Technical Efficiency and Its Determinants in China's Hog Production[1,2]

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Abstract: China's hog production is undergoing a great transformation due to the soaring demand and changing raising system. Regarding the essential role of pork in Chinese diet, a systematic analysis on the productivity and efficiency of hog production can provide significant implications for policy makers. This paper investigates the productivity and efficiency of hog production and determinants of technical efficiency in China using a household level panel data (2004-2010). A stochastic frontier translog production function with scaling property in inefficiency term is adopted for hog production analysis, and the determinants of technical efficiency are incorporated in a one-step estimation using maximum likelihood estimation. Our results show that the average technical efficiency of hog production in China is 0.5914. More importantly, we find that specialized farmers have higher technical efficiency than others, and technical efficiency in the eastern region is higher than that in central and west China.

Key words: Technical efficiency, Hog production, China

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1. INTRODUCTION

Meat consumption, particularly pork consumption, has been growing substantially along with the rapid economic development. As part of nutrition transition, traditional Chinese diet which is high in vegetable and staple food is switching to a western diet characterized by intensive meat and dairy products (Ma *et al*. 2004; Rae *et al*. 2006; Tian and Yu 2013; Xiao *et al*. 2012; Yu 2012; Yu and Abler 2009, 2014). Even though subject to substantial measurement errors (Yu and Abler 2014), the household surveys of the National Bureau of Statistics of China (NBSC) still show that per capita pork purchased by urban households increased substantially from 18.46 kg in 1990 to 21.23 kg in 2012, and the per capita consumption in rural area increased from 10.54 kg to 14.40 kg during the same period, an increase of 36.62%. At the same time, China also experienced a rapid urbanization that the urban population increased from 301.95 million in 1990 to 711.82 million in 2012. The high economic growth rates and rapid urbanization inevitably boost the demand for pork, and hence offer great opportunities as well as challenges for the hog industry. On the one hand, pork output increased substantially with an annual growth rate of 5.9% in 1990s and 2.2% in 2000s (Xiao *et al*. 2012). By 2012, total pork output in China had reached 53.43 million metric tons, accounting for almost half of the world output. On the other hand, China's hog sector undertook a dramatic structural evolution characterized by an increasing role of larger and more commercial and intensive production systems in the past three decades (Ma *et al*. 2011; Somwaru *et al*. 2003; Yu and Abler 2014). According to the China Agricultural Yearbooks, backyard hog production[3] once accounted for 91% of total output in 1980, but the share declined to 38.67% in 2009. Meanwhile, the share of specialized households[4] and commercial enterprises[5] rose from less than 9% in 1980 to 61.33% in 2009 (Chen and Rozelle 2003; Qiao *et al*. 2011; Somwaru *et al*. 2003; Xiao *et al*. 2012; Rae *et al*. 2006). However, hog farm size in China is still generally small and a large number of hog farms still follow the traditional way of feeding with intensive labor input and using agricultural and household waste such as crop straw and table left-over (Hu 2004; Xiao *et al*. 2012), which results in a low technological level and production efficiency (MOA 2006). Yu and Abler 2014 claim that feed conversion coefficient in small hog farms in China is around 3.5, which is comparable to those in developed countries such as U.S. (3.54 for farrow-to-finish farm according

[3] Backyard farming refers to households breeding a small number of hogs, usually from 3 to 5 heads by traditional farming yearly, as a sideline of family business. After the 1990s backyard farming is defined as the annual hog slaughter below 50 heads by per household or farm (Xiao et al., 2012).

[4] Specialized households denote farms where most members of the family engaged in hog production. They raised the number of hog from the original ten or scores heads to hundreds or even thousands presently. It was characterized by specialized farming (Xiao et al., 2012).

[5] Commercial enterprises refers to market-oriented large scale hog farms which adopt advanced technology and management with thousands or ten thousands hogs per farm (Xiao et al., 2012).

to the estimation of Key and McBride). The similar feed conversion coefficients in China and the U.S., however, does not mean that China's hog production is as efficient as that in the U.S. since more labor input is required in China to reach such a conversion coefficient. The China Agricultural Product Cost-Benefit Compilation indicates that the average labor input per head in small and scale hog farms in China are 11.06 and 3.55 person days (8 hours per day) respectively in 2004, while that in the U.S. is only around 1 hour according to the estimation of Key and McBride (2007). Moreover, the low efficiency of China's hog industry can also be reflected from the low carcass weight and litter size. The China Animal Agriculture Association (CAAA) claims that carcass weight of pig in China is only 82.67% of that in U.S. and 84.31% of that in Canada in 2010, and the litter size in China is only 60% of that in the U.S.. Furthermore, labor cost and feed prices have soared up in recent years. Xiao *et al*. (2012) denote that real labor cost per hog slaughtered doubled in large hog farms between 2000 and 2010, similarly, feed input cost increased by 46.8% between 2005 and 2010. The rising wage and feed prices could affect the hog farmer input behaviors and therefore change technology (Ma *et al*. 2011). In addition, increasing competition from international market also challenged domestic hog producers. Yu and Abler (2014) show that China was a net pork exporter and its imports were very small before 1999. However, imports increased significantly after 1999 and overnumbered exports during 2008-2010.

Regarding the importance of hog sector and the challenges faced by hog production, a number of studies investigate China's hog productivity and production efficiency. For instance, Zhou (1999) adopts a translog production function to analyze the hog production efficiency of specialized households and backyard household in China during the period from 1993 to 1996. He finds that specialized farms are more efficient in labor input while backyard farms are advanced in using concentrated feed. Somwaru *et al.* (2003) parametrically estimate the overall efficiency and scale elasticity of 2500 surveyed hog farms in China, and indicate that the large commercialized farms are the most efficient but the middle size specialized farms with increasing returns to scale production technology are the most profitable. Rae *et al.* (2006) calculate the total factor productivity of pork production in China during the 1980s and 1990s and decompose it into technical efficiency and technology change. Their results show that technology change is the major contributor to TFP growth while technical efficiency improvement is relatively slow, especially in specialized and commercial hog producers. Similarly, Jin *et al*. (2010) also find that TFP growth in hog production during 1985-2004 was mainly driven by technology change and technical efficiency was quite low, particularly for specialized and commercial farms. On the contrary, Wang and Li (2011) estimate the technical efficiency for 15 main hog producing areas and find a rather high technical efficiency during 2002 and 2009, which stayed between 0.862 and 0.866. Chen *et al.*

(2008) estimate the technology changes and technical efficiency changes for backyard hog farms in twenty provinces from 1991 to 2005 using DEA methods, and find that hog production efficiency fluctuated and technology change was the major restricting factor for productivity growth. Using the same method, Yan *et al*. (2012) find that the increase in hog productivity in China during 2002-2010 was mainly attributed to input expansion, while technical efficiency improvement also played an important role. Zhang *et al*. (2012) compare the hog productivity between Shandong province and the whole China, and find that large farms have the highest technical efficiency in Shandong province. Furthermore, Xiao *et al*. (2012) use stochastic frontier production functions and the Malmquist index to measure TFP in China's hog industry and decompose it into technical efficiency, technological progress, scale efficiency, and allocative efficiency using data of 25 provinces from 1980 to 2008. They find that the TFP of hog production increased by 64.3% during this period, and improvements in allocative efficiency and scale efficiency played a key role, while technical efficiency and technical progress only changed little. Table 1 presents a brief summary of these empirical studies on technical efficiency of China's hog production.

[Table 1]

The literature review outlined above suggests extensive studies on hog productivity and production efficiency. However, there are at least three shortcomings in current literatures. First, most of the literature use macro-level data such as official agricultural statistics to estimate productivity and efficiency. A number of researchers (Fuller *et al*. 2000; Lu 1998; Ma *et al*. 2004; Yu and Abler 2014) claim that the official statistics in hog production are subject to major inconsistencies such as over-reporting in production and underestimation of inputs not bought from market, which implies that productivity and efficiency estimation based on macro-data might be misleading. Moreover, technical efficiency could be partially attributed to household heterogeneity such as management ability, which cannot be controlled in macro-level data. Second, current literatures mainly focus on estimating productivity (such as TFP) and decomposing it into technical progress and technical efficiency change, but the determinants of technical efficiency is unfortunately ignored. Technical efficiency is different from productivity and current literature already shows a great heterogeneity in technical efficiency over different regions, years and scales (e.g., Rae *et al*. 2006; Xiao *et al*. 2012; Zhang *et al*. 2012). Hence improving technical efficiency can play a significant role in hog production growth in light of the difficulty in technical progress. Moreover, technical efficiency is also associated with profit and market competitiveness, a systematic analysis on technical efficiency thus can provide meaningful suggestions for maximize hog production under given technology and input constraints, and contribute to the transformation of China's hog industry. Third, estimation of technical efficiency is sensitive to the assumption on inefficiency term and the estimation method used by researchers (Wang and Schmidt 2002; Kumbhakar et al. 2014). For instance, Rae et al. (2006) and Wang and Li (2011) both use the method proposed by Battese and Coelli (1995) which assumes that variance of inefficiency term is constant (Wang and Schmidt 2002; Wang and Ho 2010). This is a very strong assumption and has been relaxed in recent developed models such as the one developed by Wang and Schmidt (2002) with scaling property. Therefore, in this study, we will shed some light on technical efficiency of hog production using a household survey data. Moreover, we will also investigate the determinants of technical efficiency in hog production. In order to correctly estimate the inefficiency, we adopt the model proposed by Wang and Schmidt (2002) which decomposes the inefficiency term into an individual effect and a positive function consisted of exogenous inefficiency determinants. This specification has numbers of advantages over other models and is commonly proved to be reliable (e.g., Kumbhakar and Lovell 2000; Wang and Ho 2012; Belotti et al. 2013). Our study fills the gap in the current literature and provides several implications for China's hog production.

The rest of this paper is organized as follows: the next section is the theoretical framework and the empirical model; section three describes the data and section four presents the empirical results, followed by the discussion; and the last section concludes with main findings of this study.

2. METHODOLOGY AND EMPIRICAL MODEL

2.1. Stochastic Frontier Model for Panel Data

Since the pioneering work of Aigner *et al*. (1977) and Meeusen and van den Broeck (1977), stochastic frontier production function has been considerably extended in a number of researches (e.g., Pitt and Lee 1981; Kalirajan 1981; Kumbhakar *et al*. 1991; Reifschneider and Stevenson 1991; Huang and Liu 1994; Battese and Coelli 1988, 1992, 1995; Greene 1993, 2005, 2008; Wang 2002; Wang and Schmidt 2002; Wang and Ho 2010; Kumbhakar and Tsionas 2011; Kumbhakar *et al.* 2014). It has become one of the most widely used methods to analyze productivity and efficiency (Latruffe *et al*. 2004). Compared with the Data Envelopment Analysis which is flexible in production function form, but very sensitive to measurement errors, the stochastic frontier analysis provides a specific function form, and yields a more reliable result when there are large measurement errors.

Simar et al. (1994), and Wang and Schmidt (2002) proposed a simple stochastic frontier production function with scaling property, which has numbers of attractive features and is commonly recommended by current literature (e.g., Kumbhakar and Lovell 2000; Belotti *et al.* 2013; Wang and Ho 2012). This study also adopts this model. The basic model can be described as follows:

Equation: $\ln Y_{it} = \ln f(X_{it};\beta) + V_{it} - U_{it}$ (1)

Here Y_{it} denotes the real production for individual i at time t and $f(X_{it};\beta)$ refers to the production potential (completely efficient), X_{it} is the inputs of production and other explanatory variables and β is the corresponding unknown parameters; V_{it} is the idiosyncratic term which is assumed to be independent and identically distributed (iid) with $N(0,\sigma_v^2)$, and is independent of X_{it} and U_{it}. U_{it} is the non-negative random variables accounting for inefficiency, which depends on some exogenous variables $U_{it} = u(Z_{it},\delta) \geq 0$.

Following Simar et al. (1994), Wang and Schmidt (2002) and Wang and Ho (2010), we assume that the inefficiency U_{it} can be decomposed into two components:

Equation: $u(Z_{it},\delta) = h(Z_{it},\delta)u^*$ (2)

Where Z_{it} is a vector of the explanatory variables associated with technical inefficiency of production, and δ is the corresponding coefficient vector. The $h(Z_{it},\delta)$ is called the scaling function and the u^* has a distribution that does not depend on Z_{it}, which is called the basic distribution. Using this specification of U_{it} can generate several attractive features: first, the shape of the distribution of U_{it} is the same for all farmers, but their mean inefficiencies differ (Wang and Schmidt 2002; Alvarez *et al.* 2006); second, the effect of Z_{it} on inefficiency can be easily generated without any assumption about the basic distribution; third, the parameters in production function and inefficiency function can be estimated without having to specify the basic distribution (Simar *et al.* 1994; Wang and Schmidt 2002; Alvarez *et al.* 2006). Compared with the model developed by Battese and Coelli (1995) which assumes $U_{it} \sim N^+(Z_{it}^{'}\delta,\sigma_u^2)$, this specification is more flexible since it relaxes the identical distribution assumption. Wang and Schmidt (2002) further show that if $u^* \sim N^+(\tau,\sigma_u^2)$, then $U_{it} \sim N^+(\tau h(Z_{it},\delta),\sigma_u^2 h(Z_{it},\delta)^2)$.

The technical inefficiency of production for the i-th individual at time t can be calculated as:

Equation: $TE_{it} = \dfrac{Y_{it}}{f(X_{it};\beta)} = \exp(-U_{it})$ (3)

Where TE_{it} has a value between 0 and 1, with 1 referring to the unobserved frontier. In practice, only $\varepsilon_{it} = V_{it} - U_{it}$ will be observed, Jondrow *et al.* (1982) and Battese and Coelli (1988) propose two different approach to calculate the inefficiency term U_{it} respectively.

To estimate the parameter, Pitt and Lee (1981) and Kalirajan (1981) have proposed a two-step approach, in which the first stage predicts the inefficiency after the specification and estimation of the stochastic frontier function, and the second step conducts a regression model for the predicted inefficiency. This method, however, is found to contradict the distribution assumption of the inefficiency effects in the stochastic frontier and suffer from missing variables bias in the first step (Battese and Coelli 1995; Wang and Schmidt 2002; Latruffe *et al*. 2004). Therefore, Kumbhakar and Lovell (2000) and Wang and Schmidt (2002) have provided Nonlinear least squares estimation (NLSE) and maximum likelihood estimation (MLE) approach to simultaneously estimate the parameters in the stochastic frontier and the inefficiency model. In this study we thus adopted the MLE method developed by Wang and Schmidt (2002). .

2.2 Empirical Model

The specification of production function is critical in productivity and efficiency analysis. In this study we follow the suggestion in current literature (Kumbhakar 2000; Wang and schmidt 2002; Alvarez *et al.* 2006; Rae *et al*. 2006; Jin *et al*. 2010; Wang and Ho 2010) and adopt the translog production function, which is a very flexible functional form and is a second-order approximation of any production technology. Moreover, this model permits the estimation of both technical change in the stochastic frontier and time-varying technical inefficiencies with scaling property (Wang and Schmidt 2002; Wang and Ho 2010).

Equation:

$$\ln Y_{it} = \beta_0 + \sum_j \beta_j \ln x_{jit} + \beta_t T + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} + \frac{1}{2}\beta_{tt} T^2 + \sum_j \beta_{jt} T \ln x_{jit} - U_{it} + V_{it} \tag{4}$$

Where $\ln$ denotes the natural logarithm, i indexes the individuals, which is farmers in our case, and t indexes the annual observations over time; Y_{it} is the total output of pork measured in kilogram in the past year; x_{jit} 's are the three major inputs, including labor devoted to hog production, feed, and capital inputs such as cost of young seedlings, discount of fixed assets, cost for preventing epidemic diseases and other management cost; T is a time trend to capture the trends in productivity change, V_{it} is the independent and identically distributed random variable, and U_{it} is the time-varying inefficiency term which can be defined as follows:

$$\text{Equation:}\quad \begin{aligned} U_{it} &= \mathrm{h}_{\mathrm{it}} * \mathrm{u}_i^* \\ \mathrm{h}_{\mathrm{it}} &= f(Z_{it}^{'}\delta) \\ \mathrm{u}_i^* &\sim N^+(\tau, \sigma_u^2) \end{aligned} \qquad (5)$$

Where $Z_{it}^{'}$ includes all factors that might affect the production efficiency. Following the current literature (e.g. Sharma *et al*. 1999; Wadun and White 2000; Wilson *et al*. 2001; Coelli *et al*. 2002; Wang 2002; Wang and Schmidt 2002; Alvarez *et al.* 2006; Wang and Ho 2010), production inefficiency can be attributed to three factors: household characteristics, environmental factors, and management factors such as specialization. Therefore, we use the gender, age, education, agricultural training and health status of household head to measure household characteristics; the environmental factors and other unobservable regional heterogeneity are controlled by regional dummies; specialization of pork production (measured by a dummy variable to identify whether raising hog is the main income source of the family or not) is used to proxy management factors. In addition, we also include the three classic inputs used in the production function to test whether they also affect the production efficiency. In order to capture the change of inefficiency over time, a time variable is also included in the inefficiency model.

3. DATA

We use the National Fixed Point Survey data in rural China conducted by the Research Center for Rural Economy (RCRE), a research institute affiliated to the Ministry of Agriculture of the People's Republic of China. The survey is conducted every year since 1986, which includes more than 20000 households selected from 360 villages that randomly distributed in 31 provinces (municipalities). However, the questionnaire changed several times and the information collected might be inconsistent. Therefore, we only use the data from 2004 (a new questionnaire is adopted) to 2010 (the latest data published). Moreover, our study focuses on production efficiency of hog production, thus we only select samples that are involved in hog production. After excluding samples with incomplete information and outliers[6], 19809 samples are finally used in empirical studies.

Table 2 presents the descriptive analysis of the variables used in our study. The average hog production is 567.92 kilograms, around 5 hogs per household since the average weight of hog is around 110 kilograms in China according to the <China Agricultural Product Cost-Benefit Compilation> issued by the National Development and Reform Commission (NDRC). The figure

[6] Observations with production less than 50 kg (less than 1 small pig) are excluded from the sample since these values are likely to be mis-reported. In addition, we also drop obsertions whose production is less or 7 times higher than feed input (implying feed-meat conversion ratio is more than 1 or less than 7).

indicates that backyard hog production is still the main production type in rural China. However, it must be explained with caution since the survey does not cover commercial pork producers. Hence our analysis is only applicable to non-commercial hog producers. Labor input is measured by person-days spent on hog production. Capital input refers to all capital inputs except for feed, which includes management cost, piglet cost, medical quarantine fees, depreciation of fixed assets and other cost (water, electricity); feed input includes all feeds used in hog production such as concentrated feed, residual feed and silage. The average inputs of these three factors are 96.43 person-day, 1321.98 Yuan and 1978.79 kilograms respectively. The summarization of household characteristics and other control variables are also shown in the table. Age, edu, gender, training and health represent the age, year of formal education, gender, agricultural training and self-reported health status of household head respectively. Husbandry is used to measure the specialization of hog production, which is 1 if hog production is the main income source of the family. Scale stands for the size of hog production in terms of total quantity of output. East and west are two regional dummies. In order to show the changes in output and inputs over time, we also present the yearly means of these variables in the Appendix.

[Table 2]

4. EMPIRICAL RESULTS

4.1. Model Specification Test

We first present the model specification test for production frontier function and inefficiency function. The results are reported in Table 3.

[Table 3]

The first hypothesis is testing the model specification of the production frontier function, that whether the production function can be reduced from a translog production function to a Cobb-Douglass production function. The null hypothesis means that coefficients of all second-order variables in the translog model are zero, indicating that the Cobb-Douglas function can well represent the data, which is however strongly rejected at 1% confidential level. Therefore we prefer the translog production function.

The rest hypothesizes (2-5) are for testing whether the inefficiency effects are absent or that they have simple specification. The second null hypothesis (2) states that the inefficiency effects are absent from the model, which is strongly rejected, implying that the inefficiency effects are highly significant in the analysis of the pork production. The third test denotes that the classic inputs (labor, capital and feed) have no effect on technical inefficiency of individuals. However, it is also rejected, meaning that the three classic inputs affect the technical inefficiency significantly as well. The hypothesis (4) is for testing the regional effect on technical inefficiency, which is also strongly rejected, implying that technical inefficiency varies across regions. The last null hypothesis assumes that the technical inefficiency is time-invariant. After controlling other covariates, our result shows that time is not statistically significant, implying the technical inefficiency does not change significantly over time.

4.2. Stochastic Frontier Function

The empirical results of the stochastic frontier function estimated by maximum likelihood estimation are presented in Table 4. The overall fitness of the model is guaranteed by the log-likelihood tests. The share of variance from inefficiency in total variance is 87.5%, indicating the inefficiency effects are likely to be highly significant in the analysis of the hog production, which is also consistent with the aforementioned model specification test (2).

[Table 4]

We find that most variables are statistically significant. In order to explain the effect of input on output more intrinsically, we calculate the partial elasticity in terms of sample means according to equation 6.

Equation: $$\varepsilon_{kt} = \frac{\partial \ln Y_{it}}{\partial \ln x_{kit}} = \beta_k + \sum_{j \neq k} \beta_{jk} \ln x_{jit} + \beta_{kk} \ln x_{kit} + \beta_{kt} T \qquad (6)$$

The results are reported in Table 5. The average elasticities of labor, capital and feed with respect to output during the whole period are 0.11, 0.42 and 0.40 respectively, implying a 1% increase in labor will increase output by 0.11%, while the same increase in capital and feed will increase output by 0.42% and 0.40% respectively. We also calculate the factor elasticity for each year. Results indicate that labor elasticity is declining over time and even turned negative after 2009, while capital elasticity is increasing, indicating labor is over-used in hog production. In general, feed and capital inputs are the main contributors to hog production, which is consistent with the fact that China is transforming from the traditional way of husbandry characterized by intensive labor input to a modern way of highly depending on feed and capital inputs. The finding that capital and feed play the prominent role in production is also consistent with current literature (e.g., Xiao *et al*. 2012; Wang and Li 2012).

Moreover, in order to show the return to scale in hog production, we calculate the scale efficiency by adding up all input elasticities of output.

Equation: $SE_t = \sum_{k=1}^{3} \varepsilon_{kt}$ (7)

Our results show that the return to scale is declining over time. In 2004 the scale elasticity was slightly higher than 1, while after that it declined significantly to 0.7626 in 2010, indicating a decreasing return to scale. Two possible reasons can be presented: first, underestimation of inputs that are not bought from market such as own labor inputs and homemade feed has significantly declined due to the improving survey method and changing raising system (shifting from backyard to specialized farms), thus the scale elasticities in the early years are overestimated while the bias is declining over time; second, over use of inputs in hog farming became more serious in recent years, which can be reflected by the soaring cost in hog production.

[Table 5]

The technology change can be estimated by differentiating the production function with respect to time, which can be expressed as follows:

Equation: $TC_{it} = \beta_t + \beta_{tt} T + \sum_j \beta_{jt} \ln x_{jit}$ (8)

Following Kumbhakar and Lovell (2000), Key and McBride (2007) and Xiao et al. (2012), we combine the stochastic frontier production function with an output-oriented Malmquist index to decompose the TFP into technology change (TC), technical efficiency change (EC), and scale efficiency change (SC)[7].

The technology change between time t and s can be calculated by taking the average technology change during these period.

Equation: $TC_i^{ts} = \beta_t + \beta_{tt}(T+S) + \frac{1}{2}\sum_j \beta_{jt}(\ln x_{jit} + \ln x_{jis})$ (9)

The technical efficiency change is calculated as $EC_i^{ts} = \frac{EC_i^t - EC_i^s}{EC_i^s}$, and the scale efficiency change is estimated using the following function:

[7] Since the price information is unavailable, the allocative inefficiency cannot be calculated. Thus we assume perfect allocative efficiency

Equation: $SC_i^{ts} = \frac{1}{2}\sum_{k=1}^{3}\left[\frac{SE_t - 1}{SE_t}\varepsilon_{kt} + \frac{SE_s - 1}{SE_s}\varepsilon_{ks}\right]\ln\left(\frac{x_{kit}}{x_{kis}}\right)$ (10)

Kumbhakar and Lovell (2000) proved that the growth rate of TFP is the sum of the growth rates of these three components $\Delta TFP_i^{ts} = TC_i^{ts} + EC_i^{ts} + SC_i^{ts}$. Table 6 reports the TFP growth rate and its components. We find that technology change is always negative while scale efficiency and technical efficiency change turn positive since 2008, implying an increasing efficiency. The TFP growth rate, however, is negative in all years. During the whole period (2004-2010), TFP declined by 20.60%, which is mainly attributed to the negative technology change. The technical efficiency and scale efficiency did not make any progress during this period neither, both of them deteriorated but the change is marginal. Our results are contrary to the findings in Xiao et al. (2012) who use macro-level data and find rather large TFP growth rate during 1980-2008. The difference might be caused by the more serious over-reporting in production and underestimation in inputs such as own labor input and feed input which is not bought from the market in macro-level data.

[Table 6]

5. DISCUSSION

5.1. Technical Efficiency

The main object of this study is to estimate the technical efficiency of hog production in China. Hence we calculate the technical efficiency for each hog farm using the conditional expectation approach proposed by Jondrow et al. (1982). We first take a look at the variation of technical efficiency across regions and over time, which is shown in Fig. 1. Results show that technical efficiency in east China is higher than that in western and central China, and the gap of technical efficiency between east and other regions is around 0.04 and is almost constant over time. The mean technical efficiency in east China is 0.6202, while that of west and central China are 0.5832 and 0.5851 respectively. In addition, Fig. 1 also shows that technical efficiency is fluctuating over time but no clear trend can be found, implying no significant improvement in technical efficiency in China's hog production. The average technical efficiency during the whole period is 0.5914, which means that there is still a great potential to improve the technical efficiency in hog production. Moreover, our estimation is much lower than that estimated in previous studies (e.g., Rae et al. 2006; Wang and Li 2011; Zhang et al. 2012; Xiao et al. 2012). All of these studies suggest the technical efficiency in China's hog production is higher than 0.75. The inconsistency between our results and previous studies can be attributed to the different data sources that all aforementioned studies use macro data published by the government while we use household survey data. Thus the high technical efficiency in their study might be caused by the over-reporting in production and underestimation of inputs such as own labor input and feed which are not bought from the market (e.g., residual feed, silage), particularly for small farms whose own input is more likely to be ignored by the government. Another reason might be that macro-data smoothed the individual variation in input and output, which might also bias the estimated efficiency upward. In addition, since the household survey data used in our study mainly cover small farmers while macro data consists hog producer with all scales, thus if large scale farms are more efficient, our study will have lower estimation than previous studies.

[Figure 1]

Further, we also calculate the distribution range of technical efficiency for the whole sample and three regions respectively. The results are reported in Table 7. We find that almost 85% households have technical efficiency score below 0.7, particularly, 20.11% of the households have a score lower than 0.5, implying a great potential to improve the production efficiency in pork industry. In addition, we also find that the eastern China has a larger share of farms with high technical efficiency scores, which confirms the regional difference presented in Fig. 1.

[Table 7]

Finally, we rank households according to the scale of production and calculate the mean technical efficiency for each group in Table 8. However, no evidence shows that technical efficiency is associated with production scale. The value did find that backyard farm has highest efficiency score. This result, however, should be explained with caution since large scale farms only accounts for a small share of total observations. In particular, large farms whose total output is more than 100000 kilograms of pork in the past year are almost absent in this survey. Therefore, no clear conclusion of the impact of scale on hog production can be made from our results.

[Table 8]

5.2. Determinants of Technical Inefficiency

To further find out the determinants for the variation of hog farm's technical efficiency, we also conduct a technical efficiency function. The results are reported in the right part of Table 4. One thing we need to mention is that the dependent variable in the technical efficiency model is the scaling function $h(Z_{it},\delta)$, thus the parameter in the inefficiency function can be expressed as $\delta = {\partial \ln[u(Z_{it},\delta)]}/{\partial Z_{it}}$ in our specification with scaling property. Therefore, a negative parameter indicates a positive effect on technical efficiency.

The three classic inputs all are statistically significant. Labor and capital have positive coefficients while feed's coefficient is negative. The results are somehow surprising but are consistent with the aforementioned decreasing return to scale, indicating that labor and capital are over-used in hog production, thus increasing labor and capital input will lower the technical efficiency. The characteristics of household head significantly affect production efficiency. In particular, Age has negative coefficient, implying that older people are more efficient, consistent with the common sense and our expectation that older farmer might have more experience; gender of household head is positive, meaning female is more efficient than male, which coincides with the fact that hog production is mainly conducted by female in rural China. Self-reported health status has a positive impact on technical inefficiency which might be because health people usually have other jobs and they are not fully involved in hog farming. The role of education and training in improving agricultural productivity and efficiency has been noted by previous studies (e.g., Begum *et al*. 2010), and our study confirms that education did contribute to the efficiency improvement in pork production. However, agricultural training has negative impact on technical efficiency, this result need further investigation. We also find that specialized farms are more efficient, which are denoted by the negative coefficients of husbandry, indicating that production efficiency can be improved by specialization, which is consistent with the findings of Somwaru *et al*. (2003) and Zhang *et al*. (2012). Finally, we find production efficiency of pork varies across regions, and the eastern area has higher efficiency than the central and western areas of China, which is consistent with findings in Figure 1. The time variable, however, is not statistically significant, implying no significant time trend for production efficiency.

6. CONCLUSION

China's hog sector is undergoing a rapid structural change from backyard production to larger and more commercial and intensive production system due to the increasing demand and changing technology. Regarding the importance of hog sector in China's agriculture, studies have been conducted on the hog productivity and production efficiency. However, current literature mainly focuses on productivity estimation and decomposition using macro-level data, technical efficiency and its determinants do not arouse much attention. In addition, the econometric models used in previous studies have some strong assumptions that are not realistic. Regarding the inconsistency in macro-level data and the great heterogeneity in technical efficiency in hog production in different regions, years and farms, this paper shed some light on the technical efficiency of China's hog production. We adopt the stochastic frontier production function with scaling property in inefficiency term to analyze the hog productivity and incorporate the determinants of technical efficiency in the one-step estimation using maximum likelihood estimation. We use 7 rounds (2004-2010) fixed-point survey data in rural China. Our finding indicates that the average technical efficiency of hog production in China is 0.5914. Particularly, the technical efficiency in eastern China is much higher than that in western and central China, and specialized farms are more efficient than others. We also find that old people and female are more efficient in hog production, and the role of education in improving technical efficiency is also confirmed in our study. However, we do not find significant evidence that technical efficiency changed over time. In addition, we also estimate the TFP growth rate of hog production using the output-oriented Malmquist index. The TFP is found to decline by 20.60% during this period, which is mainly caused by the negative technology change, whereas, we find a little improvement in the scale efficiency and technical efficiency after 2008, but during the whole period they do not change significantly.

Our study thus implies that the technical efficiency of hog production in China can be improved by 40%, which can be realized by specialization, education, as well as technical spillover from eastern to western and central China. Our results also suggest that hog production can be promoted in several ways such as supporting specialized hog farms, providing specific training and education to hog farmers, and popularizing advanced feeding and management techniques.

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Table 1 Summary of current studies

Author	Method	Data	Time	Technical efficiency or its growth rate
Somwaru et al. (2003)	DEA	1996 national agricultural census and 1999 RCRE livestock survey	1996	TE: 0.24 on average
Rae et al. (2006)	SFA	Adjusted statistical data	1998-2001	TE: 0.88 (specialized hog farms); 0.79 (commercial farms); 0.91 (backyard farms).
Chen et al. (2008)	DEA	CAPCBC	1991-2005	EC: -0.71%~1.36% (backyard farm); -1.07% (large-scale farm)
Jin et al. (2010)	SFA	National Cost of Production Data Set	1990-2004	EC: -0.14%~1.26% (1980-1990); -0.72%~1.01% (1990-2003)
Wang and Li (2011)	SFA	CAPCBC	2002-2009	TE: 0.862~0.866 (backyard farm); 0.830~0.868 (large-scale farm)
Yan et al. (2012)	DEA	CAPCBC	2002-2010	EC: 1.45%~2.09%
Zhang et al. (2012)	DEA	CAPCBC	2000-2011	TE: 0.75~1
Xiao et al. (2012)	SFA	CAHY & CAPCBC	1980-2008	TE: 0.902~0.970

Notes: 1. TE and EC refer to technical efficiency and growth rate of technical efficiency respectively.

2. CAPCBC and CAHY refer to China Agricultural Product Cost-Benefit Compilation and China Animal Husbandry Yearbook.

Table 2 Descriptive Analysis of Variables

Variable	Obs.	Mean	Std. Dev.	Min	Max	Units/definition
production	19809	567.92	3111.00	51	250000	Kilogram
labor	19809	96.43	100.74	3	7206	Person-day
capital	19809	1321.98	7820.06	2	710000	Yuan
feed	19809	1978.79	10817.01	62	800000	Kilogram
lnproduction	19809	5.57	0.95	3.93	12.43	Kilogram
lnlabor	19809	4.30	0.73	1.10	8.88	Person-day
lncapital	19809	6.28	1.12	0.69	13.93	Yuan
lnfeed	19809	6.81	1.01	4.13	13.59	Kilogram
t	19809	3.58	1.97	1	7	Count number
age	19809	51.19	10.48	19	89	Age of household head
edu	19809	6.63	2.55	0	19	Formal education years of household head
gender	19809	0.96	0.19	0	1	Gender dummy of household head
training	19809	0.20	0.40	0	1	Dummy for whether household head has taken any agricultural training
health	19809	1.79	0.92	1	5	Self-reported health status of household head
husbandry	19809	0.06	0.24	0	1	Dummy for whether husbandry is the main income source
scale	19809	1.91	0.38	1	5	Scale of production
east	19809	0.20	0.40	0	1	Regional dummy
west	19809	0.47	0.50	0	1	Regional dummy

Notes: 1. The scale of production is defined as follows: 1. self-consumption (production≤100kg); 2. backyard hog production (100kg<production≤3000kg); 3. small hog farm (3000kg<production≤10000kg); 4. middle hog farm (10000kg<production≤100000kg); 5. Large hog farm (100000kg<production≤1000000kg).

2. Capital input has been deflated to 2004 value using CPI in rural China.

Table 3 Model Specification Test

Null Hypothesis	Chi Square Value	No. of Parameters	Decision
(1) Production function is Cobb-Douglass form	1496.48***	9	Reject
(2) No inefficiency effects	155.34***	12	Reject
(3) The classic inputs do not affect inefficiency	112.54***	3	Reject
(4) No regional variation in production inefficiency	14.49***	2	Reject
(5) The inefficiency effects is constant over time	0.18	1	Cannot reject

Note: *** denotes significant level at 1%.

Table 4 Empirical Results

Stochastic frontier production function			Technical inefficiency function		
lnproduct	Coefficient	Std. Err.	Inefficiency	Coefficient	Std. Err.
lnlabor	0.2295***	0.0593	lnlabor	0.3348***	0.0458
lncapital	0.2199***	0.0444	lncapital	0.2787***	0.0287
lnfeed	0.0003	0.0475	lnfeed	-0.3155***	0.0439
lnlabor*lncapital	0.0528***	0.0101	age	-0.0018***	0.0007
lnlabor*lnfeed	-0.0986***	0.0131	gender	0.1237***	0.0405
lncapital*lnfeed	-0.1384***	0.0074	health	0.0345***	0.0100
0.5*(lnlabor)^2	0.0951***	0.0188	edu	-0.0123***	0.0034
0.5*(lnfeed)^2	0.2522***	0.0126	training	0.0399***	0.0147
0.5*(lncapital)^2	0.1363***	0.0075	husbandry	-0.2934***	0.0851
t	-0.0546***	0.0122	central	0.1360***	0.0370
t*lnlabor	-0.0078**	0.0033	west	0.0564***	0.0208
t*lnfeed	0.0162***	0.0029	t	0.0057	0.0135
t*lncapital	-0.0101***	0.0023	Tau	0.1659	0.0652
0.5*t^2	0.0063***	0.0015	Cu	-6.4186	0.5971
constant	1.6746***	0.1452	sigma_v_sqr	0.1125	0.0032
			sigma_u_sqr	0.7869	
			log-likelihood	-8023.6	
			Observations	19809	
			Wald chi^2	16746.83***	

Notes: 1. ***, ** and * denote significant levels at 1%, 5% and 10% respectively.
2. ln denotes natural logarithm.

Table 5 Partially Elasticity and scale elasticity

Year	Labor	Capital	Feed	Scale Elasticity
2004	0.2478	0.3648	0.4156	1.0281
2005	0.1866	0.3786	0.4235	0.9887
2006	0.1131	0.3549	0.4578	0.9258
2007	0.0871	0.4437	0.3735	0.9043
2008	0.0491	0.5090	0.3242	0.8822
2009	-0.0293	0.4817	0.3620	0.8143
2010	-0.0909	0.4768	0.3767	0.7626
Total	0.1068	0.4165	0.3985	0.9218

Table 6 TFP growth rate and its decomposition over time

Year	SC	TC	EC	TFP
2004	NA	NA	NA	NA
2005	0.0007	-0.1919	0.0126	-0.1786
2006	0.0050	-0.1860	0.0466	-0.1344
2007	-0.0179	-0.1760	-0.0818	-0.2757
2008	-0.0285	-0.1624	-0.0622	-0.2531
2009	0.0295	-0.1526	0.0785	-0.0447
2010	0.0168	-0.1477	0.0171	-0.1138
2004-2010	-0.0322	-0.1711	-0.0027	-0.2060

Table 7 Technical Efficiency Distribution Range in Different Regions

TE	Central	East	West	Total
<0.5	20.61%	13.90%	22.42%	20.11%
0.5-0.6	30.43%	26.81%	30.48%	29.72%
0.6-0.7	36.98%	34.62%	32.88%	34.56%
0.7-0.8	10.99%	20.64%	12.14%	13.49%
0.8-0.9	98.00%	3.98%	2.08%	2.11%
0.9-1	0.00%	0.05%	0.00%	0.01%

Table 8 Mean Technical Efficiency by Scale

Scale	Rule of category	Efficiency	Observations
self-consume	production≤100kg	0.5582	2295
Backyard	100kg<production≤3000kg	0.5964	17066
Small farm	3000kg<production≤10000kg	0.5809	354
Middle farm	10000kg<production≤100000kg	0.5404	91
Large farm	100000kg<production≤1000000kg	0.2945	3

Note: The category is based on the estimation in <China Agricultural Product Cost-Benefit Compilation> that one hog is around 110 kilograms.

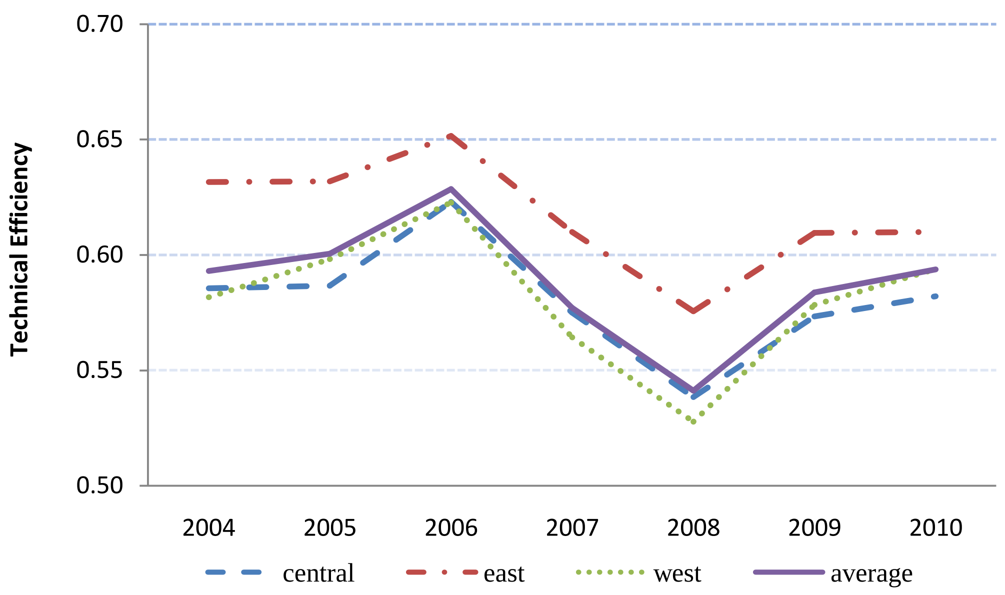

Fig. 1 TE Variation across regions and over time

Appendix

Table 1 Summary of output and inputs in each year

Year	Production	Labor	Capital	Feed	Observations
2004	505.71	100.73	1080.26	1717.72	3568
2005	641.78	100.08	1221.06	2209.57	3687
2006	527.17	94.62	763.34	1905.70	3292
2007	584.30	97.52	1595.87	2041.76	2681
2008	751.41	104.29	2444.23	2646.50	2204
2009	480.30	85.95	1337.46	1639.77	2336
2010	489.56	87.28	1238.48	1720.44	2041
total	567.92	96.43	1321.98	1978.79	19809

Note: capital input has been deflated into 2004 price.