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The Impact of Public Expenditure and International Trade on Agricultural Productivity in China

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ABSTRACT: The "industry nurturing agriculture" reforms and World Trade Organization accession led to dramatic growth in public expenditure and international trade in China's agricultural sector. This article aims to estimate the effects of public expenditure and trade on agricultural productivity in China for 2004–2015. A semi-parametric production function with shape constraints is introduced to derive more accurate productivity before the productivity determinants are analyzed with an emphasis on public expenditure and trade. The empirical result shows that public expenditure and exports can effectively improve agricultural productivity, while imports have no significant effects. Policy implications are discussed in the context of supply-side reforms.

KEY WORDS: China's agricultural productivity, China's supply-side reforms, effects of public expenditure and trade, semi-parametric model under shape constraints, Stochastic Frontier Analysis

JEL CLASSIFICATION: Q1, D24, C23, E62

Rapid growth in agriculture has taken place in China due to the fundamental reforms that began to be implemented in 1978. The past four decades are divided into six reform periods by Zhang and Brümmer (2011) and Gong (2018a). The first period (1978–1984) is the transition from the collective system to a household-based farming system (He 2015; Lin 1992), and the success that was achieved in agricultural growth has been confirmed by many scholars (e.g., Mcmillan, Whalley, and Zhu (1989), and Wen (1993)). However, growth slowed in the second period (1985–1989) due to the rising production costs, as well as the hesitation between market economy and planned economy (Brümmer, Glauben, and Lu 2006). Momentum was gained in both the third period (1990–1993) and fourth period (1994–1998) when the government further reformed the marketing and tax systems. The fifth period (1998-2003) integrated further rural development with the overall economic reforms. Overall, the rural reforms achieved tremendous success in the first five periods with a growth rate in agricultural output at 13% per year over the period of 1978–2003, compared with an average 5% growth in the socialist period (1949–1977).

However, faster growth in the urban areas is absorbing agricultural resources, which has prevented the further growth of the agricultural sector. The growth rate in the four major agricultural inputs, including labor, land, fertilizer, and machinery, were −1.2%, 0.4%, 2.4%, and 5.3%, respectively, in the 2000s, compared with 0.3%, 0.6%, 5.7%, and 5.7%, respectively, in the 1990s. More attention has been paid to the sustainable development of the agricultural sector in the sixth period (2004–present) as the government has highlighted the rural reforms in its No. 1 annual document every year since 2004. Although some policies have been implemented to maintain agricultural inputs, such as a central land policy that was stipulated to preserve at least 1.8 billion mu (120.6 million hectares) of arable land (Chien 2015), many more efforts have been made to improve agricultural productivity since it is

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fundamental for stimulating growth and raising the level of competitiveness under the input constraints and in the context of supply-side reforms.

On the one hand, the government began a nationwide push to abolish agricultural taxes and increase public expenditure in the agricultural sector, which is an important part of the "industry nurturing agriculture" reforms. On the other hand, China's World Trade Organization (WTO) accession brought about a reduction in protection policies (Luo, Zhang, and Zhu 2016), which directly led to dramatic growth in the international trade of agricultural products. Both public expenditure and trade are likely to raise agricultural productivity, as public expenditure promotes technological progress and trade reduces resource misallocation (Topalova and Khandelwal 2011). In Figure 1, the Gross Value of Agricultural Output (GVAO), on average, still achieved double-digit growth for 2004–2015 regardless of the flat growth in all four of the inputs, which implies that there was significant growth in productivity. Public expenditure and trade, as mentioned in Liu and Xin (2011), experienced rapid growth over the same period, which is highly correlated with the growth in production. Therefore, it is worth studying whether or not public expenditure and trade helped to maintain the growth in China's agricultural sector, especially after the Chinese government initiated the supply-side reforms that aimed to construct a more productive and competitive primary industry.

Causal impacts from public expenditure and trade on total factor productivity (TFP) have been documented in previous works (Alcalá and Ciccone 2004; Chanda and Dalgaard 2008; Fan and Duan 2011). The present article takes this a step further to explore the effects of public expenditure and trade on China's agricultural productivity in 2004–2015 using a two-step method. In the first step, the production function and TFP are more accurately estimated by a semiparametric production frontier model under shape constraints. In the second step, this article predicts the impact of public expenditure and trade on the derived productivity using the OLS and the IV method. The total international trade is further decomposed to capture the varying effects of exports and imports.

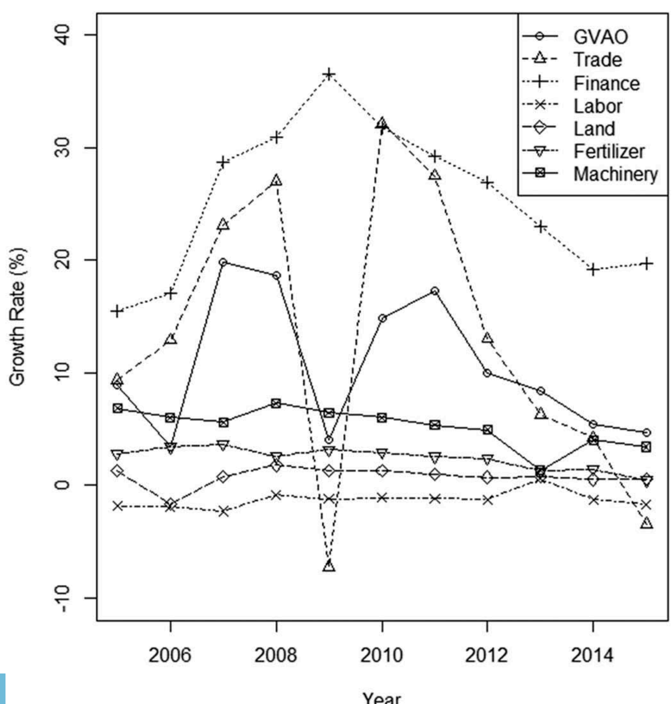

Figure 1. Growth rate of agricultural output, trade, finance, and inputs for 2005–2015.

This article provides two central contributions: (1) the improved semi-parametric production model with monotonicity and concavity restrictions combines the advantages of the two competing and conventional productivity methods to estimate productivity more accurately, and (2) to my knowledge, this is the first study to address the effects of public expenditure as well as exports and imports on China's agricultural TFP that focuses on the recent reform period after the WTO accession and the financial crisis.

The empirical results show that (1) it is necessary to relax the rigid assumption of the production function and utilize the new semiparametric model under shape constraints, as the classic parametric method overestimates the effects of labor, land, and fertilizer but underestimates the effect of machinery; (2) both trade and public expenditure have positive effects on productivity, but the endogeneity problem biases the impact of trade downward and the impact of public expenditure upward, which is corrected by the IV approach; (3) exports can significantly improve productivity, but imports have no effect when international trade is further decomposed; (4) the forestry segment is slightly more productive than farming, animal husbandry, and fisheries; and (5) diversification in these four segments can decrease productivity, which is in favor of specialization in agricultural production.

Model

Production Function Under Shape Constraints

Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are two of the most widely used methods in Productivity and Efficiency Analysis. SFA has a stochastic term to control the unpredicted error, but requires an assumption of the production's functional form, which may fail to capture the true input–output relationship. DEA does not need such a prior assumption, but has no stochastic term to control the unpredicted error.

Some scholars (i.e., Fan, Li, and Weersink (1996)) try to build a bridge between the two by developing nonparametric SFA. However, flexible parameterizations may lose fidelity to economic theory and lead to implausible predictions. Using simulation methods, Henderson and Parmeter (2009) find that nonparametric estimation can avoid monotonicity and concavity when the true data-generating process is monotonic and concave. This dilemma is tackled by semiparametric method, subject to some restrictions suggested by economic theory. The stochastic semiparametric frontier approach allows for noise and does not impose a priori assumption on the functional form, but most importantly, it still follows economic theory.

The stochastic semiparametric frontier approach under shape constraints is based on the conventional stochastic frontier model. Stochastic frontier production function model equals the deterministic frontier production function plus a symmetric random error variable, which is independently and simultaneously proposed by Aigner, Lovell, and Schmidt (1977) and Meeusen and Van Den Broeck (1977) in the form

$$\ln Y_i = x_i{}'\beta + v_i - u_i,\ \ i = 1, \ldots, N,$$

where Y_i is the output of firm i, x_i is the vector of inputs typically in logarithms, v_i accounts for measurement errors and other sources of non-systematic statistic noise, and u_i is a nonnegative random variable representing technical inefficiency (the distance to the frontier).

The stochastic frontier literature of the early 1980s mainly consists of analyses for cross-sectional data. v_i is usually assumed to follow a normal distribution that is independent of each u_i, while u_i is assumed to follow a variety of distributions including half-normal distribution (Aigner, Lovell, and Schmidt 1977), normal truncated distribution (Stevenson 1980), and gamma distribution (Greene 1990). Given the panel data, Schmidt and Sickles (1984) proposed the panel stochastic frontier model in the form

$$\ln Y_{it} = \alpha + x_{it}'\beta + v_{it} - u_i = \alpha_i + x_{it}'\beta + v_{it},\ i = 1, \ldots, N,\ t = 1, \ldots, T.$$

Then, fixed effects or random effects methods can be used to estimate α_i under different conditions. Other estimators can be found in Cornwell, Schmidt, and Sickles (1990), Kumbhakar (1990), Battese and Coelli (1992), Lee and Schmidt (1993), Kneip, Sickles, and Song (2003), and Sickles (2005). More detailed introduction and comparison of these estimator can be found in Gong and Sickles (2016) and Gong (2018b). All of these methods have a rigid functional form assumption of the parametric production function.

In economic theory, production functions are monotone increasing and concave with respect to inputs (Diewert and Wales 1987). The property of monotonicity guarantees that firms can always produce more with more inputs. Also, the property of concavity guarantees decreasing marginal products when input grows. Imposing constraints in nonparametric and semi-parametric estimations has been discussed for more than half a century. In the past, scholars developed estimators to satisfy a particular constraint. For example, a concave constrained estimator is established in Hildreth (1954) and a monotonically restricted estimator is established in Brunk (1955). In the 1980s, a series of spline- and series-based functions are designed to impose economic constraints, including concavity in Dierckx (1980) and monotonicity in Ramsay (1988). New methods to handle general constraints were then developed using either a series-based estimator in Yatchew and Bos (1997) or a spline-based estimator in Beresteanu (2004). Moreover, the Matzkin approach can impose monotonicity and concavity in more general settings (Matzkin 1991, 1992, 1993). Other restricted methods include the rearrangement approach in Dette, Neumeyer, and Pilz (2006), the data-sharpening approach in Choi and Hall (1999), and the constraint-weighted bootstrapping approach in Hall and Huang (2001). Henderson and Parmeter (2009) survey these aforementioned methods and discuss their implementation. In recent years, semi-parametric models under shape constraints, including monotonicity and concavity, have been further developed in Pya and Wood (2015) and Wu and Sickles (2017).

This article employs the newly developed semi-parametric function $\xi(\cdot)$ with monotonicity and concavity restrictions in Wu and Sickles (2017):

$$\xi(x) = \int_0^x \exp\left(\int_0^s -g(h(w))\mathrm{d}w\right)\mathrm{d}s$$

As proposed by Ramsay (1998), the positive exponential functional embedded in the integral transformation guarantees a nonnegative first derivative $\xi'(x) = \exp(\cdot) \geq 0$ and hence achieves global monotonicity. On the other hand, we assume that $g(x) = x^2$ in the second integral assures the second derivative $\xi''(x) = \xi'(x)[= -g(h(w))] \leq 0$ since $\xi'(x) \geq 0$ and $g(h(w)) = [h(w)]^2 \geq 0$, which obtains concavity for $\xi(x)$. These two transformations change a constrained problem into an unconstrained one. Finally, only the function $h(w),\ w \in [0, 1]$ needs to be modeled. This study opts to use the spline method to model $h(w)$ nonparametrically. Specifically, the truncated power series splines are

$$\phi(x) = \left(1, x, \ldots, x^p, (x-k_1)_+^p, \ldots, (x-k_M)_+^p\right)^T$$

where $0 < k_1 < \ldots < k_M < 1$ are a series of knots of the spline basis functions, $(x)_+ = \max(x, 0)$, and p is a positive integer. Then $h(x) = c^T\phi(x)$ where c vectors the coefficients with a compatible dimension.

This function $\xi(x)$ is then introduced to build a new semiparametric stochastic frontier production under shape constraints in the form

$$Y_{it} = A \cdot \left[\prod_{k=1}^{M} \xi_k\left(X_{it}^k\right)\right] \cdot \exp(\tau Z) \cdot \exp(v_{it}) \cdot \exp(-u_{it}) \quad (1)$$

where $A = \exp(\alpha)$ is the intercept. $\xi_k\left(X_{it}^k\right)$ is a monotone increasing and concave function of the kth input. Z is a vector that contains a group of year dummy variables and shifts the production frontier over time with corresponding coefficients τ. $\exp(v_{it})$ is the stochastic component that describes random shocks affecting the production process, where v_{it} is assumed to be normally distributed with a mean of zero and a standard deviation of σ_v, and $TE_{it} = \exp(-u_{it})$ denotes the technical efficiency, defined as the ratio of observed output to maximum feasible output. $TE_{it} = 1$ or $u_{it} = 0$ shows that the ith individual allocates at the production frontier and obtains the maximum feasible output at time t, while $TE_{it} < 1$ or $u_{it} > 0$ provides a measure of the shortfall of the observed output from the maximum feasible output. This study uses the popular "Error Components Frontier" (Battese and Coelli 1992).

This study improves the production function employed in Wu and Sickles (2017) by using the product of each input's effect ($\prod_{k=1}^{M} \xi_k(X_{it}^k)$), rather than the summation of them ($\sum_{k=1}^{M} \xi_k(X_{it}^k)$) for the following reasons: (1) the products of positive monotone increasing and concave functions are still monotone increasing and functions for each input; (2) the multiplication (instead of the summation) allows for positive (rather than zero) cross-productivity effects. Many studies (Nicholson and Snyder 2011; Thompson 2011) point out that positive cross-productivity effects are the most prevalent case. Take labor and capital as an example, where the positive cross-productivity effects reflect that workers would have higher marginal productivity if they had more capital. If summation is adopted, the effects of different inputs are additive and independent, which ignores the joint effects; (3) when the multiplication form is employed, a linear production function analogous to previous models can easily be derived by taking a log of production function. As a result, the advantages of the logarithmic output described in Henningsen and Kumbhakar (2009) can be seen.

The logarithm of equation Eq. (1) becomes

$$\log(Y_{it}) = \alpha + \sum_{k=1}^{M} \log\left[\xi_k\left(X_{it}^k\right)\right] + \tau Z + v_{it} - u_{it} \tag{2}$$

where

$$\xi_k\left(X_{it}^k\right) = \int_0^{X_{it}^k} \exp\left(\int_0^s -\left(c_k^T \phi(w)\right)^2 \mathrm{d}w\right) \mathrm{d}s.$$

Here c_k^T in $\xi_k\left(X_{it}^k\right)$ for all k are the flexible tools for curve fitting and need to be estimated. The TFP can then be derived sequentially. The semiparametric production frontier under shape constraints in Eq. (2) is denoted as "Shape-constrained Frontier." For comparison, this article names the conventional parametric Cobb–Douglas production frontier "Cobb–Douglas Frontier" in Eq. (3)

$$\log(Y_{it}) = \alpha + \sum_{k=1}^{M} \beta_k \log\left(X_{it}^k\right) + \tau Z + v_{it} - u_{it} \tag{3}$$

In practice, the semi-parametric model in Eq. (2) can be solved by a two-step method proposed by Fan, Li, and Weersink (1996), which is a classic approach to deal with semi-parametric frontier analysis. Suppose a stochastic frontier model has the form

$$y = f(x) + \epsilon = f(x) + \mu + v - u$$

where $f(x)$ is a semi- or nonparametric production function. u and v are the same as in a parametric stochastic model, representing the nonnegative technical inefficiency term and disturbance, respectively. μ is a constant that guarantees the expected value of ϵ equals zero. Therefore, $\epsilon = \mu + v - u$ is a new disturbance term with a zero mean.

This article implements the two-step method as follows: in the first step, the semi-parametric regression under shape constraints $y = f(x) + \epsilon$ is run to retrieve the residuals $\hat{\epsilon}$; in the second step, the residual is decomposed as $\hat{\epsilon} = \mu + v - u$ using the popular "Error Components Frontier" (Battese and Coelli 1992), where $\hat{\epsilon}$ is the dependent variable and a constant is the only independent variable. A similar method has been used in many empirical studies that adopt semi-parametric frontier models. For example, Henningsen and Kumbhakar (2009) use this approach in their applied study on Polish farms, and Gong (2018c) uses this approach in his work on the global oil field market.

Effects of Public Expenditure and Trade on Productivity

Represented by Romer (1986) and Lucas (1988), the growth theory states that the international economic interflow and domestic investment in technology and infrastructure are the major drivers of economic growth. Hansson and Henrekson (1994) suggest using productivity growth rather than GDP growth as the proxy of economic growth to estimate the effect of public expenditure since some of the expenditure is part of measured GDP, which implies that GDP may grow merely because the expenditure grows. This applies to international trade as well.

In terms of the public expenditure, Hansson and Henrekson (1994) review earlier studies about the effects of public expenditure on productivity, and these provide mixed results. On the one hand, arguments indicating positive effects include that (1) public expenditure rectifies the effects of externalities and the natural monopolies that may impede productivity growth; (2) public expenditure can partly reduce social inequality, thus fostering growth; and (3) an expansion of the public expenditure results in a higher utilization rate, which has a beneficial impact on productivity according to Verdoorn's Law. On the other hand, arguments pointing toward a negative impact include (1) interest groups strive to benefit from public expenditure, which may worsen the voerall functioning of the market economy; (2) public expenditure may crowd out private investment and thus becomes an impediment to growth; and (3) the potential profits from rent-seeking behaviors may lead to growth-retarding side effects. Using data for 14 OECD countries from 1970 to 1987, Hansson and Henrekson (1994) find evidence of both positive and negative effects on productivity as a result of public expenditure on productivity. Related studies concerning public expenditure can be found in Baciu and Botezat (2014), Apergis (2015), and Lei et al. (2017).

In terms of the agricultural sector in China, many scholars (Dong 1996; Nee and Sijin 1990) raise the argument that public expenditure in agriculture can help Chinese farmers more easily access credit, obtain economies of scale, disperse risk, gain fertilizer and other modern inputs, and organize infrastructural construction activities. Dong (2000) finds that public expenditure boosted Chinese agricultural production and the existence of underinvestment in public projects, especially in the poorer areas in the 1980s and 1990s. Public expenditure in agriculture, as sponsored by the Chinese government, has increased dramatically in recent years in the spirit of "industry nurturing agriculture" reforms. Therefore, it is important to estimate the current effect of public expenditure on productivity.

In terms of the international trade, new trade theory believes international trade is a major factor for promoting technological progress. Grossman and Helpman (1993) reason that international trade provides opportunities to improve productivity through two channels. Imports can bring commodities that cannot be generated domestically as well as the information needed to produce them. Exports can receive suggestions and recommendations from foreign buyers, and the exporters have the incentive to learn advanced technology and management experience from other countries to become more productive and competitive in the global market. Aghion and Griffith (2008) believe international trade may intensify competition and have an effect on the incentive to innovate, which consequentially increases productivity. To summarize, theoretical and empirical studies (e.g., Frankel and Romer (1999), Bensidoun, Lemoine, and Ünal (2009)) have analyzed the positive role that trade plays in economic growth.

Many scholars (Alcalá and Ciccone 2004; Chanda and Dalgaard 2008; Frankel and Romer 1999; Marelli and Signorelli 2011) utilize the sum of exports and imports as proxy of trade and openness, and they find that international trade is an important element behind successful development. Hassine and Kandil (2009) have found positive effects of total agricultural trade on agricultural productivity for 14 Mediterranean countries over the period of 1990–2005.

However, some scholars separately estimate the effects of exports and imports due to the aforementioned various impact channels of the two in new trade theory. Some development literature treats exports as a growth deriver due to the positive productivity spillover effects from the tradable to the non-tradable sector and the creation of more competitive investments (Edwards 1993). For example, Miller and Upadhyay (2000) find a significant and robust positive effect of exports-measured openness on TFP using panel data for 83 countries from 1960 to 1989. Some endogenous growth studies, however, have shifted the attention from exports to imports (Baldwin and Forslid 2000; Rivera-Batiz and Romer 1991; Romer 1990). For example, Barro and Sala-i-Martin (1995) believe that imports make it possible for local producers to choose from a wider variety of capital goods and hence increase their productivity and efficiency.

The various and controversial effects of exports and imports are also observed by some empirical studies that focus specifically on China. Li, Lu, and Zhu (2008) estimate China's manufacturing productivity for 1998–2003 and find that imports can significantly increase productivity, while exports have no significant effect. However, Marelli and Signorelli (2011) believe that exports play a more important role than imports do in China's economic development. Therefore, the true effect of trade (exports and/or imports) on agricultural productivity remains unclear, but there are more important policy implications after the WTO accession.

Some scholars study a variety of agricultural productivity determinants in China, especially from the perspective of institutional reforms, trade, and public expenditure. Besides the impact of rural reforms, most of these scholars believe the rapid growth in China's agricultural productivity also benefits from international trade and public expenditure (Shi and Zhao 2009; Wang, Song, and Han 2010).

The previous subsection estimates the production function. The TFP in logarithms can be derived from $TFP_{it} = \log(\alpha + \tau Z - u_{it})$. Econometrically, this article explores the effects of public expenditure and trade on provincial-level agricultural productivity using Eq. (4).

$$TFP_{it} = \alpha + \beta_1 Trade_{it} + \beta_2 Finance_{it} + +\beta_3 Trade_{it}{}^{*} Finance_{it} + \sum_{j=2}^{4} \delta_j ratio_j + \beta_4 H_{it} + \beta_5 W_{it} + \gamma I + \varepsilon \qquad (4)$$

where TFP_{it} is the agricultural TFP in logarithms for the ith province at time t. $Trade_{it}$ is the sum of agricultural imports and exports in logarithms. $Finance_{it}$ is the public expenditure in agriculture sector in logarithms. In order to check the potential linkage between international trade and public expenditure, this article introduces an interaction term $Finance^{*}\ Trade$ in the TFP determination equation. $ratio_1$, $ratio_2$, $ratio_3$, and $ratio_4$ are the output value shares of the four agricultural segments, including farming, forestry, animal husbandry, and fisheries, respectively. H_{it} measures agricultural output diversification for the ith province at time t by means of a Herfindahl index $H_{it} = \sum_{j=1}^{4} ratio_j^2$ over the four segments. W_{it} is the agricultural land area affected by natural disasters (primarily flooding and droughts), in logarithms, which may explain declines in output and productivity (Brümmer, Glauben, and Lu 2006; Lambert and Parker 1998). I is a vector of province dummy variables.

The reverse causation issue may bias the estimated effect of trade on productivity. Instruments are usually used to overcome the potential endogeneity problem when trade is served as a productivity determinant. Chanda and Dalgaard (2008) adopt population size and land area as instruments for trade, while Madsen (2009) treats per capita agricultural production, per capita arable land, and population density as potential instruments. Marelli and Signorelli (2011) utilize value added share of the corresponding industry in GDP and lagged value of GDP per capita to instrument trade. Inspired by Madsen (2009) and Marelli and Signorelli (2011), this article chooses per capita agricultural production and value added share of agriculture in GDP as the two instruments and uses the Two-Stage Least Square method to deal with the endogeneity problems.

Another potential problem is whether to combine or disaggregate exports and imports to proxy trade and openness. In Eq. (4), we follow Chanda and Dalgaard (2008) and Marelli and Signorelli (2011) to use the sum of exports and imports (i.e., total international trade). However, some aforementioned studies use either exports alone (Miller and Upadhyay 2000) or imports alone (Madsen 2009) to measure openness. Moreover, other scholars (Li, Lu, and Zhu 2008; Marelli and Signorelli 2011) find different effects of exports and imports on productivity. Therefore, this article also decomposes trade to exports and imports and estimates their separate effects on productivity. More specifically, two independent variables, including $Export_{it}$ (agricultural exports in logarithms) and $Import_{it}$ (agricultural imports in logarithms), are added to Eq. (4) to replace $Finance_{it}$. Moreover, the Two-Stage Least Square method is also utilized in order to correct the potential endogeneity problem of imports and exports.

Data

The data utilized are provincial-level agricultural outputs and inputs of 31 provinces in mainland China over the period of 2004–2015. This article follows the traditional literature (e.g., Kalirajan, Obwona, and Zhao (1996), Chen (2006), Zhou and Zhang (2013), Liu et al. (2015), and Gong (2018a)) in selecting inputs and outputs for the production function. The deflated GVAO is used as the output variable, which is the sum of the total value of production from farming, forestry, animal husbandry, and fisheries (in billion CNY at 1980 constant prices). Inputs in the data set include four categories: labor, land, fertilizer, and machinery. Labor is measured as the size of the labor force (in millions) in farming, forestry, animal husbandry, and fisheries. Land refers to the sown area (in million hectares) reflecting the actual utilization of the cultivated land. Fertilizer is measured by the sum of the gross weight of nitrogen, phosphate, potash, and complex fertilizers (in million tons). Machinery refers to the total power of agricultural machinery (in million kilowatts), which includes the total mechanical power of machinery used in the primary industry.

The output value share of the four segments in agriculture (i.e., $ratio_j$) can be calculated, as the respective values of production from farming, forestry, animal husbandry, and fisheries are available. The agricultural output diversification (H_{it}) can be calculated accordingly. The agricultural land area affected by natural disasters (W_{it}) is also collected. In terms of public expenditure in agriculture ($\text{Finance}_{\text{it}}$), this article collects the government's expenditure on agriculture, forestry, and water affairs. In order to estimate the effect of public investment stocks, rather than flows, on agricultural productivity, this article adopts the unified perpetual inventory method to convert investment flows to stocks, which is widely used in productivity analysis (Berlemann and Wesselhöft 2014; Gong 2016, 2017). The Appendix introduces the definition of government's expenditure and explains the data-generating process of public agricultural expenditure stocks.

Most of the aforementioned data are from *China Statistical Yearbook*. Some data are supplemented (e.g., the labor statistics in 2013–2015) and adjusted (e.g., data of Chongqing and Hainan) using the *China Compendium of Statistics 1949–2008* and the provincial-level statistical yearbooks. The agricultural imports and exports data for 2004–2015 are available on the website of the Ministry of Commerce of the People's Republic of China. Finally, province-level population and GDP data were also collected from *China Statistical Yearbook* to derive both instruments (per capita agricultural production and value added share of agriculture in GDP) that are needed to deal with the endogeneity problem.

Table 1 summarizes provincial-level outputs, four inputs, and four potential productivity determinants in China's agricultural sector 2004 and 2015. The average deflated GVAO tripled from 30.8 billion CNY (at 1980 constant prices) in 2004 to 48.3 billion CNY (at 1980 constant prices) in 2015, showing a real growth rate of 4.2% per year. In the labor market, the average size of the labor force in the primary industry decreased by around 1.3% per year, from 10.1 million in 2004 to 8.7 million in

Table 1. Summary statistics.

			2004				2015				
Category	**Variable**	**Unit**	**Mean**	**S.D.**	**Min**	**Max**	**Mean**	**S.D.**	**Min**	**Max**	**Annual Growth Rate (%)**
Output	GVAO	Billion CNY at 1980 prices	30.8	23.4	1.7	90.9	48.3	34.0	2.1	134	4.2
Inputs	Labor	Million	10.1	8.0	0.6	32.4	8.7	6.5	0.5	25.9	−1.3
	Land	Million hectares	4.9	3.5	0.2	13.8	5.4	3.8	0.2	14.4	0.7
	Fertilizer	Million tons	1.5	1.2	0.04	4.9	1.9	1.5	0.06	7.2	2.4
	Machinery	Million kilowatts	20.7	22.0	1.1	87.5	36.0	33.0	1.2	134	5.2
Productivity Determinants	*Finance*	Billion CNY	21.5	11.0	2.2	42.2	254	112	73.4	505	25.2
	Trade	Billion CNY	13.6	20.8	0.04	82.7	37.4	50.3	0.1	195	9.6
	Export	billion CNY	6.1	9.8	0.04	46.2	14.1	20.6	0.1	95.4	7.8
	Import	Billion CNY	7.5	12.7	0	49.3	23.3	34.1	0.01	111	10.8

2015. The sown land area slightly increased from 4.9 million hectares in 2004 to 5.4 million hectares in 2015, demonstrating a 0.7% annual growth. The amount of chemical fertilizer used rose 2.4% annually, from 1.5 million tons in 2004 to 1.9 million tons in 2015. The total power of agricultural machinery in 2015 was almost double what it was in 2004, and this is the fastest growing input with an annual growth rate above 5%. The public expenditure stock was 12-fold, from 21.5 billion in 2004 to 253.6 billion in 2015. International trade increased 9.6% per year, from 13.6 billion in 2004 to 37.4 billion in 2015, which shows growth rate that is at a similar speed to GVAO. The growth rates for agricultural exports and imports are 7.8% and 10.8%, and these rates enlarged the trade deficit from 1.4 billion in 2004 to 9.2 billion in 2015.

Results

Production Function and TFP

The Shape-constrained Frontier approach cannot estimate coefficients of the production function that are directly comparable with those in the Cobb–Douglas Frontier approach. For each of the four inputs, Figure 2 visualizes their impact on output derived from the Shape-constrained Frontier algorithm, which is comparable to the input elasticities estimated from the Cobb–Douglas Frontier method.

The effects of labor, land, and fertilizer estimated in the Shape-constrained Frontier algorithm are more concave than those in the Cobb–Douglas Frontier, while the impact of machinery estimated in the Shape-constrained Frontier is less concave than the one in the Cobb–Douglas Frontier. The results show that the classic parametric production function that most existing studies utilized not only overestimates the effects of labor, land, and fertilizer but also underestimates the effect of machinery on China's agricultural production. The production functions estimated from the two methods are significantly different and hence imply that the Cobb–Douglas assumption is not fully valid. The adoption of this rigid assumption of the functional form fails to capture the true input–output relationship in China's agricultural sector, which may lead to a biased estimation of the production frontier as well as TFP. As a result, the impacts of trade and public expenditure on productivity are likely to be inaccurately estimated in the second-step regression unless the Shape-constrained Frontier method is utilized.

China's agricultural TFP as well as its growth rate are given in Figure 3. Significant growth above 5% in productivity was witnessed in 2005, followed by a slowdown for the next 3 years. The

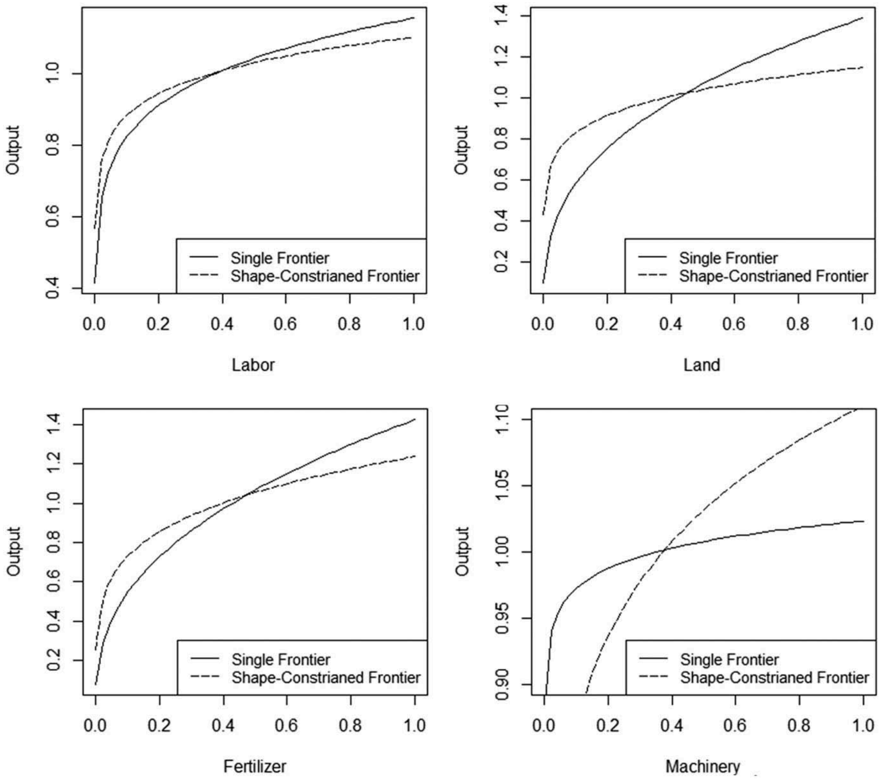

Figure 2. Effects of inputs on output in various methods.

productivity increased by more than 6% in 2009 but soon lost the momentum in the following two years. However, a consecutive 3-year high-speed growth of around 5% per year occurred during the period of 2012–2014. In 2015, the growth rate dropped to 2%. To summarize, there are obvious cyclical fluctuations in productivity growth. The growth rates in recent years are higher and more stable, but the next slowdown may come soon.

Productivity Determinants

The most important question this article seeks to answer is concerning the current impact of public expenditure and trade on agricultural TFP in China. This article discusses the benefits of analyzing the effects of public expenditure and international trade together, rather than through the "separate" models, as is often used in literature. Table 2 reports the estimated results of the productivity determination equation in Eq. (4). In columns (2)–(6) where trade variables are included, the Two-Stage Least Square method is applied to deal with the endogeneity problems. The first two columns of Table 2 give the estimation results of the "separate" models, where public expenditure and international trade are separately included in the equation. Compared with the combined model in column (3), "separate" models overestimate the effect of the two variables. This article concludes that the combined model outperforms the "separate" models for two reasons: (1) the coefficients of both public expenditure and international trade are significant in the combined model; and (2) the adjusted R^2 of the combined model is higher than the two "separate" models.

Table 2 also checks the potential linkage between public expenditure and international trade. The level of openness may affect the impact of public expenditure, while the level of public expenditure may

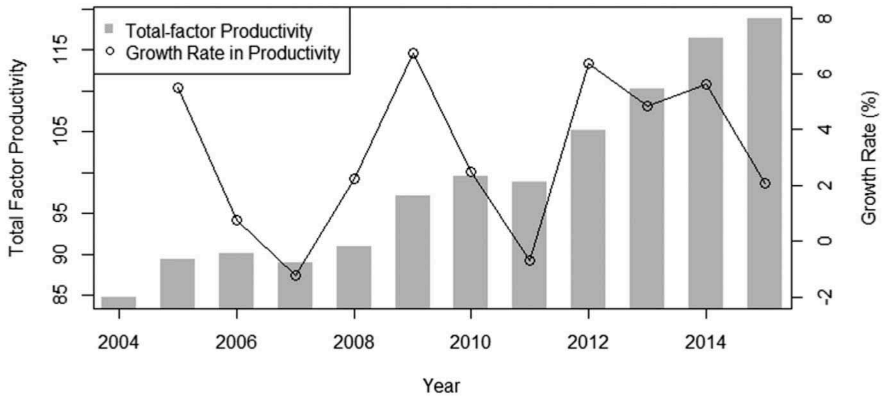

Figure 3. China's agricultural total factor productivity and its growth rate in 2004–2015.

change the effect of international trade. In order to test such a potential linkage, this article introduces the interaction term *Finance* Trade* in the TFP determination equation, the result of which is reported in column (4) of Table 2. The result shows that the coefficient of *Finance* Trade* is statistically insignificant and the adjusted R^2 decreased when adding this interaction term. Hence, there is no linkage or spillover effect between public expenditure and international trade. Furthermore, the fifth column of Table 2 reports the estimation result when international trade is divided into exports and imports. The result shows that exports can significantly enhance TFP, while imports have no significant influence. This article also introduces the interaction terms *Finance*Export* and *Finance*Import* to see if linkages exist between public expenditure and exports or imports. Column (6) of Table 2 confirms the findings from column (4), indicating that there is no linkage between public expenditure and international trade, as the coefficients of the interaction terms are insignificant and the adjusted R^2 declined.

Using column (5) to summarize, the estimation result interprets that (1) a 1% increase in agricultural exports can raise agricultural productivity by 0.037%, (2) agricultural imports do not significantly affect agricultural productivity, and (3) a 1% increase in public expenditure in agriculture can raise agricultural productivity by 0.066%. In terms of other productivity components, the estimation result in column (5) shows that (1) the productivity is the highest in the fisheries segment, followed by the farming and forestry segments, whereas animal husbandry is the least productive; (2) diversification in the four segments can increase productivity in agricultural production; and (3) an increase in natural disasters can decrease agricultural productivity.

Conclusion and Policy Implications

This article built a two-step approach to estimate the impacts of public expenditure and trade on agricultural productivity in China. A semiparametic stochastic frontier model under shape constraints is introduced to derive province-level TFP and is followed by a productivity determination equation to estimate how trade and public expenditure, as well as other variables, affected agricultural productivity during the period of 2004–2015.

The empirical results show that (1) it is necessary to relax the rigid functional form of the production function to achieve accurate production function and productivity in China's agricultural sector, (2) a significant increase in agricultural productivity has been witnessed in the past decade, (3) both public expenditure and exports in agriculture can significantly increase productivity, and (4) agricultural imports have no significant impact on productivity. These results lead to three policy implications.

First, the effects of WTO accession and international trade are mixed. On the one hand, more exports of agricultural commodities help to improve agricultural productivity, which confirms the

Table 2. Regression results of the semi-parametric model under shape constraints.

TF̂P	(1)	(2)	(3)	(4)	(5)	(6)
Finance	0.107***	–	0.032***	0.310***	0.066***	0.049**
	(0.003)	–	(0.003)	(0.118)	(0.016)	(0.020)
Trade	–	0.189***	0.137***	0.320**	–	–
	–	(0.010)	(0.046)	(0.161)	–	–
Export	–	–	–	–	0.037***	0.041**
	–	–	–	–	(0.009)	(0.020)
Import	–	–	–	–	0.021	0.003
	–	–	–	–	(0.030)	(0.010)
*Finance*Trade*	–	–	–	–0.027	–	–
	–	–	–	(0.149)	–	–
*Finance*Export*	–	–	–	–	–	0.005
	–	–	–	–	–	(0.003)
*Finance*Import*	–	–	–	–	–	0.001
	–	–	–	–	–	(0.002)
ratio2	0.004***	–0.002	–0.000	0.008**	0.001	0.002*
	(0.001)	(0.002)	(0.002)	(0.004)	(0.002)	(0.001)
ratio3	–0.003***	–0.002	–0.002**	–0.002	–0.002*	–0.003***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
ratio4	0.007***	0.007**	0.008***	0.006	0.006**	0.007***
	(0.002)	(0.004)	(0.003)	(0.004)	(0.003)	(0.002)
diver	0.000	0.000	0.000	0.0001*	0.00001**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
weather	–0.003*	–0.005*	–0.004*	–0.009*	–0.004**	–0.002
	(0.001)	(0.003)	(0.002)	(0.005)	(0.002)	(0.001)
province	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
constant term	3.626***	1.741***	2.221***	0.317	3.115***	4.003***
	(0.047)	(0.192)	(0.475)	(1.677)	(0.300)	(0.176)
Adjusted R^2	0.987	0.988	0.992	0.985	0.994	0.993

Notes: *, **, *** represent significance at 10%, 5%, and 1% levels, respectively. Standard error in parentheses.

positive effect from competition and the advice brought by foreign competitors and buyers. On the other hand, agricultural imports fail to increase productivity, which could have been achieved as a result of better resource allocation and the absorption of advanced technology, as suggested in theory. Therefore, the government should encourage and support more agricultural exports. In terms of imports, the government can help local producers absorb information and techniques that are embedded in the imported goods. Furthermore, more attention should be paid to the rapidly growing trade deficit in agriculture, especially before the imports can be taken advantage of. Under the current circumstances, massive import expansion is not a wise choice.

Second, the positive effect of public expenditure provides evidence of the success of the "industry nurturing agriculture" reforms. Significant growth in agricultural productivity is observed to be due to the increase in government spending. Public expenditure does play an important and effective role in technical progress and the optimization of resource allocation in the context of supply-side reforms. Moreover, the provinces with lower productivity may need more support from the central government. Based on our estimation result, increasing public expenditure in less developed areas can improve agricultural productivity, which is an important method for speeding up the poverty alleviation process.

Third, this article finds that productivity is the highest in fisheries, followed by farming and forestry segments, while animal husbandry is the least productive segment. Therefore, coastal provinces and other provinces with abundant water resources can expand their fisheries segment to further improve their productivity. Moreover, more public expenditure and private R&D funding should be invested in the animal husbandry segment, enabling it to catch up with other segments.

Although public expenditure and international trade are the keys to productivity growth (Lucas 1988; Romer 1986), foreign investments and domestic trade may also affect productivity. Future studies can include Foreign Direct Investment and cross-regional trade in the productivity determination equation. Moreover, the shocks from WTO accession and the financial crisis can be utilized to identify the effects of finance and trade if any trade data are available before 2001. Finally, the accuracy of the analysis can be further improved if city-level or county-level data are accessible as well.

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References

Aghion, P., and R. Griffith. 2008. *Competition and growth: Reconciling theory and evidence*. Cambridge, MA: MIT press.

Aigner, D., C. A. Lovell, and P. Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* 6 (1):21–37. doi:10.1016/0304-4076(77)90052-5.
Alcalá, F., and A. Ciccone. 2004. Trade and productivity. *The Quarterly Journal of Economics* 119 (2):613–46. doi:10.1162/0033553041382139.
Apergis, N. 2015. Convergence in public expenditure across a sample of emerging countries: Evidence from club convergence. *Emerging Markets Finance and Trade* 51 (3):448–62. doi:10.1080/1540496X.2015.1025670.
Baciu, L., and A. Botezat. 2014. A comparative analysis of the public spending efficiency of the new eu member states: A dea approach. *Emerging Markets Finance and Trade* 50 (sup4):31–46. doi:10.2753/REE1540-496X5004S402.
Baldwin, R. E., and R. Forslid. 2000. Trade liberalisation and endogenous growth: A q-theory approach. *Journal of International Economics* 50 (2):497–517. doi:10.1016/S0022-1996(99)00008-2.
Barro, R. J., and X. Sala-i-Martin. 1995. *Economic growth, advanced series in economics*. New York, London and Montreal: McGraw-Hill.
Battese, G. E., and T. J. Coelli. 1992. Frontier production functions, technical efficiency and panel data: With application to paddy farmers in india. *Journal of Productivity Analysis* 3 (1):153–169.
Bensidoun, I., F. Lemoine, and D. Ünal. 2009. The integration of China and India into the world economy: A comparison1. *The European Journal of Comparative Economics* 6 (1):131.
Beresteanu, A. 2004. *Nonparametric estimation of regression functions under restrictions on partieal derivatives*. Durham, NC: Duke University, Department of Economics.
Berlemann, M., and J.-E. Wesselhöft. 2014. Estimating aggregate capital stocks using the perpetual inventory method–A survey of previous implementations and new empirical evidence for 103 countries. *Review of Economics/Jahrbuch Für Wirtschaftswissenschaften* 65 (1):1–34.
Brümmer, B., T. Glauben, and W. Lu. 2006. Policy reform and productivity change in Chinese agriculture: A distance function approach. *Journal of Development Economics* 81 (1):61–79. doi:10.1016/j.jdeveco.2005.04.009.
Brunk, H. D. 1955. Maximum likelihood estimates of monotone parameters. *The Annals of Mathematical Statistics* 26 (4):607–16. doi:10.1214/aoms/1177728420.
Chanda, A., and C. J. Dalgaard. 2008. Dual economies and international total factor productivity differences: Channelling the impact from institutions, trade, and geography. *Economica* 75 (300):629–61. doi:10.1111/j.1468-0335.2007.00673.x.
Chen, C. 2014. Estimation of variable depreciation rate and measurement of capital stock. *Economic Research Journal* 49 (12):72–85.
Chen, W. 2006. Productivity growth, technical progress and efficiency change in Chinese agriculture:1990-2003. *China Rural Survey* 16 (1):203–22.
Chien, S. S. 2015. Local farmland loss and preservation in China—A perspective of quota territorialization. *Land Use Policy* 49:65–74. doi:10.1016/j.landusepol.2015.07.010.
Choi, E., and P. Hall. 1999. Data sharpening as a prelude to density estimation. *Biometrika* 86 (4):941–47. doi:10.1093/biomet/86.4.941.
Cornwell, C., P. Schmidt, and R. C. Sickles. 1990. Production frontiers with cross-sectional and time-series variation in efficiency levels. *Journal of Econometrics* 46 (1):185–200. doi:10.1016/0304-4076(90)90054-W.
de la Fuente, A., and R. Doménech. 2006. Human capital in growth regressions: How much difference does data quality make? *Journal of the European Economic Association* 4 (1):1–36. doi:10.1162/jeea.2006.4.1.1.
Dette, H., N. Neumeyer, and K. F. Pilz. 2006. A simple nonparametric estimator of a strictly monotone regression function. *Bernoulli* 12 (3):469–90. doi:10.3150/bj/1151525131.
Dierckx, I. P. 1980. An algorithm for cubic spline fitting with convexity constraints. *Computing* 24 (4):349–71. doi:10.1007/BF02237820.
Diewert, W. E., and T. J. Wales. 1987. Flexible functional forms and global curvature conditions. *Econometrica* 55 (1):43–68. doi:10.2307/1911156.
Dong, X. Y. 2000. Public investment, social services and productivity of Chinese household farms. *Journal of Development Studies* 36 (3):100–22. doi:10.1080/00220380008422630.
Dong, X.-Y. 1996. Two-tier land tenure system and sustained economic growth in post-1978 rural China. *World Development* 24 (5):915–28. doi:10.1016/0305-750X(96)00010-1.
Edwards, S. 1993. Openness, trade liberalization, and growth in developing countries. *Journal of Economic Literature* 31 (3):1358–93.
Fan, B., and Z. Duan. 2011. The relationship between agricultural financial expenditure and agricultural economic development. *Theoretical Exploration* 2011 (1):66–70.
Fan, Y., Q. Li, and A. Weersink. 1996. Semiparametric estimation of stochastic production frontier models. *Journal of Business & Economic Statistics* 14 (4):460–68.
Frankel, J. A., and D. Romer. 1999. Does trade cause growth? *American Economic Review* 89:379–99. doi:10.1257/aer.89.3.379.
Gong, B. 2016. Efficiency and productivity analysis of multidivisional firms. Ph.D. diss., Department of Economics, Rice University.
Gong, B. 2017. Multi-dimensional interactions in the oilfield market: A jackknife model averaging approach of spatial productivity analysis. *Energy Economics*. doi:10.1016/j.eneco.2017.08.032.
Gong, B. 2018a. Agricultural reforms and production in China changes in provincial production function and productivity in 1978–2015. *Journal of Development Economics* 132:18–31. doi:10.1016/j.jdeveco.2017.12.005.
Gong, B. 2018b. Different behaviors in natural gas production between national and private oil companies: Economics-driven or environment-driven? *Energy Policy* 114 (3):145–52. doi:10.1016/j.enpol.2017.12.004.
Gong, B. 2018c. The shale technical revolution – Cheer or fear? Impact analysis on efficiency in the global oilfield service market. *Energy Policy* 112 (1):162–72. doi:10.1016/j.enpol.2017.09.054.

Gong, B., and R. C. Sickles. 2016. *Non-structural and structural models in productivity analysis: Study of the british isles during the 2007-2009 financial crisis*. Houston, TX: Rice University, Department of Economics.
Greene, W. H. 1990. A gamma-distributed stochastic frontier model. *Journal of Econometrics* 46 (1):141–63. doi:10.1016/0304-4076(90)90052-U.
Grossman, G. M., and E. Helpman. 1993. *Innovation and growth in the global economy*. Cambridge, MA: MIT press.
Hall, P., and L. S. Huang. 2001. Nonparametric kernel regression subject to monotonicity constraints. *Annals of Statistics* 29 (3):624–47.
Hansson, P., and M. Henrekson. 1994. A new framework for testing the effect of government spending on growth and productivity. *Public Choice* 81 (3):381–401. doi:10.1007/BF01053239.
Hassine, N. B., and M. Kandil. 2009. Trade liberalisation, agricultural productivity and poverty in the Mediterranean region. *European Review of Agricultural Economics* 36 (1):1–29. doi:10.1093/erae/jbp002.
He, Q. 2015. Quality-adjusted agricultural land abundance curse in economic development: Evidence from postreform Chinese panel data. *Emerging Markets Finance and Trade* 51 (sup4):S23–S39. doi:10.1080/1540496X.2015.1026715.
Henderson, D. J., and C. F. Parmeter. 2009. Imposing economic constraints in nonparametric regression: Survey, implementation, and extension. *Advances in Econometrics* 25 (2009):433–69.
Henningsen, A., and S. Kumbhakar. 2009. Semiparametric stochastic frontier analysis: An application to Polish farms during transition. European Workshop on Efficiency and Productivity Analysis (EWEPA) in Pisa, Italy, June.
Hildreth, C. 1954. Point estimates of ordinates of concave functions. *Journal of the American Statistical Association* 49 (267):598–619. doi:10.1080/01621459.1954.10483523.
Kalirajan, K. P., M. B. Obwona, and S. Zhao. 1996. A decomposition of total factor productivity growth: The case of Chinese agricultural growth before and after reforms. *American Journal of Agricultural Economics* 78 (2):331–38. doi:10.2307/1243706.
Kneip, A., R. Sickles, and W. Song. 2003. On estimating a mixed effects model with applications to the U.S. Banking industry. *Rice University, Mineo*.
Kumbhakar, S. C. 1990. Production frontiers, panel data, and time-varying technical inefficiency. *Journal of Econometrics* 46 (1):201–11. doi:10.1016/0304-4076(90)90055-X.
Lambert, D. K., and E. Parker. 1998. Productivity in Chinese provincial agriculture. *Journal of Agricultural Economics* 49 (3):378–92. doi:10.1111/jage.1998.49.issue-3.
Lee, Y. H., and P. Schmidt. 1993. A production frontier model with flexible temporal variation in technical efficiency. In *The Measurement of Productive Efficiency: Techniques and Applications*. New York: Oxford University Press.
Lei, J., Y. Chen, J. Jia, and K. Liu. 2017. Public expenditure interactions of Chinese local governments: A simultaneous equations network approach. *Emerging Markets Finance and Trade* 53 (9):1943–1960.
Li, X., X. Lu, and Z. Zhu. 2008. International trade, technological progress and productivity growth of Chinese industries. *China Economic Quarterly* 7 (2):549.
Lin, J. Y. 1992. Rural reforms and agricultural growth in China. *American Economic Review* 82 (1):34–51.
Liu, S. W., P. Y. Zhang, X. L. He, and L. Jing. 2015. Efficiency change in north-east China agricultural sector: A DEA approach. *Agricultural Economics* 61 (11):522–32.
Liu, X., and X. Xin. 2011. Why has China's trade grown so fast? A demand-side perspective. *Emerging Markets Finance and Trade* 47 (1):90–100. doi:10.2753/REE1540-496X470105.
Lucas, R. E. 1988. On the mechanics of economic development. *Journal of Monetary Economics* 22 (1):3–42. doi:10.1016/0304-3932(88)90168-7.
Luo, Y., C. Zhang, and Y. Zhu. 2016. Openness and financial development in China: The political economy of financial resources distribution. *Emerging Markets Finance and Trade* 52 (9):2115–27. doi:10.1080/1540496X.2016.1186451.
Madsen, J. B. 2009. Trade barriers, openness, and economic growth. *Southern Economic Journal* 76 (2):397–418. doi:10.4284/sej.2009.76.2.397.
Marelli, E., and M. Signorelli. 2011. China and India: Openness, trade and effects on economic growth. *The European Journal of Comparative Economics* 8 (1):129.
Matzkin, R. L. 1991. Semiparametric estimation of monotone and concave utility functions for polychotomous choice models. *Econometrica* 59 (5):1315–27. doi:10.2307/2938369.
Matzkin, R. L. 1992. Nonparametric and distribution-free estimation of the binary threshold crossing and the binary choice models. *Econometrica* 60 (2):239–70. doi:10.2307/2951596.
Matzkin, R. L. 1993. Nonparametric identification and estimation of polychotomous choice models. *Journal of Econometrics* 58 (1–2):137–68. doi:10.1016/0304-4076(93)90116-M.
Mcmillan, J., J. Whalley, and L. Zhu. 1989. The impact of China's economic reforms on agricultural productivity growth. *Journal of Political Economy* 97 (4):781–807. doi:10.1086/261628.
Meeusen, W., and J. Van den Broeck. 1977. Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review* 18 (2):435–44. doi:10.2307/2525757.
Miller, S. M., and M. P. Upadhyay. 2000. The effects of openness, trade orientation, and human capital on total factor productivity. *Journal of Development Economics* 63 (2):399–423. doi:10.1016/S0304-3878(00)00112-7.
Nee, V., and S. Sijin. 1990. Institutional change and economic growth in China: The view from the villages. *The Journal of Asian Studies* 49 (1):3–25. doi:10.2307/2058430.
Nicholson, W., and C. Snyder. 2011. *Microeconomic theory: Basic principles and extensions*, 11th ed. 44 (4):370–72. Mason, OH, USA: Cengage Learn.
Pya, N., and S. N. Wood. 2015. Shape constrained additive models. *Statistics and Computing* 25 (3):543–59. doi:10.1007/s11222-013-9448-7.
Ramsay, J. 1998. Estimating smooth monotone functions. *Journal of the Royal Statistical Society. Series B, Statistical Methodology* 365–75. doi:10.1111/1467-9868.00130.

Ramsay, J. O. 1988. Monotone regression splines in action. *Statistical Science* 3 (4):425–41. doi:10.1214/ss/1177012761.
Rivera-Batiz, L. A., and P. M. Romer. 1991. Economic integration and endogenous growth. *The Quarterly Journal of Economics* 106 (2):531–55. doi:10.2307/2937946.
Romer, P. M. 1986. Increasing returns and long-run growth. *Journal of Political Economy* 94 (5):1002–37. doi:10.1086/261420.
Romer, P. M. 1990. Endogenous technological change. *Journal of Political Economy* 98 (5, Part 2):S71–S102. doi:10.1086/261725.
Schmidt, P., and R. C. Sickles. 1984. Production frontiers and panel data. *Journal of Business and Economic Statistics* 2 (4):367–74.
Shi, Y., and T.-F. Zhao. 2009. Analysis on influencing factors of total factor productivity of agriculture [j]. *Journal of Huazhong Agricultural University (Social Science Edition)* 2:005.
Sickles, R. C. 2005. Panel estimators and the identification of firm-specific efficiency levels in parametric, semiparametric and nonparametric settings. *Journal of Econometrics* 126 (2):305–34. doi:10.1016/j.jeconom.2004.05.004.
Stevenson, R. E. 1980. Likelihood functions for generalized stochastic frontier estimation. *Journal of Econometrics* 13 (1):57–66. doi:10.1016/0304-4076(80)90042-1.
Thompson, H. 2011. *International economics: Global markets and competition*, 3rd ed. River Edge, NJ, USA: Social Science Electronic Publishing:i.
Topalova, P., and A. Khandelwal. 2011. Trade liberalization and firm productivity: The case of India. *Review of Economics and Statistics* 93 (3):995–1009. doi:10.1162/REST_a_00095.
Wang, J., W. Song, and X. Han. 2010. Spatial analysis of agriculutral total factor productivity and its influencing factors in China: Based on the provincial panel data in 1992-2007. *Chinese Rural Economy* 8:24–35.
Wen, G. J. 1993. Total factor productivity change in China's farming sector: 1952-1989. *Economic Development and Cultural Change* 42 (1):1–41. doi:10.1086/452063.
Wu, X., and R. Sickles. 2017. Semiparametric estimation under shape constraints (forthcoming). *Econometrics and Statistics*. doi:10.1016/j.ecosta.2017.06.001.
Yatchew, A., and L. Bos. 1997. Nonparametric regression and testing in economic models. *Journal of Quantitative Economics* 13:81–131.
Zhang, Y., and B. Brümmer. 2011. Productivity change and the effects of policy reform in China's agriculture since 1979. *Asian-Pacific Economic Literature* 25 (2):131–50. doi:10.1111/apel.2011.25.issue-2.
Zhou, L. I., and H. P. Zhang. 2013. Productivity growth in China's agriculture during 1985–2010. *Journal of Integrative Agriculture* 12 (10):1896–904. doi:10.1016/S2095-3119(13)60598-5.

Appendix: Public Expenditure and Perpetual Inventory Method

This article uses "government's expenditure on agriculture, forestry, and water affairs" as the public expenditure flows data. According to the Ministry of Finance of the People's Republic of China, this expenditure includes agricultural expenditure, forestry expenditure, water conservancy expenditure, expenditure of the south-to-north water transfer, poverty alleviation expenditure, agricultural comprehensive development expenditure, and other agricultural and forestry water affairs expenditures. In 2010, these seven categories accounted for 55.7%, 7.3%, 15.1%, 17.2%, 1.1%, 2.6%, and 1.0%, respectively. The expenditures finance the production activities, update the rural infrastructure, improve service provision, boost technical and marketing expertise, and enhance education and health care, all of which have positive effects on production (Dong 2000).

The perpetual inventory method (PIM) is the most widely employed approach to convert investment from flows data to stocks data in many statistical offices (Gong 2016, 2017). In the spirit of De La Fuente and Doménech (2006), Berlemann and Wesselhöft (2014) combine three PIMs into a unified approach in order to prevent the drawbacks of the various methods. The PIM interprets investment stock as an inventory of investment flows. The aggregate stock falls at the depreciation rate per period. Therefore, the stock of public expenditure in period t is a weight sum of the history of the public expenditure flows: $Finance_t = \sum_{i=0}^{\infty} (1-\delta)^i \cdot I_{t-(i+1)}$, where $Finance$ is the stock in public expenditure, I is the annual flows in public expenditure, and δ is the depreciation rate.

This article collects annual flows in public expenditure from 1978 to 2015. Since the expenditure in 1978 is very small, we assume zero public expenditure before 1978. This assumption has a negligible effect on public expenditure stock estimation, as public expenditures before 1978, if not equal to zero, are close to zero following more than two decades of depreciation. Moreover, this article adopts a depreciation rate of 5.6% in Chen (2014) to estimate expenditure stocks $Finance_t$.