food demand has shifted towards high-protein and high-value products. Between 1978 and 2017, the share of the non-crop sector (mainly livestock) in the total agricultural output value increased from 15.8 per cent to 35.4 per cent. Within the crop sector, the share of grain value decreased from 48.7 per cent to 23.3 per cent over the same period. Second, agricultural production has become more specialised with an increase in the average farm size and in the number of professional farmers. Since the 1990s, millions of farmers have rented out their land and worked full-time off the farm (Wang *et al*. 2011; Huang and Ding 2016). This trend of rising off-farm employment has facilitated rural transformation as rural households specialise into either full-time off-farm labour or full-time farming (Meng 2000; Meng *et al*. 2005).

It is widely believed that institutional innovation, policy reforms, and infrastructural investment are three pillars driving agricultural productivity growth in China in the post-reform period. For example, the initial HRS reform for the period 1979 - 1984 provided farmers impetus to increase production efficiency. As a result, farmers are able to produce more output without having to increase inputs (McMilian 1989; Lin 1992). The marketisation reform gradually liberalised the agricultural pricing and marketing system throughout the 1980s and 1990s, eliminating the segregation of regional market and the isolation of the domestic market in 2000s. This improved the efficiency of resource reallocation within the agriculture sector, as well as between this sector and the rest of the economy (Fan and Zhang 2002; Brümmer *et al*. 2006; Zhang and Brümmer 2011).[4] In 2000, China started to develop the world's largest and most decentralised public agricultural R&D system (Chen *et al*. 2012). Between 2000 and 2013, public investment in agricultural R&D has quadrupled, making China the largest investor in public agricultural research in the world (Stads 2015; OECD 2018). Meanwhile, improved agricultural production infrastructure in rural areas (e.g. the farmland and irrigation system) and the network of roads and rails promote technological diffusion in agricultural production of China, which also contributes to agricultural productivity growth (Huang and Rozelle 2018; OECD 2018). Recently, China has further strengthened its reforms in the agricultural sector and rural area through a series of policies, including rural land and labour market reforms; and has initiated both urban - rural integration and the 'New Rural Revitalization Development Strategy' (MOA 2014; Han 2015).[5]

Although previous institutional and policy reforms in China are believed to have substantially improved agricultural productivity growth through restoration of the market's role in allocating resources and facilitating technological progress and diffusion (OECD 2018), questions remain regarding the following aspects: (i) How has agricultural productivity, and in particular, agricultural TFP, evolved throughout the post-reform period in China? and (ii) What is the relationship between agricultural productivity growth and institutional and policy reforms in China? To answer these questions, it is essential to construct long time-series estimates of agricultural TFP for China for the period 1978 - 2016 and its related production accounts, following the international standard national accounting procedure.

[4] Since 2001 when China gained access to the World Trade Organization (WTO), it has reduced its tariff rates for agricultural products from 42.2 per cent to 21.0 per cent and then down to 12.0 per cent in 2004. Such open-to-trade policies reduced domestic support and facilitated market integration, making China one of the most free-agricultural-trading nations in the world (Huang and Rozelle 2018).

[5] Chinese President Xi Jinping placed 'pursuing a rural revitalization strategy' during the 19th CPC National Congress on 18 October 2017, which is the leading agenda for government work on agriculture, rural areas and rural residents.

To date, more than 60 studies have focused on the measurement of agricultural TFP and its growth in China between 1982 and 2016, providing 2,136 estimates for the post 1978 period (Tian and Yu 2012; Pan 2013; Wang *et al*. 2013; Zhang and Cao 2015; Gong, 2018). However, most of these estimates are unreliable for two reasons. First, average agricultural TFP estimates have significantly increased during the post 1978 period, with an average annual growth rate of 3.30 per cent a year.[6] Such an estimate indicates that China's long-run technological progress has been far higher than that of many developed countries. For example, agricultural TFP in the United States has grown at a rate of 1.69 per cent a year since 1978, but the country leads the world in agricultural technology innovation and adoption. Second, the estimated annual TFP growth rates are significantly different from each other, making it difficult for researchers and policymakers to understand the changing trends in agricultural productivity. For example, the estimated annual growth rates of agricultural TFP for the period (or sub-periods) of 1978 - 2016, based on 1,926 time-series estimates, range from −33.2 per cent a year to 50.1 per cent a year (Guo and Li 2009; Pan 2013). Given the high heterogeneity in TFP estimates in different studies, it is very difficult to draw consistent and accurate conclusions on the underlying channels through which TFP growth rates are affected.

Three potential measurement limitations could contribute to unreliable TFP estimates. First, the majority of existing studies have not properly measured real agricultural output. For example, many studies have directly used the consumer price index to deflate the agricultural output value without properly accounting for structural changes in output (Tian and Yu 2012, Zhang and Cao 2015); this may lead to biased estimation of agricultural output. Second, most studies have used total labour force as an approximation of agricultural labour input and have failed to differentiate off-farm employment or non-agricultural labour from agricultural labour input (Jin *et al*. 2002, 2010). In addition, for the estimation on capital services, most studies have used total power of machinery as an indicator rather than calculating capital stock for each asset (Wang *et al*. 2013). Third, many studies have focused only on the crop industry (particularly coarse grains, e.g. rice, maize, and wheat) (Jin *et al*. 2002, 2010). However, they do not pay enough attention to the livestock industry and its impact on aggregate agricultural TFP growth in China. Consequently, those estimates of agricultural TFP growth may not accurately capture the change in production structure in China's agriculture during the post-1978 period.

3. Method

We use a gross output-based model (which originated from Gollop *et al*. 1987) to measure agricultural TFP. A similar approach was first used by the US

[6] Please refer to the online appendix for more detailed summary of existing literature.

Department of Agriculture (USDA) to construct the official statistics of multifactor productivity for the farm sector in 1985 and then was revisited and revised in 1987, 1993, and 2009 (Ball 1985; Yee *et al.* 1993). The Economic Research Service of USDA has built a more sophisticated system of production accounts for the estimation, following the recommendations made by an American Agricultural Economics Association taskforce (Ball *et al.* 2015a,b) and a more recent panel. The approach has been widely used for country-specific analysis and cross-country comparisons (Ball *et al.* 2001, 2010, 2019).

In this model, agricultural TFP is derived as the ratio of a gross agricultural output index ($\overline{Y_t} = \sum Y_t$) over a gross agricultural input index ($\overline{X_t} = \sum X_t$), such that:

$$\mathrm{TFP}_t = \frac{\overline{Y_t}}{\overline{\overline{X_t}}}. \tag{1}$$

Taking logarithmic differentials of Equation (2) with respect to time (t), yields:

$$\widehat{\mathrm{TFP}}_t = \hat{\bar{Y}}_t - \hat{\bar{X}}_t, \tag{2}$$

where $\widehat{\mathrm{TFP}}_t = \mathrm{dTFP}/\mathrm{d}t$, $\hat{\bar{Y}}_t = \mathrm{d}\bar{Y}_t/\mathrm{d}t$ and $\hat{\bar{X}}_t = \mathrm{d}\bar{X}_t/\mathrm{d}t$. Therefore, TFP growth ($\widehat{\mathrm{TFP}}_t$) equals the aggregate output growth rate ($\hat{\bar{Y}}_t$) minus the aggregate input growth rate ($\widehat{\overline{X}}_t$).

To implement Equations (1) and (2), we need to aggregate individual inputs and outputs into aggregator quantity indexes. Following Ball *et al.* (2008) and Sheng *et al.* (2018), we use the indirect Fisher quantity index method for the aggregation process.[7] Specifically, a Fisher index formula is first employed to calculate an average price (using the corresponding quantities as weights). Then, the aggregate quantity index is derived by dividing the total revenue (or cost) by the average price, such that.:

$$\overline{Y_t} = \frac{R_t}{P_t}, \tag{3}$$

$$\overline{X_t} = \frac{C_t}{W_t}, \tag{4}$$

where R_t denotes the total revenue of agricultural production and C_t denotes the total cost. P_t and W_t are price indexes for aggregate output and input, respectively. Theoretically, the indirect Fisher quantity index method is the

[7] Alternatively, we can use the Tönqvist–Thiel index for the aggregation process (Diewert 1992). For the detailed discussion on the advantage of using the index method for agricultural TFP estimation, please refer to Fuglie *et al.* (2012).

same as the Fisher index since it satisfies the reversibility condition (Jorgenson 1966).

To demonstrate how the aforementioned method works, we adopt the chained Fisher index to derive the aggregate price index and denote the average price indexes of output and input as the geometric mean of the Laspeyres and the Paasche indexes:

$$P^F_{t-1,t} = \left(P^L_{t-1,t} P^P_{t-1,t}\right)^{1/2} = \left(\frac{\sum_{i=1}^N p_{it} q_{i,t-1}}{\sum_{i=1}^N p_{i,t-1} q_{i,t-1}} \frac{\sum_{i=1}^N p_{it} q_{it}}{\sum_{i=1}^N p_{it-1} q_{it}}\right)^{1/2}, \quad (5)$$

$$W^F_{t-1,t} = \left(W^L_{t-1,t} W^P_{t-1,t}\right)^{1/2} = \left(\frac{\sum_{j=1}^M w_{jt} x_{j,t-1}}{\sum_{j=1}^M w_{j,t-1} x_{j,t-1}} \frac{\sum_{j=1}^M w_{jt} x_{jt}}{\sum_{j=1}^M w_{jt-1} x_{jt}}\right)^{1/2}, \quad (6)$$

where $P^L_{t-1,t} = \frac{\sum_{i=1}^N p_{it} q_{i,t-1}}{\sum_{i=1}^N p_{i,t-1} q_{i,t-1}}$ and $W^L_{t-1,t} = \frac{\sum_{j=1}^M w_{jt} x_{j,t-1}}{\sum_{j=1}^M w_{j,t-1} x_{j,t-1}}$ are the Laspeyres output and input indexes for period t, and $P^P_{t-1t} = \frac{\sum_{i=1}^N p_{it} q_{it}}{\sum_{i=1}^N p_{it-1} q_{it}}$ and $W^P_{t-1t} = \frac{\sum_{j=1}^M w_{jt} x_{jt}}{\sum_{j=1}^M w_{jt-1} x_{jt}}$ are the Paasche output and input indexes, respectively, for period t. p_{it-1}, p_{it}, w_{jt-1}, and w_{jt} represent the prices of the i^{th} output or j^{th} input items in the base (say, $t-1$) and current periods (t), and q_{it-1}, q_{it}, x_{jt-1} and x_{jt} are the quantity of the i^{th} or j^{th} item in the two periods.

Applying this approach to measure China's agricultural TFP, a set of particular assumptions is made on measurement of capital and labour, such as specifications of average capital service life, the parameter for depreciation of depreciable assets, choice of measurement unit for labour, as well as input quality adjustment to reflect specific characteristics of agricultural production in China.[8]

4. Data

We use mainly three groups of data to construct production accounts for crop and livestock industries in China, namely: the output data; input - output relationship data; and data on capital stocks and services. The output data were sourced from the national account statistics, provided by China's National Bureau of Statistics (CNBS) and the Ministry of Agriculture and Rural Affairs. The data include output quantities of most crop and livestock commodities, total arable land areas, and gross output value of major commodity groups (i.e. cereals, oilseeds, fibre, vegetables, fruit, meat, and

[8] Interested readers can also refer to Ball *et al*. (2016) for the methodology used to calculate capital stock and capital services.

meat products). The second data source is the Cost-Benefit Collection for Agricultural Commodities compiled by the National Development and Reform Commission, which provides the input - output relationship for major agricultural commodities and detailed information on land, labour, and material and service usage for producing each unit of output and the unit price of each commodity. Data collected for 26 commodities was then aggregated to construct the production accounts for agriculture (mainly the crop and livestock industries) as a whole, using the total output of each commodity as weights. Data on capital stocks and services came from China's Fixed Asset Investment database (CNBS 2018) and China Contemporary Agricultural Production and Trade Statistics (Xu 1983), which provided information on fixed asset investment in buildings and structures, plant and machinery, and transportation vehicles since 1847. We use this time-series investment data to construct capital stock and capital services for agricultural production in China. Details on how we calculate output intermediate inputs and key inputs are described below.

1. Output: Agricultural outputs include all crop and livestock commodities that are produced on farm. The 65 crop products were categorised into eight categories: cereals; fibre crops; oil seeds; sugar; cash crops; vegetables fruit; and other crops, and 13 livestock products categorised into five categories: meat; poultry; eggs; milk; and other animal products (e.g. wool, hair, honey, and pelts).[9] For crop products, physical quantities of each commodity were estimated by multiplying yield and harvest area; while, for meat products, physical quantities were estimated by multiplying carcass weight and animal numbers. In terms of commodity prices, we use the unit value of each commodity and government procurement price as proxies for the period before and after 1993, respectively.
2. Intermediate inputs: We estimate intermediate inputs at the industry level by aggregating the data collected for 26 major commodities. For each crop product, intermediate inputs are categorised into eight types: fuel and lubricants; seedlings; fertiliser; chemicals; outsourcing services; maintenance and repairs; other materials; and other services. For each livestock product, intermediate inputs are categorised into nine types: fuel and lubricants, breeding costs, feedstuffs, vet services, tools and material costs, outsourcing services, maintenance and repairs, other materials and other services. The total costs for each intermediate input are estimated by multiplying total output by the unit cost of that intermediate input. The implicit quantity of each intermediate input is then derived as total costs divided by the corresponding price index. We account for quality difference for fertilisers and chemicals by using the hedonic prices, which differ between commodities.

[9] As there is no detailed input - output information for all 65 crop and 13 livestock products, we used the 26 major products for agricultural TFP estimates.

3. Land: To account for difference in land quality across regions and over time, we collect rental prices for different types of land used for producing the 26 commodities since 2002 and the opportunity costs for land use before 2002. The index method is applied to measure the aggregated land rental prices employing land areas used for producing each commodity as weights, which accounts for the difference in land quality. The quantity of land service is derived by dividing total land service value by the aggregate land rental price index, where total value of land service is measured by multiplying total sowing area by unit land rental.
4. Capital: Construction of capital input begins by estimating capital stock for each depreciable asset, including non-dwelling buildings and structures, plants and machinery, and transportation vehicles, as the weighted sum of all past fixed asset investment. The weights correspond to the relative efficiencies of capital goods at different ages, so that the weighted components of capital stock have the same efficiency. Then, we convert capital stock into capital services by means of rental prices, calculated by using the correspondence between the purchase price of the asset and the discounted value of future service flows derived from that asset. For more details about the estimation procedure, refer to Ball *et al*. (2016). In addition to conventional depreciable capital assets, we also include draught animal as additional bio-capital input following Sheng *et al*. (2018).
5. Labour: We split labour into two types, hired and self-employed, to account for their different roles in agricultural production. Data on the total hired labour usage and their wage for producing the 26 commodities are collected and aggregated to capture their quality differences. The real wage for self-employed labour is measured by using total labour costs, equal to gross output value minus the costs of land, capital, intermediate inputs, and hired workers to divide labour quantities.

5. Results

We measure aggregate input, output, and TFP indices between 1978 and 2016 and their growth rate. The results are shown in the Figures 1–7 and Table 1.

5.1. Agricultural TFP growth

Over the post-reform period 1978-2016, the sector-level agricultural productivity has significantly increased but with periodic fluctuations (Figure 1). The measured agricultural TFP index first increased from 100 in 1978 to 151 in 1983 and then fell to 98 in 1989 before it reached a new peak of 230 in 2008 after around 20 years of growth. Thereafter, the measured TFP index started to trend down from 230 in 2008 to 193 in 2009 and remained around this level until 2016. Throughout the period, the average growth rate of the sector-level

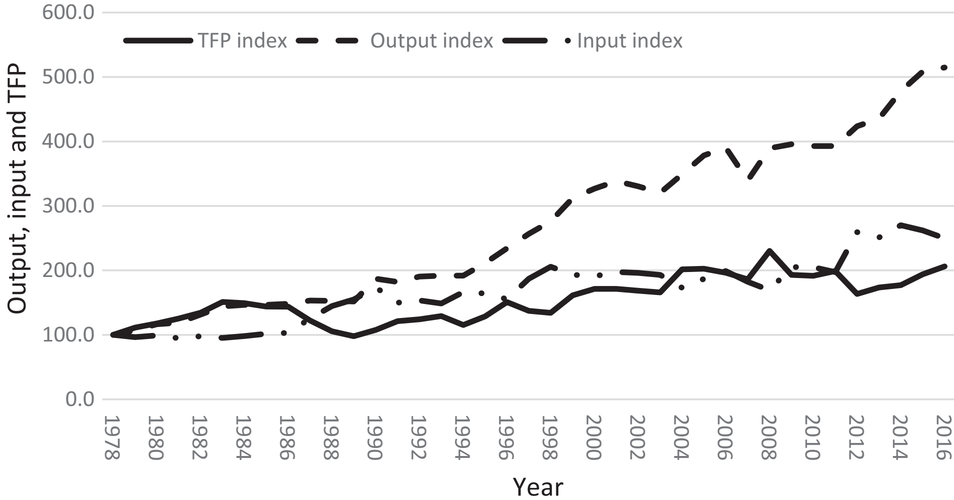

Figure 1 China's agricultural total factor productivity (TFP) index, 1978 - 2016. Source: Authors' estimation.

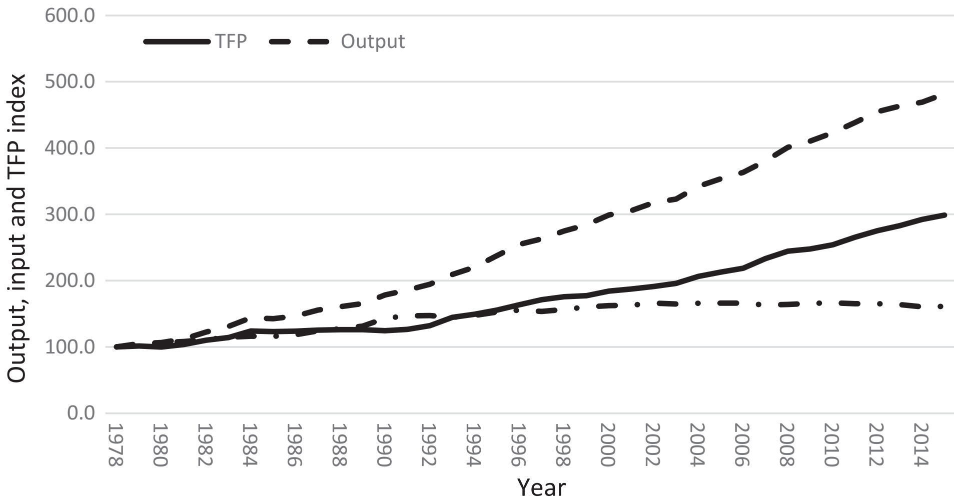

Figure 2 China's agricultural total factor productivity (TFP) index by ERS USDA, 1978 - 2015. Source: ERS USDA.

agricultural TFP was 1.9 per cent a year, which accounted for approximately 40 per cent of output growth.

Our measurements of aggregate input, output, and TFP growth for China's agricultural sector show that all three items grew during the post-reform period after 1978. However, the increasing pattern between aggregate input, output, and TFP is different in two ways from that obtained in previous studies, such as Fuglie and Rada (2018) and Wang *et al.* (2013).

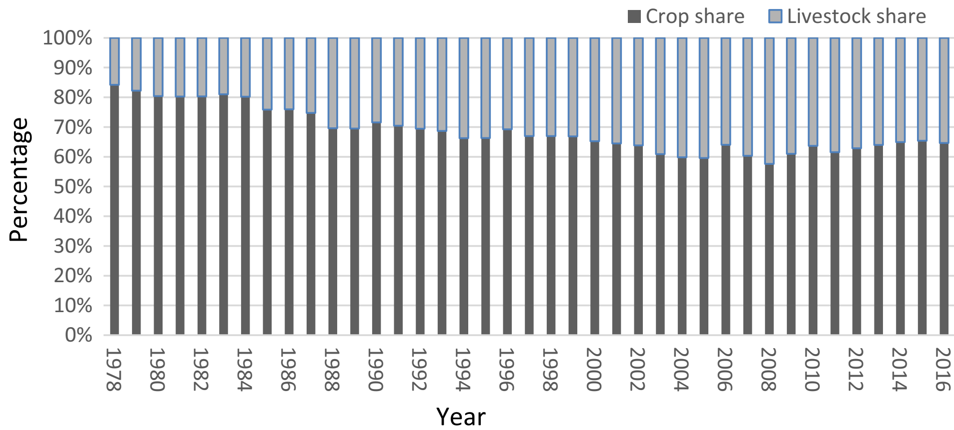

Figure 3 The share of crop sector and livestock sector in China's total agricultural output value, 1978 - 2016. Source: Authors' own estimation. [Colour figure can be viewed at wileyonlinelibrary.com]

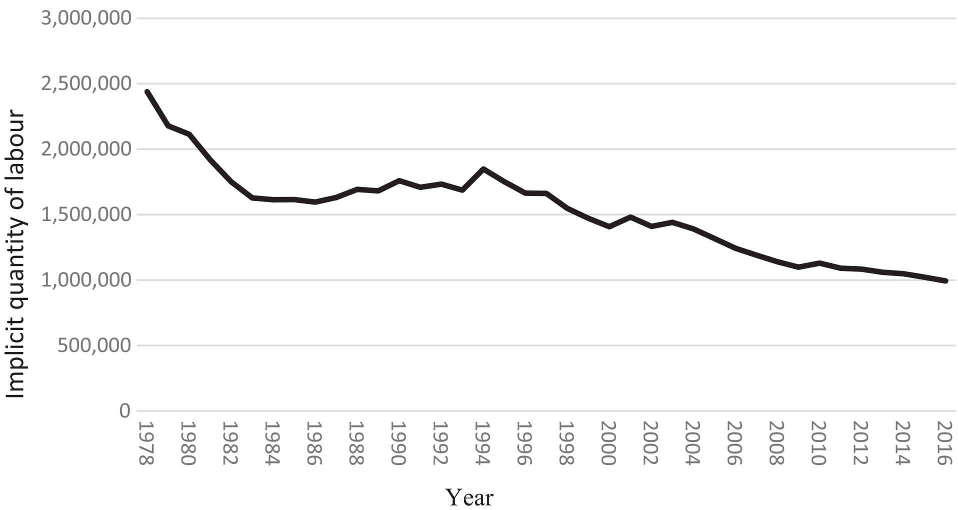

Figure 4 China's agricultural labour input, 1978 - 2016. Source: Authors' own estimation.

First, our measurement of the average TFP growth rate for the post-reform period is far less than that obtained by Fuglie and Rada (2018). Using FAO data, Fuglie and Rada (2018) showed that agricultural TFP grew smoothly at an average growth rate of 3.0 per cent a year for the period 1978 - 2015, which was triple the world average and accounted for two thirds of output growth for the post-reform period. By contrast, with improved statistics on outputs and inputs, we show that the average TFP growth was 1.9 per cent, twice the world average, which accounted for approximately 40 per cent of output growth. This finding confirms the argument that agricultural output expansion in China over the past four

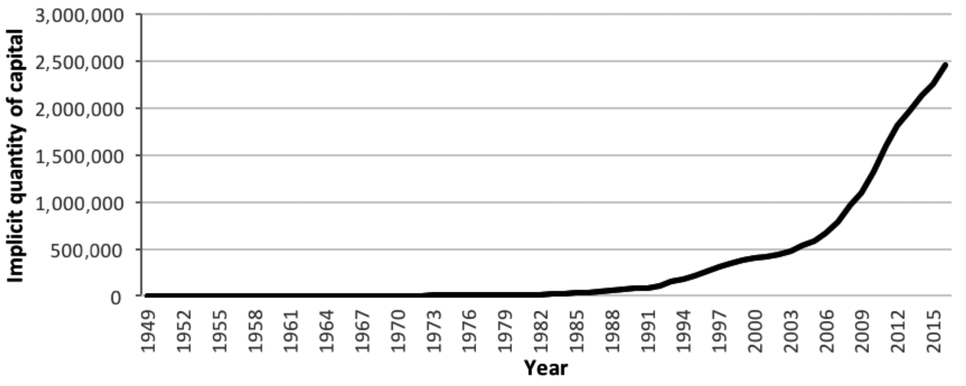

Figure 5 China's agricultural capital input, 1978 - 2016. Source: Authors' own estimation.

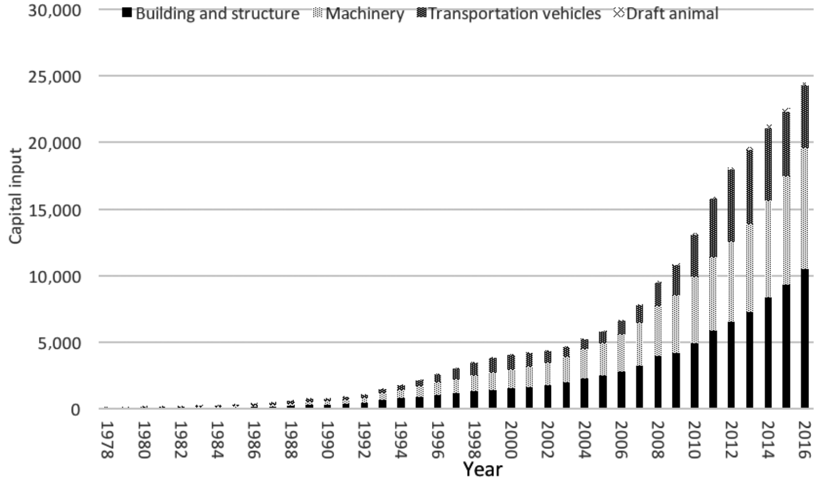

Figure 6 Structure of capital input: 1978 - 2016.

decades mainly came from increased input usage (Krugman 1992; Bai *et al.* 2006). In accordance with studies in other countries, our measure lies in a reasonable range from an international comparison perspective, since the average agricultural TFP for major OECD countries (which took the lead in agricultural technology progress and adoption) between 1973 and 2011 was only 1.6 and accounted for half of their output growth (Ball *et al.* 2019). Despite all the positive drivers of agricultural TFP growth, some factors still exist constraining the technology progress and adoption in the long run, such as the relatively small operational scale.

Second, we observe more intertemporal variations in TFP measures than other studies. By contrast, previous studies such as Fuglie and Rada (2018) and Wang *et al.* (2013) showed that agricultural TFP growth has been growing smoothly throughout the whole period, which is questionable

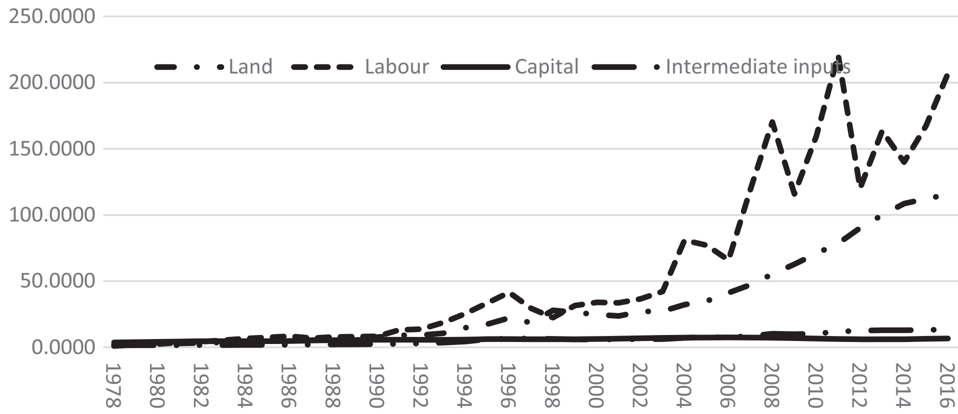

Figure 7 Comparing the relative prices of land, labour, capital and intermediate inputs, 1978 - 2016. Source: Authors' own estimation.

Table 1 Output, input and total factor productivity (TFP) growth (%): 1978–2016

	1978 - 2016	1978 - 1984	1984 - 1992	1992 - 2009	2009 - 2016
TFP growth	1.922	5.883	−1.634	2.598	0.943
Output growth	4.406	5.610	2.963	4.303	3.754
Crop growth	3.361	5.220	1.251	3.196	4.409
Livestock growth	6.894	11.552	8.783	6.727	1.845
Input growth	2.438	−0.257	4.673	1.705	2.811
Land growth	1.713	0.684	1.987	2.048	1.366
Capital growth	12.950	20.620	15.310	9.790	6.400
Labour growth	−2.363	−6.876	0.883	−2.617	−1.718
Intermediate inputs' growth	3.345	1.716	8.742	1.696	2.466

Source: Authors' own estimation.

(Figure 2). The intertemporal variations in our estimates corroborate the findings of Brümmer *et al.* (2006) about the different impact of institutional reforms in different sub-periods. For example, the agricultural TFP growth immediately after the HRS reform (i.e. from 1978 to 1984) is strong with a mean annual growth rate of more than 5.0 per cent a year. However, such rapid TFP growth did not last for longer period as the effects of policies diminished over time. In addition, the recent slowdown in TFP growth in China reflects the bottlenecks already faced by the agricultural sector and other emerging challenges.

To summarise, from an international and intertemporal perspective, we argue that the TFP measures in this study are more likely to reflect the change in agricultural technological progress and efficiency improvement over the post-reform period in China. In the following two subsections, we further investigate the relationships between reforms and agricultural TFP by focusing on specific policy periods.

5.2. Institutional and policy reforms and their impact on China's agricultural TFP

It is widely believed that agricultural TFP growth in China over the past four decades has been heavily influenced by institutional and policy reforms as well as public R&D and infrastructural investment. To further illustrate the relationship between those reforms and agricultural TFP at different stages, we split the post-reform period. Following Brümmer *et al.* (2006) and Zhang and Brümmer (2011) we use four sub-periods, which are 1978 - 1984, 1984 - 1992, 1992 - 2008 and 2008 - 2016.

During the first period of reform between 1978 and 1984, China implemented the HRS reform, which equitably contracted cultivated land to individual household farms based on the number of people per household. This reform provided strong incentive to improve the efficiency of labour usage. As shown in Table 1 (Column 2), according to our measurement, the annual growth rate of TFP for 1978 - 1984 is 5.9 per cent a year, which accounts for approximately 95 per cent of the output growth for the period. Such a measure supports the findings from McMillan *et al*. (1989), Lin (1992) and Jin *et al*. (2002), which show that the HRS reform raised agricultural TFP by a significant amount immediately after 1978.

Following the fast growth after the HRS reform, China's agricultural sector experienced a significant slowdown in agricultural output and TFP growth between 1984 and 1992 (Column 2, Table 1). The slowdown may be attributable to two reasons. First, although the HRS reform immediately boosted the agricultural productivity growth by improving farmers' incentive, such technical efficiency gains diminished quickly over time (Fan 1991; Fan *et al*. 2004). Second and more importantly, the marketisation reform implemented since the late 1980s did not succeed (Sicular 1995; Huang and Rozelle 1998). At that time, the agricultural market was a two-tier system, including both a market and a planning system, in which there was frequent policy adjustment in favour of either the market economy or planned economy (Brümmer *et al*. 2006). This uncertainty in politics further exacerbated the slowdown in agricultural output and TFP growth between 1984 and 1992 (Huang and Rozelle 1996; Fan and Zhang 2002; Fan *et al*. 2004). In particular, our measure shows that during 1984 - 1992, the agricultural TFP declined at the rate of 1.6 per cent a year with input growth double the size of output growth, which provides additional supportive evidence on such a changing agricultural TFP pattern.

The year 1992 is chosen as the starting of the third sub-period because China embarked on further marketisation reform in both rural and urban areas following the famous speech by former Chinese leader Deng Xiaoping during his tour of south China in 1992. Since then a functioning agricultural market has existed. Between 1992 and 2009, the estimated TFP index grew at a rate of 2.6 per cent a year, which accounted for more than half of output expansion. The marketisation reform at this stage focused on unifying government procurement and marketing systems, as well as integrating rural development with the overall economy (Zhang and Brümmer 2011). Although the central Government intervened in the grain market from time to time to smooth price fluctuations, regulations on other agricultural products (in particular, vegetables and fruits) have been relaxed since the early 1990s (Huang *et al*. 2004; Huang and Rozelle 2006). In fact, the Chinese Government also tried to reform grain market for several times, during which the procurement prices set by Government were improved for different categories. Such a marketisation reform eliminated the regional market segregation, especially between rural and urban areas and the isolation of the domestic market from the world. As a result, the farm gate price rose and the flexibility of farmers to choose what to produce increased, which in turn improved the efficiency of resource usage (Fan and Zhang 2002; Fan *et al*. 2004). Another factor which facilitated technology growth was the increase in public investment in agriculture. There has been a marked increase in government investment on agricultural R&D and public infrastructure because the taxation reform since 1994 has increased the tax revenue of the central Government (Huang and Yang 2017; Huang and Rozelle 2018).

While TFP growth was impressive before the mid-2000s (2.6 per cent a year), it appears to have slowed after 2008 when institutional reforms move to the further stages. Between 2009 and 2016, the estimated TFP grew at a rate of 0.9 per cent a year, which was less than half of its long-term growth rate. Underlying the slowdown of TFP growth, the most striking observation to emerge is the comparison between the changes in growth rates of aggregate output and input. The growth rate of aggregate output declined from its long-term trend of 4.4 per cent a year to 3.5 per cent a year; by contrast, that of aggregate input increased from its long-term trend of 1.9 per cent a year to 4.9 per cent a year. The decline in agricultural TFP growth supports a series of emerging challenges suggested by the literature. On the one hand, the yield growth of major crops slowed down owing to degraded land from decades of overuse of fertiliser and crop chemicals (Zhang *et al*. 2013; Lu *et al*. 2015). Some studies also suggest that the changing climate conditions led to economic losses of major crops in the past decade and yields are projected to decline in the future (Chen *et al*. 2016; Zhang *et al*. 2017). On the other hand, the substitution between labour and capital inputs is restricted for two reasons: first, rising wages due to increasing non-agricultural employment reduce agricultural labour supply; and second, the relatively small operational scale constrains household farms from adopting of more efficient capital-intensive technologies (Han 2015; Huang and Yang 2017). Those emerging challenges are difficult to tackle in the short term, even though actions have been taken recently to encourage 'land transfer and consolidation' and the purchase of 'machinery services' (Lambert and Parker 1998; Huang, Gao and Rozelle 2012; Han 2015).

5.3. Recent TFP slowdown: Input and output analysis

There is no consensus in the literature on whether China's agricultural TFP growth has slowed down in recent decades. Some scholars found that agricultural TFP continued to grow after the mid-1990s (Chen *et al.* 2008; Tong *et al.* 2009; Zhou and Zhang 2013; Fuglie and Rada 2018), while others found evidence that China's agricultural TFP growth gradually lost the momentum since the mid-2000s (Pratt *et al.* 2008; Dekle and Vandenbroucke 2010; Wang *et al.* 2013). Our measurements on agricultural TFP growth for recent years not only support the second argument, but also provide additional evidence to interpret the underlying channels through which such a change has emerged. The following paragraph discusses the key findings from three perspectives, that is: output structure; changes in input of capital; and changes in input relative prices, and explains the TFP slowdown in recent years.

We first look at the changes of output structure in the last decade. Contrary to general development patterns of agricultural production, the share of grain crop in total output increases since 2008 (Figure 3). This is surprising as along with a rise in income, agricultural output structure is expected to shift from grain food towards non-grain food as food demand shifts towards high-protein and high-valued products. The increase in crop share can be explained by increased production subsidies and the implementation of stock policies for major crops, which distort the domestic market.[10]

With only a moderate increase in farmers' income, the price interventions of Chinese Government in the past decade resulted in many policy challenges, such as massive government storage, high finance burdens, and the large gap between domestic and imported prices, which hurt the downstream industries. (Huang and Yang 2017; Huang and Rozelle 2018). Yet, still relatively little is known about how these price interventions affect the progress of technological innovation and adoption of grain production. According to our measure of TFP growth, the price interventions of Chinese Government on major crops may contribute to the slowdown of technology progress. Although it is out the scope of this study to identify and accurately measure the effects of such policies on TFP growth empirically, our findings, while preliminary, can help to understand the long-term impacts on agricultural pathways of short-term price interventions.

Second, another factor that could be related to the fluctuation of TFP growth in recent years is the change in way of production. Agricultural production in China has long been dominated by small household farms using the labour-intensive technology partly due to the HRS land allocation

[10] The temporary reserve policy in north-east China and Inner Mongolia started in 2008. The Chinese government assigned China Grain Reserves Corporation, a state-owned cooperation to purchase corn from farmers in the targeted areas at a fixed price. Since 2008, Chinese farmers received a price above the market price due to Government purchasing. The main purpose of the policy is to stabilise farmers' incomes as well as corn production.

system. Yet, the trend has been gradually changing with a persistent decline in total labour input throughout the post-reform period since 1978. The structure change in demography and urbanisation causes labor scarcity in some seasons and areas. Labor costs have been increasing dramatically in recent years. Meanwhile, we show that the total capital input has started to increase drastically since 2008 (Figure 5). The rise in the capital - labour ratio is not only a result of increases in labour costs but also a result of huge increase in capital investment. Increasingly household farms choose to use capital to substitute labour with increased government subsidies for machinery purchase (Sheng *et al*. 2018; Yi *et al*. 2019). While the government subsidies could facilitate the substitution between labour and capital input, they may distort the market structure of agricultural machinery. Therefore, additional efforts are needed to investigate how the big significant rise in capital input is related to the fluctuations in agricultural TFP growth.

Finally, it is to be noted that the relative price of labour and land increased more quickly in recent years. Between 2008 and 2016, the annual growth rate of the relative price of labour and land is 13.4 per cent and 10.4 per cent, respectively, which are seven times and nine times the change in the relative price of intermediate inputs. Similar results were found in some studies using farm survey data (Wang *et al*. 2016; OECD 2018). The rapid increase in land rental prices is partly due to the rapid development of the land rental market and 'confirmation of land user rights', which in turn could become a factor negatively affecting land consolidation allowing farms to benefit from increasing returns to scale.

6. Conclusion

In this paper, we answer an important question: 'How have 'institutional reform and openness to trade' policies affected agricultural productivity growth over the past four decades?' For this purpose, we apply the index method with the gross output model to measure China's agricultural productivity for the crop and livestock industries for the post-reform period from 1978 to 2016. This involves construction of production accounts for 26 agricultural commodities and aggregation to the industry level, which creates the direct correspondence between inputs and output.

We show that agricultural TFP in China has grown rapidly and unevenly over the post-reform period since 1978. Throughout the whole period, the average growth rate of the industry-level agricultural TFP was 1.9 per cent a year. TFP growth accounts for approximately 40 per cent of output growth for the whole post-reform period, suggesting input growth is still the main driver of output growth in the past. We also pointed out that agricultural TFP growth slowed down to 0.9 per cent between 2008 and 2016, which was less than half of its long-term growth rate, and it was partly due to distorting Government policies and constrained growth of capital service, labour, and land inputs calling for further institutional reform.

This is one of the first studies to measure aggregate output, input, and TFP for crop and livestock industries in China throughout the whole period 1978 - 2016. Our measurements are comparable with the rest of the world. From a cross-country perspective, we believe our measurements lie in a more reasonable range than earlier studies on China's agricultural TFP growth of China. Meanwhile, compared with earlier studies on China's agricultural TFP growth, our measurements reveal more fluctuations in the growth rates, which corroborate the heterogeneous impact of institutional reforms over time. Further work should be carried out to investigate the causal relationship between specific policies and their associated effects on the paths of inputs and TFP growth rates.

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