Received: 29 December 2021 | Accepted: 22 September 2022

DOI: 10.1111/1467-8489.12495

The Australian Journal of Agricultural and Resource Economics
AARES

ORIGINAL ARTICLE

Total factor productivity change in China's grain production sector: 1980–2018

Zhihao Zheng[1] | **Shen Cheng**[2] | **Shida R. Henneberry**[3]

[1]College of Economics and Management, Northwest A&F University, Yangling, Shaanxi, China

[2]Grossman School of Medicine, New York University, New York, USA

[3]Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma, USA

Correspondence
Zhihao Zheng, College of Economics and Management, Northwest A&F University, No. 3 Taicheng Road, Yangling, Shaanxi 712100, China.
Email: zhihao.zheng@cau.edu.cn

Abstract

This study analyses changes in total factor productivity (TFP) of grains as an aggregate commodity and major grain crops including rice, wheat, and corn, using pooled provincial and time-series data from 1980 to 2018 for China. Results show that the growth of TFP in the grain sector was driven by technical improvements. Moreover, the grain output and wheat production benefited more from TFP growth, whereas the growth in the usage of inputs drove the growth in rice and corn production. Findings also indicate that the laissez-faire market-oriented policy led to a dramatic fall in output while the intervention-led policy resulted in a substantial rise in output, but neither of them fostered the growth of productivity. Conversely, the incentive-led policy in a market-oriented environment that raised the comparative profitability in grain production promoted the growth in both output and productivity in the grain sector. As the comparative advantage shifts away from agriculture in China, an appropriate support is thus necessary to stimulate farmers' incentive in growing grain crops.

KEYWORDS
China, grain sector, policy reforms, total factor productivity growth

JEL CLASSIFICATION
O47, Q48

1 | INTRODUCTION

China's grain output has grown rapidly, with an average annual rate of 1.94%, since the economic reforms of the late 1970s. Nevertheless, the grain output has not grown linearly on an annual basis and has been affected by considerable fluctuations. Grain output rose substantially and continuously from 1978 to 1984; hovered in a low level from 1985 to 1988; recovered from low levels and grew during 1989–1993; increased gradually from 1994 to 1998; fell continuously from 1999 to 2003; rose continuously year by year during 2004–2015; and continued to grow, although slowly, during 2016–2018. Over the past 40 years, during the periods of grain shortage and low beginning stocks, the government of China instituted a series of price support policies and measures to stimulate growth in the grain production system. Alternatively, during periods of oversupply and excess stocks, in order to restrain the growth in output, the government adopted contractionary policies and/or implemented market-oriented reforms (such as the reduction or elimination of producers' subsidies) with the goal of decreasing the comparative profitability in grain production. The policy reforms have not only affected the rate of growth in grain output but also had a profound impact on the pattern of growth in grain production (Gong, 2018; Wang et al., 2013).

This study analyses total factor productivity (TFP) change in China's grain production sector (hereafter grain sector) over the past 40 years. We focus on grains as an aggregate commodity and its major crops—rice, wheat and corn. Specific objectives of this study include: (1) estimating the growth rates of TFP and its components—technical change (TC) and technical efficiency (TE); and (2) determining the impact of policy reforms on TFP growth rates during selected time periods.

Exploring the sources of growth in agricultural output of China has been an important topic since the late 1980s. Studies in the late 1980s and 1990s have measured agricultural TFP growth rates and the contribution of rural institution innovation to agricultural TFP growth in the early 1980s (e.g. Huang & Rozelle, 1996; Lin, 1992; McMillan et al., 1989; Wen, 1993; Zhang & Carter, 1997). Studies undertaken since the late 1990s have estimated agricultural growth rates and the contributions to agricultural TFP growth of policy reforms within the existing rural institution environment (e.g. Brummer et al., 2006; Chen et al., 2008; Colby et al., 2000; Gautam & Yu, 2015; Gong, 2018; Jin et al., 2010; Wang et al., 2013). Except for a limited number of studies focussing on the grain sector, however, almost all of the above-mentioned studies concentrate on agricultural TFP growth. Moreover, except for Zhang and Carter (1997) focussing solely on grains as an aggregate commodity, the focus of most of the studies on TFP growth in the grain sector has been on the analysis of TFP growth of specific grain crops during a certain period of time.

With the rapid economic growth and the improvement in living standards of households over the past 40 years, the structure of food consumption in China has changed towards more animal-sourced protein, fruits and vegetables and less cereal foods, resulting in demand-driven changes in agricultural structure. More specifically, the shares of forestry, animal husbandry and fishery in gross value of agricultural output have more than doubled, rising from 20% in 1978 to 41% in 2018, whereas the shares of crop production in total agricultural output decreased from 80% to 54% during that period. Besides, during the 1978–2018 period, the shares of fruits and vegetables as a percentage of acreage and gross value of output grew rapidly, while the shares of grains decreased. Given the changes in agricultural structure, the results regarding the growth of agricultural TFP from published studies since the late 1980s could not accurately reflect TFP growth in the grain sector, albeit an accurate presentation of TFP changes in the agricultural sector. While the results about the TFP growth of individual grain crops during a certain period of time are helpful in understanding the sustainable growth of a specific grain crop for that period of time, they might not accurately reveal the whole picture of TFP changes in the grain sector over the past 40 years.

We make two contributions to the literature. First, we analyse TFP growth in the grain sector over the past 40 years. To achieve this, we construct a unique provincial time-series input–output data set that contains information on outputs (gross value) and inputs (land, labour and capital) of grains as an aggregate commodity. In particular, data on yields, labour days and capital (nonlabour inputs) of grain crops are from the National Agricultural Production Cost and Revenue Information Summary. Data on acreage under the production of grain crops are sourced from the China Agricultural Yearbook. We aggregate grain crops as this strategy not only facilitates a broadscale analysis of productivity growth in the grain sector but also reflects the importance of grains as an aggregate commodity in China. Grain in China has always been regarded as the most important commodity as China is the world's most populous country with limited land and water resources. Due to data limitation, however, only a few studies focus on the productivity growth of grains as an aggregate commodity. Thus, the unique and comprehensive data analysis of this study extends the scope of past studies and generates more valuable insights in this field.

Second, we examine the relationship between various policies and the rates of TFP growth in the grain sector. Previous studies have been confined to comparing the differences in productivity growth among selected periods. They did not explore the association between relevant policies and the productivity growth in the grain sectors. The policy reforms implemented over the past decades provide an experiment, in which the differential impacts of policies on the rates of TFP growth in the grain sector can be determined. Over the past 40 years, the policies governing grain production can be classified as incentive-led policy, intervention-led policy and market-oriented policy. We estimate the relative impacts of the three types of policy reform on the rates of TFP growth in the grain sector. This study can improve our understanding of the inherent relationship between the policy reforms and the TFP changes in China's grain sector, which helps policymakers identify effective ways to foster productivity growth.

The remainder of this study is organised as follows. Section 2 is an overview of policy reforms. Section 3 describes data. Empirical models are presented in Section 4. Section 5 describes the estimation of production functions as well as presents and discusses the results. Section 6 presents the concluding remarks and policy implications.

2 | OVERVIEW OF THE POLICY REFORMS

The reforms on the agricultural policy governing grain production have been proven to be highly associated with the grain output changes over the past 40 years (Cai et al., 2008; Chen et al., 2018). Following Chen et al. (2018) and Gong (2018) regarding the various phases of policy reform in China's grain production system, this study divides the development stages of the grain sector in China over the past 40 years into seven phases: 1978–1984, 1985–1988, 1989–1993, 1994–1998, 1999–2003, 2004–2015 and 2016–2018. The features of policy reform during the selected periods are summarised in Table 1.

The first period (1978–1984) is the period of rural institutional transition from the collective system to the individual household-based farming system, the so-called 'household responsibility system (hereafter HRS)'. By the end of 1983, about 98% of grain producing households all over the China had adopted HRS (Lin, 1992). Effective in 1979, state-planned prices for grain quota deliveries, which were sold in fulfilment of procurement obligations, were raised by more than 20%, and percentage price bonus for above-quota deliveries increased from 30% to 50% for grain and oil-bearing crops. Moreover, the national grain quota and tax were reduced 20%, with the reduction to some extent targeted regionally to benefit low-income and disadvantaged areas (Sicular, 1988). Finally, local and regional market exchanges were allowed and even encouraged to develop. During this period, the average annual growth rate of grain output was 4.9%.

TABLE 1 Features of grain production policy reforms in China during selected periods, 1980–2018

Period	Contents of the policy reform	Profitability	Intervention
1978–1984	Reforming rural institution, raising the prices for quota deliveries and the price bonus for above-quota deliveries, reducing quota level and allowing local and long-distance trade	High	High
1985–1988	Adopting the negotiated contract system in the beginning of this period and then mandatory quota deliveries again, and opening free markets to all farm products (excluding grain, cotton and oil-bearing crops) and industrial products	Low	Medium
1989–1993	Raising procurement prices, subsidising fertilisers and pesticides, and further reducing grain quota level	Medium+	Medium
1994–1998	Introducing provincial grain self-sufficiency policy (the governor's responsibility system), raising procurement price in the early part of the period and implementing the price protection policy in the late part of the period	Medium	High
1999–2003	Reducing price supports, and opening grain purchase and sale markets in most parts of China	Low	Low
2004–2015	Eliminating tax, introducing direct subsidy for farmers and subsidies for purchasing machinery and high quality of crop variety, and introducing the minimum price policy for rice, wheat, corn and soybeans in major grain-producing provinces	High	Low
2016–2018	Introducing the producer subsidy policy for corn, keeping constant for 2015–2016 and lowering for 2017–2018 the minimum prices for rice and wheat, and introducing the targeting price policy for 2015–2017 and the producer subsidy policy in 2018 for soybeans	Medium	Low

Note: The contents of policy reform are from Chen et al. (2018, pp. 295–350). The comparative profitability here is defined as the growth rates of grain prices relative to the growth rates of whole agricultural products along with the specific policy priority in the respective periods. The intervention is classified based on whether the quota deliveries exist and whether there is an administrative intervention in grain production.

The second period (1985–1988) is the period of a dual-track system during which a market-driven system coexisted with state planning. With the bumper crop year after year during the first period, the existing quota system led to a substantial rise in the state's financial burden for the government was obliged to buy as much output as farmers wished to sell. As a way to reduce the state's burden and to increase the role of markets, beginning in 1985, the mandatory quotas were replaced by procurement contracts that were supposed to be negotiated between the state and the farmers. The contract price was a weighted average of the basic quota price and the above-quota price. This change gave rise to a 9.2% drop in the price margin paid to farmers (Lin, 1992). However, the contracts were made mandatory again in 1986 as the grain production dropped dramatically in 1985. Concurrently, industrial products and agricultural products excluding grains, cotton and oil-seed crops were allowed to be sold in the free markets, as economic reforms were shifted from rural to urban areas. This led to a rise in prices of these products. The average annual growth rate of grain output dropped from 4.9% in the previous period to 1.3% during this period.

The third period (1989–1993) involved additional market-oriented reforms on the monopsony procurement system.[1] As the grain output had hovered around 392 million tonnes for four consecutive years (1985–1988), the government had raised the grain procurement prices several times since 1989, causing grain prices to rise at a rate higher than that of prices of agricultural production materials and services. Moreover, the government introduced a policy to subsidise fertilisers and pesticides for grain-producing households. Finally, the national grain quota continued to be reduced and, as a result, the share of state-purchased grain as a percentage of total grain marketed increased. During this period, the grain sector experienced healthy growth rate of 2.9% per year on average.

The fourth period (1994–1998) is the period marked by price controls and administrative interventions in the grain production. Affected by the exponential growth of the macro-economy, the grain market prices rose rapidly in the second half of 1993 and, meanwhile, the grain output fell by 3.03% in 1994 as compared with 1993. To raise grain output, the governor's responsibility system was instituted in 1995, which required that the provincial governments must be ultimately responsible for grain self-sufficiency for their respective provinces. Moreover, the private marketing activities for grain commodities were restricted through a set of administrative measures. Finally, the grain procurement prices were raised by 40% in 1994 and by another 42% in 1996. As grain output grew rapidly, the market prices of grains began to fall below the government-set price level. The government then introduced the price protection policy through providing subsidies to the state grain-purchasing enterprises to compensate for their loss incurred in purchasing grains at state-set prices. From 1994 to 1998, the average annual growth rate of grain output was 3.6%.

The fifth period (1999–2003) is characterised as the period of deepening reforms on the monopsony procurement system. As the state's financial burden arose because the government bought as much output as farmers wished to sell, the government executed a series of market-oriented reforms to lower grain output growth. The number of crops covered by price protection policy was reduced, while the geographic areas qualifying for the price protection policy were restricted. The grain purchase and sale markets were first opened in the grain-deficit provinces in 2001 and then in most parts of China at the end of this period. From 1999 to 2003, the average annual growth rate of grain output was −3.5%, which has been the lowest growth rate since 1978.

The sixth period (2004–2015) is marked as the period of focussing on the problems of food, farm and rural development. As agricultural and grain output decreased continuously during the previous period, the market status of grain commodities in China switched from a surplus to deficit in 2004, which called attention to food security (Gong, 2018). The government thus took bold market reforms to fully liberalising the purchase and sale markets. The monopsony procurement system introduced in 1953 was completely abolished in 2004; direct subsidy for farmers and subsidies for purchasing machinery and crop varieties of high quality were instituted in 2004; agricultural taxes were abolished totally in 2006; the minimum purchase price policy for major grain crops (including rice, wheat, corn and soybeans) was introduced, especially in major grain-producing provinces in 2004. The average annual growth rate of grain output reached 3.2% in this period.

The seventh period (2016–2018) is the period of continuation of market-oriented reforms. Since the government purchased as much output as farmers wished to sell, the state's financial burden arose with the introduction of the price support policy since 2004. The government-set prices for rice and wheat in their respective major producing provinces were kept constant during 2015–2016 and were lowered during 2017–2018. The price support policy for corn covering Heilongjiang, Jilin, Liaoning and Inner Mongolia was replaced by the producer subsidy

[1]The monopsony procurement system is also called the unified purchase and marketing system instituted in 1953. Under this system, the surplus grain of farmers shall be uniformly purchased at the state-set prices, all the grain needed by the whole society shall be uniformly supplied by the state, and the quantity and variety of grain eaten by farmers themselves must be approved by the state (Chen et al., 2018). The policy reforms in this study are essentially the reforms on this system aimed at transforming the state-planned pricing system to the market price formation mechanism.

policy in 2016. The price support policy for soybeans was replaced by the target price policy in 2015 and then replaced by the producer subsidy policy in 2018. These reforms lowered the prices received by farmers and subsequently the comparative profitability in grain production. From 2016 to 2018, the average annual growth rate of grain output was 0.2%.

The association between policy reforms and changes in grain output shows that the inconsistency in the nature of the policy reforms has played a key role in shaping grain output growth over the past 40 years. Except for the policies for the period 1978–1984, the policies in other periods can be grouped into incentive-led policy (i.e. 1985–1988, 1989–1993, 2004–2015 and 2016–2018), intervention-led policy (i.e. 1994–1998) and market-oriented policy (1999–2003), in accordance with the priorities of policy reform (see Table 1). How the rates of TFP growth have changed and whether the three types of policy reform have had differential impacts on TFP growth in the grain sector are the focal points of the following sections.

3 | DATA SOURCES

The pooled provincial and time-series data for the grain sector consist of 24 provinces, which exclude Beijing, Tianjin, Shanghai, Qinghai and Tibet while Hainan is combined into Guangdong and Chongqing into Sichuan, covering the period 1978–2018. The pooled

TABLE 2 The average annual changes of input and output in the production (%) and average of ratios of land irrigated and land disaster-affected

Variables	1980–1984	1985–1988	1989–1993	1994–1998	1999–2003	2004–2015	2016–2018	1980–2018
Grain sector (24)								
Output	5.772	0.827	0.685	2.391	−3.767	2.370	1.202	1.691
Land	−0.932	0.409	−0.367	0.963	−2.419	1.002	−1.792	0.023
Labour	−9.780	−1.113	−3.287	−1.694	−5.835	−3.692	−3.871	−4.411
Capital	4.334	2.943	0.030	2.856	−4.630	3.135	1.811	2.248
Rice (21)								
Output	5.501	−0.187	−1.489	1.745	−3.303	1.393	0.391.	1.009
Land	−0.491	−0.100	−1.817	0.846	−3.933	0.578	−0.051	−0.285
Labour	−7.871	−1.474	−5.253	−2.628	−7.057	−5.161	−6.127	−4.934
Capital	4.350	3.890	−1.600	2.479	−3.981	2.440	1.200	2.160
Wheat (15)								
Output	10.592	−0.203	3.351	3.248	−6.794	2.955	−4.430	1.889
Land	1.082	−0.552	0.174	0.654	−5.976	1.138	0.359	−0.297
Labour	−10.022	−3.249	−3.032	−2.026	−11.475	−3.642	−5.124	−5.010
Capital	6.995	1.056	1.745	4.603	−8.368	3.175	0.020	2.012
Corn (19)								
Output	2.638	6.898	3.084	7.206	−1.714	5.121	8.153	3.819
Land	−1.971	3.659	0.389	4.410	−1.675	3.781	7.437	2.002
Labour	−10.564	2.975	−1.116	2.049	−4.936	−1.063	1.648	−2.111
Capital	2.673	6.505	0.935	5.389	−2.449	6.257	7.274	4.413
Ratio of land irrigated	0.304	0.309	0.323	0.334	0.353	0.385	0.410	0.350
Ratio of land disaster-affected	0.265	0.322	0.329	0.341	0.340	0.245	0.139	0.282

Note: Figures in parentheses are the number of provinces included.

provincial and time-series data for rice consist of 21 provinces, for wheat 15 provinces and for corn 19 provinces, covering the period 1978–2018. The data sets are taken from several statistical yearbooks, and a number of adjustments were required to make the data suitable for this study. Detailed information on sources and adjustments is given in the Appendix. Here, we only report a summary description of the data sets.

In this study, grain output refers to outputs of 10 crops (including early Indica rice, middle Indica rice, late Indica rice, Japonica rice, wheat, corn, soybeans, sorghum, millet and potatoes). Gross values of grain output for each province are calculated from the physical outputs of the 10 crops, using the 1985 producer prices as weights for aggregation. Outputs of rice, wheat and corn in their respective production functions are physical outputs. Inputs in the data set include three categories: land, labour and capital (nonlabour inputs). Land refers to sown acreage of crops. Labour refers to labour days spent in crop cultivation. Capital (nonlabour inputs) refers to variable expenses (costs of intermediate inputs) and fixed expenses (capital depreciation) in the crop production, deflated using the 1985 provincial price index of agricultural production materials and services.

In addition to outputs and inputs, other five variables are also used in the econometric analyses. Grain producer price index, price index for agricultural production materials and service, and wage index of farm workers are used in the models for input demand for addressing the potential endogeneity problem in the production function. Ratio of land irrigated to total cropland and ratio of land disaster-affected to total cropland are incorporated into the model for determinants of TFP growth. All the five variables are provincial-level observations from 1978 to 2018. Summary statistics on outputs, inputs, ratio of land irrigated and ratio of land disaster-affected are presented in Table 2. Because the observations for 1978–1979 are used in the models for input demand, the summary statistics cover those for the period 1980–2018.

4 | EMPIRICAL APPROACH

Our study adopts a two-step procedure. In the first step, the growth rates of TFP and its components are estimated, using the translog stochastic frontier production function. In the second step, the impact of policy reforms on the rates of TFP growth is determined, using a fixed effects model.

4.1 | Translog stochastic frontier production function

The translog function is a flexible functional form. Relative to the commonly used Cobb–Douglas function, the translog function is a general functional form that allows the possibility of non-neutral returns of scale and technical progress. It is also the second-order Taylor approximation of any form of production function (Kim & Lau, 1994).

The translog stochastic frontier production function is specified as follows:

$$\ln y_{it} = \beta_0 + \sum_j \beta_j \ln x_{jit} + \beta_t T + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} + \frac{1}{2}\beta_{tt} T^2 + \sum_j \beta_{jt} \ln x_{jit} T - u_{it} + v_{it} \quad (1)$$

where ln indicates natural logarithms; i represents province; $t = 1980, \ldots, 2018$ denotes years covered in this study; y_{it} is the output of province i in year t; x_j's denotes sown area, labour days and capital (nonlabour inputs), respectively; time T denotes a neutral technological improvement; β's are the coefficients to be estimated; u_{it} is the technical inefficiency term, and the technical efficiency is defined as $\exp(-u_{it})$; v_{it} is error terms, where $v_{it} \sim N(0, \sigma_v^2)$. Based on the fit of the model, the specification developed by Battese and Coelli (1995) is used to estimate wheat production, while the specification developed by Battese and Coelli (1992) is used to estimate production functions for the grain sector, rice and corn, respectively.

In the light of function form (1), the approximation of TFP can be written as:

$$\ln\mathrm{TFP}_{it} \approx \left(\beta_0 + \beta_t T + 0.5\beta_{tt} T^2 + v_{it}\right) + \sum_j \beta_{jt} \ln x_{jit} T - u_{it} \tag{2}$$

Taking a partial derivative of the form (2) with respect to time t, the rate of TFP growth is derived as follows:

$$\Delta\ln\mathrm{TFP}_{it} = \left(\beta_t + \beta_{tt} T + \frac{\partial v_{it}}{\partial t}\right) + \sum_j \beta_{jt} \ln x_{jit} - \frac{\partial u_{it}}{\partial t} \tag{3}$$

where, in the right side of the form (3), the first term is the growth rate of neutral technical change; the second term is the growth rate of technical biases, and a combination of the two is the rate of technical change; the third term is the growth rate of technical efficiency.[2]

4.2 | The fixed effects model for determinants of TFP growth

As the policy reforms affected the comparative profitability in grain production, they had an impact both on the usage and allocation of production inputs and on the adoption of new technologies and the management practices in the production (Huang & Rozelle, 1996; Lin, 1992; McMillan et al., 1989). While the policy reforms within an unaltered institutional framework can influence both technological progress and technical efficiency change, they would have a larger impact on technological progress than on technical efficiency change relative to the effect of an institutional innovation on TFP change (e.g. HRS in the late 1970s).

Our strategy for determining the impact of policy reforms on TFP growth is to compare the rates of TFP growth among selected periods. Assuming that technology differs among selected periods, the fixed effects model for determinants of TFP growth is thus specified as follows (Baldoni & Estposti, 2020; Chen et al., 2008):

$$\ln\mathrm{TFP}_{it} = b_0 + b_1 T + \delta_1 R\_\mathrm{dis}_{it} + \delta_2 R\_\mathrm{irr}_{it} + \theta_i + \varepsilon_{it} \tag{4}$$

where TFP_{it} denotes total factor productivity for the grain sector and its major grain crops during selected periods; time T is year variable; R_dis_{it} denotes the ratio of land disaster-affected to total cropland that is used to represent weather conditions and R_irr_{it} denotes the ratio of land irrigated effectively to total cropland that is used to characterise conditions of agricultural infrastructure (Gong, 2018); θ_i indicates provincial fixed effects; b's and δ's are the coefficients to be estimated; ε_{it} is an error term. The $\hat{b}_1$ is the estimated average annual rate of TFP growth during a selected

[2]TFP change can be decomposed into technical change, technical efficiency change, a scale effect and an input price allocative effect if the assumptions of constant returns to scale and competitive markets are relaxed (Kumbhakar, 2000). Our results indicate that the grain sector is still characterized by constant returns to scale, and thus TFP growth of the grain sector and major grain crops can be thought of no contributions from scale effects. The allocative effects are also ignored in this study due to the lack of complete price data.

period that accounts for the effects on productivity of time-variant and time-invariant variables, and hence it can be used to reflect the effects of policy reforms on productivity growth.

5 | RESULTS

5.1 | Results on regressions of stochastic frontier production model

Since farmers' decision on input usage relies on information influencing production profit margins, an individual input or all inputs in the function is/are possible to correlate with errors or inefficiency terms, resulting in biased estimates of coefficients and/or inefficiency (Ackerberg et al., 2015). A two-stage procedure recommended by Amsler et al. (2016) is thus applied to deal with the potential endogeneity problem. In the first stage, the fixed effects models for input demand are regressed to derive the estimates of residuals. In the second stage, the estimated residuals are then incorporated into the production function as an exogenous variable. The maximum likelihood estimator is used to estimate production functions for the grain sector, rice, wheat and corn, respectively, and the standard errors of estimated coefficients are adjusted for intraprovince clustering. A series of hypothesis tests show that the translog stochastic frontier production function accounting for the endogeneity problem can produce consistent coefficient estimates. Detailed information on estimation procedure, coefficient estimates and relevant tests is given in Appendix S1.

5.2 | Changes in total factor productivity, technical change and technical efficiency

The average annual growth rates of TFP, TC and TE in the grain sector are presented in Table 3. The TFP across all provinces and years grew at an average annual rate of 1.42%, with mean annual estimates ranging from 0.35% (Guizhou) to 2.66% (Heilongjiang). The average annual growth rate of TC across all provinces and years was 1.47%, with mean annual estimates ranging from 0.42% (Guizhou) to 2.71% (Heilongjiang). The TE declined by 0.05% per year, on average, across all provinces and years. The technical inefficient item u_{it} in the specification developed by Battese and Coelli (1992) is specified as $u_{it} = \{\exp[-\eta(t-T)]\}u_i$. The estimated coefficient $\hat{\eta}$ is −0.0022 and statistically indistinguishable from zero (see Table S1), indicating that technical efficiency did not change significantly. Thus, the productivity growth in the grain sector was totally driven by technical improvements over the period 1980–2018.

The Chinese government has classified 13 provinces as major grain-producing provinces (hereafter major provinces) according to their respective weights in the national grain output since 1980s. These provinces include Hebei, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan and Sichuan. Because the policy reforms are more relevant to major provinces than they are for the other provinces (hereafter nonmajor provinces), it is of interest to see how the performance of major provinces differs from that of nonmajor provinces. According to the TFP growth rates by province in Table 3, the average annual rate of TFP growth was 1.76% for major provinces (top 13 provinces), while it was 1.02% for nonmajor provinces (bottom 11 provinces). Thus, the productivity in the major provinces grew more rapidly than in the nonmajor provinces over the past four decades.

As compared with the results on agricultural TFP and TC growth rates from previous studies (e.g. Chen et al., 2008; Gautam & Yu, 2015; Gong, 2018; Wang et al., 2013), the average annual growth rates of TFP and TC in the grain sector from this study are lower than those for general agriculture. The technical efficiency estimated in our study is consistent with the finding on agricultural technical efficiency from Gautam and Yu (2015). Over the past 40 years,

TABLE 3 Average annual total factor productivity change and average annual changes in its components for grain sector by province, 1980–2018 (%)

Province	TFP	TC	TE	Province	TFP	TC	TE
Hebei	2.017	2.077	−0.059	Shanxi	1.702	1.760	−0.058
Inner Mongolia	2.280	2.345	−0.065	Zhejiang	1.284	1.322	−0.038
Liaoning	1.587	1.624	−0.036	Fujian	0.414	0.472	−0.058
Jilin	1.520	1.562	−0.042	Guangdong	0.659	0.744	−0.085
Heilongjiang	2.656	2.710	−0.054	Guangxi	0.706	0.794	−0.088
Jiangsu	1.932	1.960	−0.028	Guizhou	0.345	0.421	−0.076
Anhui	1.873	1.932	−0.058	Yunnan	0.511	0.547	−0.036
Jiangxi	1.170	1.240	−0.070	Shaanxi	1.410	1.473	−0.063
Shandong	2.068	2.213	−0.055	Gansu	0.979	1.023	−0.044
Henan	2.333	2.218	−0.012	Ningxia	0.872	0.899	−0.027
Hubei	1.693	1.748	−0.055	Xinjiang	2.333	2.373	−0.040
Hunan	1.208	1.269	−0.061				
Sichuan	0.601	0.653	−0.052	Average	1.423	1.474	−0.053

Note: All growth rates are ln growth rates. The top 13 provinces in the table are major grain-producing provinces.

the output and technical change in animal husbandry, fishery and horticulture that includes vegetables, fruits and flowers have grown substantially. Consistent with these observations, the growth rates of output and productivity in the traditional grain sector are thus expected to be lower than those for the agricultural sector in general.

The growth rates of TFP, TC and TE for major grain crops included in this study are reported in Table 4. During 1980–2018, the average annual growth rates of TFP, TC and TE across all provinces and years were 0.33%, 0.72% and −0.38%, respectively, for rice; 1.69%, 1.66% and 0.04%, respectively, for wheat; and 1.3%, 1.5% and −0.25%, respectively, for corn. Thus, the TFP growth of these crops is almost all attributable to technical improvements; technical efficiency change has a weakly positive impetus function in wheat productivity growth while playing a retarding role in the productivity growth of rice and corn. Specifically, except for Hebei and Shandong which are not major rice-producing provinces, where the average annual TFP growth rates for rice are larger than 1%, the TFP growth rates for rice in other provinces are all under 1%. In contrast to rice, except for Sichuan, Yunnan, Gansu and Ningxia, the average annual TFP growth rates of wheat in the other 11 provinces are all above 1%, and those in more than one-third of the provinces included are larger than 2%. Situated between rice and wheat, the average annual TFP growth rates of corn are larger than 1% for a majority of the provinces included. Therefore, among individual crops and during 1980–2018, the rate of TFP growth was the highest for wheat, the second highest for corn and the lowest for rice.

The growth rates of TFP and its components reflect the changes in planting structure of the grain sector. Over the past 40 years, the share of the sown area allocated to Japonica rice in the north and that to the single-cropping Indica and Japonica rice in the south have increased; while the area under corn production has expanded considerably in the major corn-producing region (northeast) as well as in the southwest and northwest regions. Relative to the role played by variety innovation in raising wheat yield and productivity, variety innovation has a weaker effect in raising rice yield and productivity because no rice variety innovation comes out as hybrid rice, and super rice has been widely applied in China (Li, 2010). Corn acreage has expanded mostly through reclaiming land or squeezing out other crops, which tends to lower the corn production possibilities frontier and consequently productivity. Thus, the slow growth in

TABLE 4 Average annual total factor productivity change and average annual changes in its components for rice, wheat and corn by province, 1980–2018 (%)

	Rice			Wheat			Corn		
Province	**TFP**	**TC**	**TE**	**TFP**	**TC**	**TE**	**TFP**	**TC**	**TE**
Hebei	1.159	1.287	−0.128	2.414	2.165	0.249	1.176	1.458	−0.283
Inner Mongolia	0.639	0.864	−0.225	1.585	1.261	0.322	2.287	2.474	−0.187
Liaoning	0.385	0.622	−0.237				0.901	1.151	−0.251
Jilin	0.365	0.691	−0.327				1.379	1.648	−0.268
Heilongjiang	0.466	0.989	−0.523	2.867	2.834	0.033	2.283	2.528	−0.245
Jiangsu	0.315	0.684	−0.370	2.012	2.164	−0.152	0.003	0.005	−0.188
Anhui	−0.110	0.372	−0.482	2.518	2.546	−0.028	1.467	1.715	−0.128
Jiangxi	0.055	0.732	−0.677						
Shandong	1.121	1.351	−0.230	2.127	2.137	−0.010	1.377	1.665	−0.288
Henan	0.257	0.539	−0.282	2.635	2.612	0.023	1.501	1.781	−0.280
Hubei	0.305	0.769	−0.464	2.287	2.252	0.036	0.845	1.171	−0.327
Hunan	−0.106	0.510	−0.617						
Sichuan	−0.218	0.045	−0.262	0.859	0.859	−0.001	0.647	0.916	−0.269
Shanxi	0.323	0.607	−0.285	1.312	1.269	0.044	1.518	1.680	−0.162
Zhejiang	0.252	0.747	−0.495						
Fujian	0.262	0.752	−0.489						
Guangdong	−0.195	0.568	−0.763						
Guangxi	−0.010	0.694	−0.705				1.187	1.735	−0.549
Guizhou	0.455	0.735	−0.280				0.544	0.997	−0.453
Yunnan	0.483	0.685	−0.202	0.094	0.325	−0.230	0.734	1.102	−0.368
Shaanxi	0.764	0.790	−0.026	1.884	1.676	0.208	0.981	1.271	−0.289
Gansu				0.864	0.858	0.006	0.991	1.022	−0.031
Ningxia				0.252	0.267	−0.015	1.191	1.262	−0.071
Xinjiang				1.689	1.649	0.039	2.813	2.899	−0.087
Average	0.332	0.716	−0.384	1.693	1.658	0.035	1.296	1.499	−0.249

Note: All growth rates are ln growth rates. The top 13 provinces in the table are major grain-producing provinces.

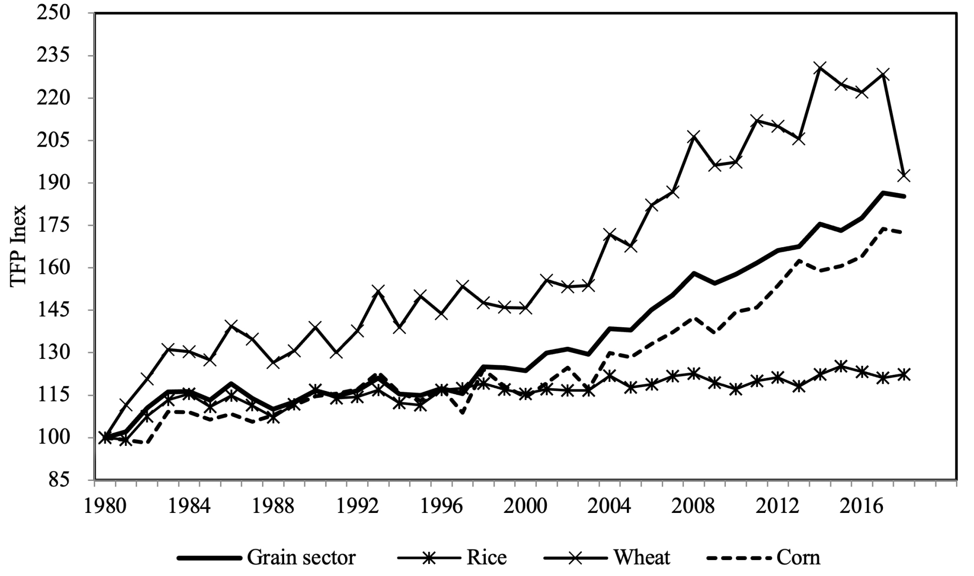

FIGURE 1 Total factor productivity indexes for grain production in China with 1980 as a base year, 1980–2018

technical change for rice could be to be correlated with the change in structure of rice variety planted and the lag in breed renewal, whereas the slow growth in technical change for corn could be attributed to a fall in the production possibilities frontier stemming from rapid acreage expansion.

Except for the slow growth in technical change, the fall in technical efficiency in rice and corn production has led to a further slowing down of their respective TFP growth rates. Technical efficiency measures the province's performance in exploiting existing technical possibilities, and hence the fall in technical efficiency is interpreted as failing to adapt to changing technological possibilities (Chambers & Pieralli, 2020). Since technological progress continues to grow over time, the fall in technical efficiency suggests that the technical efficiency change lags behind the frontier shift (Mugera et al., 2016). The heterogeneity in adopting new technology and slowdown in diffusion of agricultural innovation across provinces might be responsible for the slow change in technical efficiency relative to technical progress.

The trajectory of TFP growth, in terms of TFP index (TFPI) with 1980 as a base year, is illustrated in Figure 1. Wheat TFP index is always above grain TFPI, whereas rice and corn TFPIs are below grain TFPI except for those during the period 1988–1998 when the TFPIs basically overlapped. Except for wheat TFPI in 2018 that declined dramatically, due to the cold weather in spring season and the continuous rainy weather in harvest season in northern China, the trend of wheat and corn TFPIs is consistent with that of grain TFPI. However, rice productivity went from a slow uptrend in the early stages to a horizontal trend in the late stages. The slow growth in rice and corn productivity, particularly rice productivity, thus hindered productivity growth in the grain sector as a whole.

The ratio of TFP growth rate over output growth rate can be used to understand the sources driving output growth (Plastina & Lence, 2018). As shown in Tables 2–4, the average annual growth rates of output for grains as an aggregate commodity, rice, wheat and corn are 1.69%, 1.01%, 1.89% and 3.82%, respectively; the corresponding TFP growth rates are 1.42%, 0.33%, 1.69% and 1.3%, respectively. Accordingly, grain output and wheat production benefit more from TFP growth, whereas growth in the usage of inputs drives growth in rice and corn production. It can thus be seen that an effective way to raise the rate of TFP growth in the grain sector is to raise the rates of TFP growth for rice and corn.

5.3 | Total factor productivity changes across selected periods

The estimated rates of TFP growth across periods are reported in Table 5. Several observations can be made from the TFP change estimates for the grain sector. First, the rates of TFP growth estimated with and without incorporation of ratios of land disaster-affected and land irrigated differ across all periods, although some considerably and others marginally (columns (1) and (2)). The results are consistent with economic expectations that both weather and infrastructure conditions are important determinants in the productivity growth. Second, the rates of TFP growth during 1980–2003 were relatively lower and variable, whereas they were comparatively higher and stable during 2004–2018 (column (2)). The results suggest that the rates of TFP growth are strongly associated with the changes in policy because the policies changed more frequently for 1980–2003 than for 2004–2018 (see Table 1). Third, the first period (1980–1984) witnessed the fastest productivity growth since the late 1970s, corroborating the finding that institutional innovation and a raise in procurement prices in the early 1980s significantly boosted agricultural productivity (Lin, 1992; McMillan et al., 1989).

The incentive-led policy covers the policies implemented in the second period (1985–1988), the third period (1989–1993), the sixth period (2004–2015) and the seventh period (2016–2018). As shown in Tables 1 and 5, fluctuations of TFP growth in the grain sector are associated with changes in comparative profitability in grain production during these periods. The TFP growth rate in the second period has been the lowest over the past 40 years, which is compatible with the agricultural TFP growth rates reported by previous studies (e.g. Lin, 1992; Wen, 1993). The TFP growth rate in the seventh period was 1.04% with the significance level of 11.13%, which is the second lowest of the four periods. While the rate is not much lower if it is compared with rates during 1985–2003, it is much lower relative to that during 2004–2015. The policy reforms in the two periods all aimed at decreasing support in grain production to reduce the state's financial burden. The fall in grain procurement prices relative to prices of production materials and services and of nongrain crops led to a fall in the comparative profitability in grain production. While the slowdown in TFP growth for 1985–1988 was possibly related to the fall in comparative profitability in grain production and the reduced public investment in agricultural research and development since the late 1970s (Colby et al., 2000), it might be largely due to the fall in comparative profitability in grain production over 2016–2018.

The average annual rate of TFP growth in the third period was 1.49%, which is appreciably higher than the output growth rate (0.83%). The result is consistent with the agricultural TFP growth rates from Brummer et al. (2006), Chen et al. (2008), Gong (2018) and Wang et al. (2013). There still existed a degree of intervention in grain production in that the mandatory quota had to be fulfilled during this period. However, as the market prices rose and the state controls were loosened during this period, farmers took advantage of the higher prices to sell their surplus grains. The higher comparative profitability in grain production thus promoted technical progress and productivity growth during this period.

The TFP in the sixth period grew at an annual rate of 1.78%, which is the second highest rate across all periods. The result is compatible with the agricultural TFP growth rate from Gong (2018) in that the majority of output growth can be explained by TFP growth in both studies. The high output growth rate can be attributed to the 'appropriate policies, farmers' hard-work, and favorable weather conditions' explained by a vice minister of the Ministry of Agriculture in response to a reporter's question (China News Service: https://www.chiannews.com/gn/2011/09-29/3362520.shtml). The 'appropriate policies and farmers' hard-work' are also the sources technological progress and productivity growth during this period.

The intervention-led policy refers to the group of policies introduced in the fourth period (1994–1998), in the setting where food security became a major concern as agricultural resources (particularly land) had been moved to nonagricultural sectors along with rapid economic growth. The average annual rate of TFP growth in this period was 0.76%, which is

TABLE 5 Average annual total factor productivity change estimates for the grain sector and major grain crops during selected periods (%)

	Grain sector							
	All provinces							
	W/o	W/	Major provinces	Other provinces	Diff. ((3)–(4))	Rice	Wheat	Corn
Periods	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1980–1984	4.376** (0.516)	3.955** (0.547)	4.544** (0.656)	3.197** (0.788)	1.348 (1.020)	3.668** (0.659)	6.465** (0.971)	1.744** (0.895)
1985–1988	−1.422** (0.524)	−1.543** (0.440)	−1.430** (0.608)	−1.675** (0.729)	0.245 (1.000)	−1.470** (0.495)	−1.018 (0.842)	−0.508 (0.828)
1989–1993	1.385** (0.366)	1.486** (0.384)	2.255** (0.693)	0.900** (0.449)	1.354* (0.797)	0.295 (0.433)	3.857** (0.107)	2.143 (1.400)
1994–1998	1.483** (0.451)	0.761* (0.397)	0.365 (0.458)	1.222** (0.522)	−0.857 (0.600)	1.411** (0.497)	0.543 (0.666)	−0.752 (1.030)
1999–2003	1.243** (0.482)	0.626 (0.550)	1.027** (0.529)	0.121 (0.884)	0.905 (0.915)	−0.371 (0.445)	1.432* (0.803)	−0.740 (1.290)
2004–2015	2.039** (0.168)	1.778** (0.189)	2.277** (0.245)	1.082** (0.201)	1.195** (0.285)	0.147 (0.167)	1.601** (0.289)	1.589** (0.210)
2016–2018	1.719** (0.662)	1.035† (0.637)	1.073 (0.949)	0.980 (0.898)	0.093 (1.370)	−0.499 (0.337)	−9.354** (3.580)	1.135 (1.010)
1980–2018	1.423** (0.101)	1.163** (0.124)	1.500** (0.141)	0.853** (0.157)	0.647** (0.147)	0.266** (0.065)	1.327** (0.185)	1.100** (0.196)

Note: TFP change rates in column (1) are estimated using Equation (4) excluding the ratios of land irrigated and land disaster-affected, while those in columns (2)–(8) are estimated using Equation (4) with incorporation of the two variables. Estimates in columns (3)–(5) are derived using Equation (4) incorporating an additional variable D^*t, where D is a dummy variable representing the major provinces. Figures in parentheses are standard errors. The standard errors in all columns but column (3) are estimated using the heteroscedasticity- and autocorrelation-consistent covariance matrix estimator, while the standard errors of TFP change rates in column (3) are computed using the delta method. ** and * represent significance levels of 5% and 10%, respectively, while "†" denotes the significance level at 11.13%.

considerably lower than the output growth rate (2.39%). A raise in grain procurement prices at the beginning of this period was in response to high market prices, whereas an introduction of the price protection policy in the later part of this period was in response to low market prices. Thus, the comparative profitability in grain production in this period was not necessarily high (Table 1). Since the government also initiated a series of administrative measures to promote the expansion of crop acreage and usage of other inputs, the administrative measures together with favourable weather conditions played a more important role in grain production. The higher growth rate in output than in productivity during this period thus suggests an extensive pattern of output growth where the contribution of input growth outweighs that of technical growth (Gong, 2018).

The market-oriented policy is the group of policies introduced in the fifth period (1999–2003), in the setting where handling the problem of oversupply and excess stocks of grains became the policy priority. The average annual rate of TFP growth in this period was insignificant at 0.63%, which is in striking contrast to the output growth rate (−3.77%). While the price protection policy was still implemented in this period, it was a 'discount' policy in the context of low market prices because the state-owned grain-purchasing enterprises purchased grains at low prices in disguise. As the purchase and sale markets were first opened in the grain-deficit provinces and then in most parts of China, farmers basically organised their agricultural activities in accordance with market prices. A large reduction in grain sown area thus led to the negative growth of grain output. Quality-poor plots probably accounted for the reduced grain acreage; the farmers who chose to reduce grain acreage are likely to be less productive. As a consequence, the production possibilities frontier and subsequently the productivity were raised accordingly.

The difference in the rates of TFP growth between major and nonmajor provinces further confirms the findings for the periods 1994–1998 and 1999–2003. The expansion for 1994–1998 and the shrink for 1999–2003 in crop acreage were more intense for major than for nonmajor provinces. As a result, the possibilities frontier and productivity for major provinces were lowered more in the period 1994–1998, whereas they were raised more in the period 1999–2003, relative to those for nonmajor provinces (columns (3) and (4)).

The TFP change estimates by province across periods are derived using Equation (4) by replacing both b_0 and $b_1 T$ with $\sum b_k \left(D^k T\right)$ (where D denotes dummy variables for 24 provinces included). As illustrated in Figure 2, the TFP change estimates by provinces support the findings above. Specifically, the incentive-led policy during the periods 1985–1988 and 2016–2018 was associated with lower rates of TFP growth (panels a and f), whereas it was correlated with higher rates of TFP growth for the periods 1989–1993 and 2004–2015 (panels b and e). There are eight provinces with negative rate and five provinces with a rate below 0.5% in the intervention-led policy period (1994–1998). Similarly, there are seven provinces with negative rate and three provinces with a rate below 0.5% in the market-oriented policy period (1999–2003).

The TFP change estimates for major grain crops are also consistent with the findings for the grain sector as a whole (columns (6)–(8) in Table 5). For the periods 1980–1984, 1985–1988, 1989–1993 and 2004–2015, the rates of TFP growth for rice, wheat and corn were consistent with those for the grain sector. During 1994–1998, the rates for rice and wheat were positive while the rate for corn was negative; during 1999–2003, the rate for wheat was positive, whereas the rates for rice and corn were negative; during 2016–2018, the rate for corn was positive, but the rates for rice and wheat were negative. The negative TFP changes of individual crops thus hindered the TFP growth in the grain sector during these periods.

Does the impact of policy reforms on TFP growth differ between major and nonmajor provinces? Although the TFP change estimates for 1980–1984, 1985–1988, 1994–1998, 1999–2003 and 2016–2018 differed in magnitude, they were not statistically significant at the conventional level (column (5)). The only two periods during which TFP growth rates differed significantly between the two groups of provinces are 1989–1993 and 2004–2015. Specifically, the rates of TFP growth were significantly larger for major than for nonmajor provinces in the

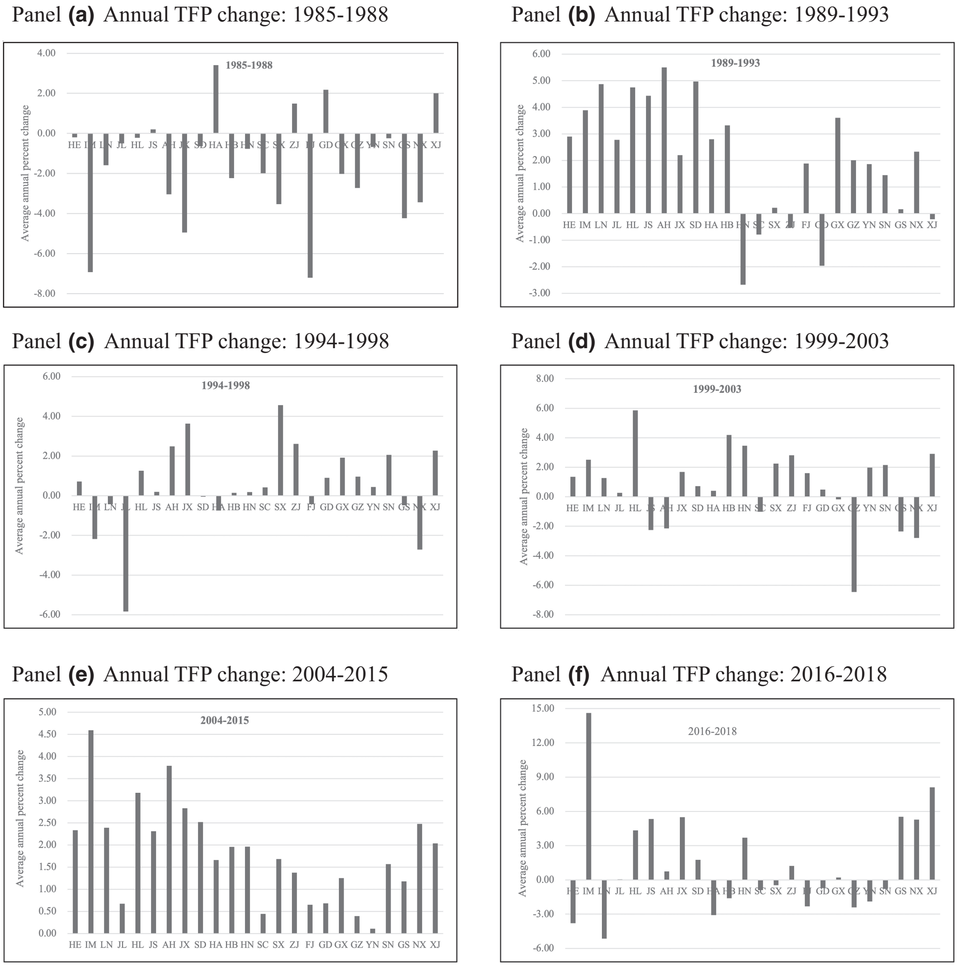

FIGURE 2 Average annual total factor productivity change for grain sector by province during selected periods, 1985–2018 (%)

two periods, suggesting that the incentive-led policy that raised the comparative profitability in grain production fostered TFP growth more for major than for nonmajor provinces.

In sum, policy reforms led to periodic fluctuations not only in output growth but also in productivity growth in the grain sector over the past 40 years. Specifically, the intervention-led policy that resulted in a substantial rise in output did not promote productivity growth; the basically laissez-faire market-oriented policy in the setting of low market prices that led to a dramatic fall in output did not hinder productivity growth; and the incentive-led polices in a market-oriented environment that raised the comparative profitability in grain production fostered growth in output and productivity, whereas those that lowered the comparative profitability in grain production hindered growth in output and productivity.

6 | CONCLUDING REMARKS

This study analyses changes in TFP of grains as an aggregate commodity and major grain crops, including rice, wheat and corn, by examining the growth rates of TFP and its components as well as the impact of policy reforms on productivity growth, using pooled provincial and time-series data from 1980 to 2018 for China. Our results show that the growth in TFP in the grain sector was totally driven by technical improvements and that the grain output and wheat production benefited more from the TFP growth, whereas the growth in the usage of inputs drove the growth in rice and corn production.

Our results also show that the policy reforms led to periodic fluctuations not only in output growth but also in productivity growth in the grain sector. Specifically, the intervention-led policy that resulted in a substantial rise in output did not promote productivity growth; the laissez-faire market-oriented policy in the setting of low market prices that led to a dramatic fall in output did not hinder productivity growth; the incentive-led policy in a market-oriented environment that raised the comparative profitability in grain production fostered growth in both output and productivity.

The stage of China's economic development passed the 'Lewis turning point' (i.e. labour supplies are no longer unlimited; Cai et al., 2008; Lewis, 1954). At this stage, as labour transferred continuously to nonagricultural sectors, the comparative advantage shifts away from agriculture. The only way to ensure sustainable growth in the agricultural sector at this stage is to raise agricultural productivity (Ranis & Fei, 1961). Our study suggests that the incentive-led policy in a market-oriented environment, which is able to raise the comparative profitability in grain production, can facilitate growth in both output and productivity in the grain production sector. An appropriate support is thus necessary to stimulate farmers' incentive in growing grain crops.

China is a large country with a large number of part-time small-scale farmers. As a source of motivation to engage in agricultural activities, profit-maximisation is suitable for large-scale farmers or subsistence peasants, but it cannot be fully applied to China's farmers who are largely income-maximisation pursuers. While a low-level support does not work on farmers' incentive in grain production, high levels of support can lead to a heavy state financial burden. This is the fundamental reason for the frequent changes in agricultural policies over the past 40 years. The way out of this dilemma should focus on reforming the rural land system and the household registration system to realise large-scale operation in agriculture.

ACKNOWLEDGEMENTS

The authors are grateful for comments from Qihui Chen, Ming Gao, Hongqi Ma, Wanglin Ma and Huan Wang.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Zhihao Zheng https://orcid.org/0000-0003-3588-1509

REFERENCES

Ackerberg, D.A., Caves, K. & Frazer, G. (2015) Identification properties of recent production function estimators. *Econometrica*, 83, 2411–2451.

Amsler, C., Prokhorov, A. & Schmidt, P. (2016) Endogeneity in stochastic frontier models. *Journal of Econometrics*, 190, 280–288.

Baldoni, E. & Estposti, R. (2020) Agricultural productivity in space: An econometric assessment based on farm-level data. *American Journal of Agricultural Economics*, 103, 1525–1544.

Battese, G. & Coelli, T. (1992) Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis*, 3, 153–169.

Battese, G. & Coelli, T. (1995) A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20, 325–332.

Brummer, B., Glauben, T. & Liu, W. (2006) Policy reform and productivity change in Chinese agriculture: A distance function approach. *Journal of Development Economics*, 81, 61–79.

Cai, F., Wang, D. & Du, Y. (2008) *China's rural reforms and changes: 30 years' evolution and experiences (in Chinese)*. Shanghai: Gezhi Press.

Chambers, R.G. & Pieralli, S. (2020) The sources of measured US agricultural productivity growth: Weather, technological change, and adaption. *American Journal of Agricultural Economics*, 102, 1198–1226.

Chen, P., Yu, M., Chang, C. & Hsu, S. (2008) Total factor productivity growth in China's agricultural sector. *China Economic Review*, 19, 580–593.

Chen, X., Luo, D. & Zhang, Z. (2018) *40 years' rural reforms in China (in Chinese)*. Beijing: People's Press.

Colby, H., Diao, X. & Somwaru, A. (2000) *Cross-commodity analysis of China's grain sector: Source of growth and supply response*. Washington, DC: Economic Research Service/USDA, Tb-1884.

Gautam, M. & Yu, B. (2015) Agricultural productivity growth and drivers: A comparative study of China and India. *China Agricultural Economic Review*, 7, 573–600.

Gong, B. (2018) Agricultural reforms and production in China: Change in provincial production function and productivity in 1978–2015. *Journal of Development Economics*, 132, 18–31.

Huang, J. & Rozelle, S. (1996) Technological change: Rediscovering the engine of productivity growth in China's rural economy. *Journal of Development Economics*, 49, 337–369.

Jin, S., Ma, H., Huang, J., Hu, R. & Rozelle, S. (2010) Productivity, efficiency and technical change: Measuring the performance of China's transforming agriculture. *Journal of Productivity Analysis*, 33, 191–207.

Kim, J. & Lau, L. (1994) The Sources of economic growth of the East Asian newly industrialized countries. *Journal of the Japanese and International Economies*, 8, 235–271.

Kumbhakar, S.C. (2000) Estimation and decomposition of productivity change when production is not efficient: A panel data approach. *Econometric Reviews*, 19, 425–460.

Lewis, A. (1954) Development with unlimited supplies of labor. *The Manchester School*, 22, 139–192.

Li, Z. (2010) Review and prospect of wheat breeding in China. *China Agricultural Science and Technology Guide*, 12, 1–4 (in Chinese).

Lin, Y.J. (1992) Rural reforms and agricultural growth in China. *American Economic Review*, 82, 34–51.

McMillan, J., Whalley, J. & Zhu, L. (1989) The impact of China's economic reforms on agricultural productivity growth. *Journal of Political Economy*, 97, 781–807.

Mugera, A., Langemeier, M. & Ojede, A. (2016) Contributions of productivity and relative price changes to farm-level profitability change. *American Journal of Agricultural Economics*, 98, 1210–1229.

Plastina, A. & Lence, S. (2018) A parametric estimation of total factor productivity and its components in U.S. agriculture. *American Journal of Agricultural Economics*, 100, 1091–1119.

Ranis, G. & Fei, J. (1961) A theory of economic development. *American Economic Review*, 51, 533–565.

Sicular, T. (1988) Plan and market in China's agricultural commerce. *Journal of Political Economy*, 96, 283–307.

Wang, S.L., Tuan, F., Gale, F., Somwaru, A. & Hansen, J. (2013) China's regional agricultural productivity growth in 1985–2007: A multilateral comparison. *Agricultural Economics*, 44, 241–251.

Wen, G.J. (1993) Total factor productivity change in China's farming sector: 1952–1989. *Economic Development and Cultural Change*, 42, 1–41.

Zhang, B. & Carter, C. (1997) Reforms, the weather, and productivity growth in China's grain Sector. *American Journal of Agricultural Economics*, 79, 1266–1277.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Zheng, Z., Cheng, S. & Henneberry, S.R. (2023) Total factor productivity change in China's grain production sector: 1980–2018. *Australian Journal of Agricultural and Resource Economics*, 67, 38–55. Available from: https://doi.org/10.1111/1467-8489.12495