

Article

Impact of African Swine Fever Epidemic on the Cost Intensity of Pork Production in China

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Abstract: China's African swine fever (ASF) outbreak, which started in 2018, has had a huge and far-reaching impact on China's hog industry, and it has not been completely eliminated so far. This article analyzes the impact of the ASF epidemic on the costs and technical efficiency of hog production in China based on data from the China Agricultural Product Cost–Benefit Compilation (2012–2021) using a stochastic frontier trans-log production function model. The results show that, after the outbreak of the ASF epidemic in China, feed costs, medical and epidemic prevention costs, and other costs of hog production in China increased significantly; the technical efficiency of China's hog production decreased significantly; large-scale hog farms were the most responsive to and greatly affected by the ASF epidemic; and there are regional differences in the impact of the ASF epidemic on technical efficiency of hog production. Future policies should focus on strengthening the R&D investment and technology promotion capacity of hog production, developing moderate-scale farming, and enhancing regional cooperation to improve technical efficiency of hog production.

Keywords: African swine fever; cost intensity; technical efficiency; hog production; China; stochastic frontier production function



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1. Introduction

African swine fever (ASF) is a highly contagious swine disease with severe socio-economic consequences [1]. The disease first occurred in Kenya in 1921 and has appeared in several European and Asian countries [2–6]. China, the world's largest producer and consumer of pork, reported the first case of ASF in one of its northeastern provinces on 3 August 2018. Within eight months, ASF spread throughout mainland China [7]. The ASF epidemic in China caused a huge impact on the pig market and pig products, thus causing great economic losses [8,9]. According to our group's survey of sixteen counties in eight provinces in China in 2019 [10], we found that most hog farms were directly or indirectly affected by ASF. The direct impact on farms is infection of hogs with ASF, while the indirect impact on farms is manifested by the need for high-temperature granulation, fumigation disinfection, and sealed transportation of feed, as well as strengthening epidemic prevention measures, etc. However, after the Chinese government implemented a series of ASF prevention and control policies, the outbreak of ASF in China has been effectively controlled, and the hog industry recovered to the normal pre-epidemic level in 2021. However, the far-reaching impact of the ASF epidemic on China's hog industry cannot be underestimated, and it still deserves continuous attention and in-depth research.

Recent studies on the ASF epidemic in China and its impact on the Chinese hog industry have focused on several major topics. First, the spatiotemporal transmission characteristics and causes of the ASF epidemic in China have been revealed. The existing literature illustrated that the prevalence of ASF in China increased at first and then decreased rapidly and tended to be stable [11]. The largest number of ASF outbreaks occurred in Southwest and Northeast China, and the most concentrated region was Northeast China [12]. The temporal and spatial changes of the epidemic were affected by both

meteorological factors and socio-economic factors [13]. Second, the impact of ASF on China's hog production and market was studied. China's Ministry of Agriculture and Rural Affairs (MARA) reported that annual domestic pork production in 2019 fell by 21% from its 2018 level [14]. The severe decline in hog production capacity strained the pork market supply, thus driving an overall rise in livestock prices [15]. In terms of consumption, due to the tight pork supply and high prices caused by the ASF epidemic, most urban residents chose other livestock products to replace pork consumption [16]. In addition, ASF caused a serious negative impact on the hog industry chain, but the impact degree had obvious heterogeneity among different provinces and links of the hog industry chain [17]. Third, measures for recovery and development of hog production in China under the ASF epidemic are discussed. The existing literature put forward suggestions from the aspects of improving disease prevention and control capacity of hog farms [10], improving the hog farming insurance system [18], developing a vertical integrated organizational model [19], clarifying the subject of hog production resumption [20], improving technical efficiency of hog production [21], and drawing on the effective experience of Russia [22].

Although the characteristics, impacts, and recovery of ASF outbreaks in China have been well documented, few studies have explored the impacts of ASF outbreaks on costs and technical efficiency of hog production in China. In fact, since the outbreak of ASF in China, the Chinese government has issued a series of policy measures, such as "Circular of Subsidies for Compulsory Culling of African Swine Fever", "Emergency Implementing Program for African Swine Fever (2019 Edition)", "Opinions on Strengthening the Prevention and Control of African Swine Fever", etc. These measures required that hog farms change their original production and management procedures to meet the requirements of epidemic prevention policies and reduce risk of disease infection. Therefore, what is the impact of the ASF epidemic on costs and technical efficiency of hog production in China? How should the hog production industry adjust to normalization of epidemic prevention and control requirements to achieve sustainable development? This study uses the data from China Agricultural Product Cost–Benefit Compilation (CAPCBC) compiled by the Price Department of the National Development and Reform Commission (NDRC) of the People's Republic of China to analyze in detail the costs and technical efficiency changes in hog production in China before and after the outbreak of ASF and puts forward suggestions to promote sustainable and healthy development of China's hog production industry.

Our paper is structured as follows. Section 2 presents a literature review. Section 3 presents the data, variables selection, and methods. Section 4 analyzes the impact of the ASF epidemic on the costs and technical efficiency of hog production in China. Section 5 presents the conclusions. The final section provides some policy implications.

2. Literature Review

2.1. The Costs of Hog Production

The relatively low costs of production are a direct reflection of the international competitiveness of the hog industry, and Canada has become an important pork exporter in the world by virtue of its low cost of hog production [23]. The production costs of fattening pigs in China are at a very high level relative to the main pork producing countries in the world, for example, twice as high as in Canada in 2017 [24]. Some studies show that high piglet costs, feed costs, and labor costs are the direct sources of high hog production costs in China, and the basic reason is the high price of production materials and low level of farming technology and scale in China [25–27]. According to the theory of economies of scale, when more units of a good or service can be produced on a larger scale yet with (on average) fewer input costs, economies of scale are said to be achieved [28]. Some studies have also shown that there are economies of scale in hog production, and, as the scale of a hog farm increases, feed costs and labor costs, etc., decrease [29,30]. Some studies based on the Chinese hog industry have concluded that there are economies of scale in hog production, but it does not mean that a large-scale farm is better because manure treatment costs and epidemic prevention costs increase when the individual farm size is

too large [31,32]. In addition, some studies based on cost–benefit data of hogs in China found that production costs of hogs decreased and then increased with farming scale, concluding that the production costs of medium-scale farms were the lowest, thus arguing that moderate-scale farms should be developed [33,34].

2.2. *The Technical Efficiency of Hog Production*

According to productive efficiency theory, technical efficiency means producing maximum output with given inputs, or, equivalently, using minimum inputs to produce a given output [35]. Therefore, improving technical efficiency is the core element in hog production; it not only increases profits and improves market competitiveness but also enables more pork production under given technology and input constraints, thus contributing to the growth of hog production and transformation of China’s hog industry [36,37]. Several studies have been conducted to investigate the technical efficiency of hog production in China, and they have shown that there is great heterogeneity in technical efficiency of China’s hog production over different regions, years, and scales. Jin et al. [38] found that the technical efficiency of hog production in China was very low during 1985–2014, particularly for specialized and commercial farms. On the contrary, Wang and Li [36] estimated the technical efficiency for 15 main hog producing areas and found rather high technical efficiency during 2002–2009, which stayed between 0.862 and 0.866. In addition, they found that there were significant differences in technical efficiency of hog production in different geographical areas, with technical efficiency in the main grain producing areas being higher than that in the economically developed coastal areas. Zhang et al. [39] compared the hog productivity between Shandong Province and all of China and found that large farms have the highest technical efficiency in Shandong Province. Tian et al. [37] found that specialized farmers had higher technical efficiency than others, and technical efficiency in the eastern region was higher than that in Central and West China based on household level panel data (2004–2010).

2.3. *The Impact of Animal Disease on Farm Production*

Farmers are the victims of animal disease outbreaks and spread, as well as the implementers of government epidemic prevention and control measures, and their response to animal diseases directly affects the effectiveness of government animal disease prevention and control [40]. As rational economic men, farmers maximize their income mainly through rational allocation of resources [41]. Farmers’ performance behavior towards animal diseases is influenced by the size of the farm, individual characteristics of the farmer, etc. [42,43]. Huang et al. [43] found that small-scale farms are managed in a sloppy manner and the farm environment cannot be effectively sterilized and disinfected. Yan et al. [44] found that large-scale pig farms were more sensitive to risks due to certain advantages in access to information, so they would take preventive measures in a timely manner. Zhou et al. [45] found that, compared with free-range farmers, large-scale pig farmers were more active in biosafety construction, with more various types of biosafety behavior. However, there are some studies that show that large-scale farming is not a ballast to stabilize livestock production under epidemic shocks. Yu et al. [46], based on survey data, found that degree of impact of avian influenza on farms varies by size: the larger the scale of the farm, the greater the decline in poultry breeding. Zhang et al. [47] found that, as larger farms have more capital, they are more likely to receive an epidemic shock and reduce their scale of farming. Based on survey data from eight provinces in China in 2019, Li et al. [10] found that, under the ASF epidemic, small-scale and medium-scale farms exhibited epidemic prevention and control advantages due to their smaller size and ease of controlling frequency of human and vehicle access.

The previous literature provides a solid theoretical background and research foundation for this study, but there are still several aspects that need further research. First, since the epidemic period of ASF in China is mainly from 2018 to 2020, there was a lack of a representative data that can reflect cost–benefit changes regarding hog production in China

before and after the ASF outbreak. Fortunately, the data of CAPCBC have been updated to 2020 now, so we can use it. Second, as hog farms of different scales differ in capital and technical level, whether the ASF epidemic had different impacts on farms of different scales requires further study. Third, different regions in China have differences in resource endowment and time affected by African swine fever, and the impact of the ASF epidemic on different regions is worth exploring. Therefore, this study uses the data of CAPCBC to analyze in detail the impact of the ASF epidemic on costs and technical efficiency of hog production in different scales and geographical areas of China.

3. Materials and Methods

3.1. Data Source

The data used in the present study were obtained directly from the China Agricultural Product Cost–Benefit Compilation (CAPCBC 2012–2021), which was issued by the National Development and Reform Commission (NDRC) of China, and the data have been used in several other studies [48–50]. These data record the cost and benefit of the national average and the provinces of hog production in detail, and the latest data year has been updated to 2021, which can well reflect the production and technical efficiency of hog production in China before and after the outbreak of ASF epidemic. Considering farms of various scales, the CAPCBC defines small-scale farms and medium-scale farms as those raising 30 to 100 hogs and 100 to 1000 hogs per year, respectively, and large-scale farms are those raising more than 1000 hogs per year. These farms are partly raising only fattening pigs and partly are raising both sows and fattening pigs. The number of hogs counted on each farm is the sum of the number of fattening pigs sold from the farm and the net increase in fattening pigs on the farm during the survey period, while piglets, boars, and sows for breeding are not included in the statistics. The sample period is from 2011 to 2020. Due to missing data in some provinces in CAPCBC, this study finally selected 22 provinces: Anhui, Gansu, Guangdong, Guangxi, Guizhou, Hebei, Henan, Heilongjiang, Hubei, Jilin, Jiangsu, Jiangxi, Liaoning, Inner Mongolia, Qinghai, Shandong, Shanxi, Shaanxi, Sichuan, Yunnan, Zhejiang, and Chongqing. The pork production of the 22 sample provinces in 2020 and their share in China are shown in Table 1. The total number of samples is 660, with 220 samples for small-scale farms, medium-scale farms, and large-scale farms, respectively, as there are 22 provinces with 10 years of data for each scale. In addition, to make the indicators of the amount involved in different years comparable, this paper uses the corresponding price deflator for some indicators. Feed price index, rural consumer price index, and price index of other agricultural means of production are all from China Statistical Yearbook.

Table 1. Pork production and proportion in 22 sample provinces in 2020 (units: thousand tons; %).

Provinces	Pork Production	Proportion	Provinces	Pork Production	Proportion	Provinces	Pork Production	Proportion
Anhui	1834	4.5	Hubei	2038	5.0	Shanxi	628	1.5
Gansu	492	1.2	Jilin	1050	2.6	Shaanxi	777	1.9
Guangdong	1924	4.7	Jiangsu	1407	3.4	Sichuan	3948	9.6
Guangxi	1741	4.2	Jiangxi	1807	4.4	Yunnan	2916	7.1
Guizhou	1463	3.6	Liaoning	1835	4.5	Zhejiang	542	1.3
Hebei	2269	5.5	Mongolia	614	1.5	Chongqing	1088	2.6
Henan	3248	7.9	Qinghai	37	0.1	All of China	41,133	100.0
Heilongjiang	1439	3.5	Shandong	2710	6.6			

Data source: National Bureau of Statistics of China.

3.2. Variables Selection

3.2.1. Output Variable

The output variable of hog production can be selected mainly from the output value and the output weight. Considering that the ASF epidemic caused the price of hog to fluctuate violently, the output value of hogs was also greatly affected. Therefore, to eliminate

the influence of price factors, according to the practice of Wang et al. [36], net weight gain of hog is used as the output variable, that is, the weight of the hog out of the slaughterer minus the weight of the piglet.

3.2.2. Input Variables

1. Feed input: the sum of the concentrate feed costs, green coarse feed costs, and feed processing costs for each hog production, and we deflate the depreciation data using Feed Price Index in different provinces in China;
2. Labor input: labor costs for each hog production, and we deflate the depreciation data using Rural Consumer Price Index in different provinces in China;
3. Medical and epidemic prevention input: medical treatment and epidemic prevention costs for each hog production, and we deflate the depreciation data using Price Index for Other Means of Agricultural Production in different provinces in China;
4. Other input: the sum of water costs, fuel and power costs, tools and materials costs, and fixed assets depreciation costs for each hog production, and we deflate the depreciation data using Price Index for Other Means of Agricultural Production in different provinces in China.
5. The above 4 kinds of inputs are the main sources of the total cost of hog production (except the piglet cost), with feed input accounting for 77.9%, labor input accounting for 14.4%, medical and epidemic prevention input accounting for 2.2%, and other input accounting for 2.2% in 2020; the 4 inputs together account for 96.7% of the total input (except piglet fee), which can basically represent the overall input situation of hog production.

3.3. Study Methods

There are two main methods of measuring technical efficiency: parametric methods and non-parametric methods. The parameter method is to set a specific functional form, which can consider the natural environment, statistical error, and other random factors that may affect output. Non-parametric method uses linear planning technology, which can avoid the problems caused by error setting of function form, but it ignores the influence of random factors, such as statistical error, on output. The data of each province used in this study are collected by summarizing and sorting out the input–output data of randomly selected hog farms in the province, so the data are prone to statistical errors. In addition, hog production is affected by natural environment, supervision costs, and other factors, and there may be bias in the data recording process. Therefore, the parametric method considering random factors is more suitable for measurement of the technical efficiency of hog production. The stochastic frontier production function is most widely used in parametric methods, and it has also been extended in much literature with many different functional forms [51–58]. In this study, we follow the recommendations in current literature [38,48,55,56,59] and adopt the trans-log production function, which is a very flexible functional form and is a second-order approximation of any unknown function. Moreover, this model permits estimation of both technical change in the stochastic frontier and time-varying technical inefficiencies with scaling property [37,55,56]. The function is defined as:

$$\begin{aligned} \ln Y_{it} = & \beta_0 + \beta_1 \ln F_{it} + \beta_2 \ln L_{it} + \beta_3 \ln M_{it} + \beta_4 \ln O_{it} + \beta_5 T + \frac{1}{2} \beta_{11} (\ln F_{it})^2 + \\ & \frac{1}{2} \beta_{22} (\ln L_{it})^2 + \frac{1}{2} \beta_{33} (\ln M_{it})^2 + \frac{1}{2} \beta_{44} (\ln O_{it})^2 + \frac{1}{2} \beta_{55} T^2 + \frac{1}{2} \beta_{12} (\ln F_{it} \times \ln L_{it}) + \\ & \frac{1}{2} \beta_{13} (\ln F_{it} \times \ln M_{it}) + \frac{1}{2} \beta_{14} (\ln F_{it} \times \ln O_{it}) + \frac{1}{2} \beta_{23} (\ln L_{it} \times \ln M_{it}) + \\ & \frac{1}{2} \beta_{24} (\ln L_{it} \times \ln O_{it}) + \frac{1}{2} \beta_{34} (\ln M_{it} \times \ln O_{it}) + \beta_{15} (\ln F_{it} \times T) + \beta_{25} (\ln L_{it} \times T) + \\ & \beta_{35} (\ln M_{it} \times T) + \beta_{45} (\ln O_{it} \times T) + v_{it} - u_{it} \end{aligned} \quad (1)$$

where i is the province and t is the year. Y represents the net increase in hog (kg/head); F represents the feed input (yuan/head); L represents the labor input (yuan/head); M represents the medical and epidemic prevention input (yuan/head); O represents other input (yuan/head); T represents a time trend to capture the trends in productivity change;

β represents the corresponding unknown parameters; v_{it} represents a random error term that is assumed to be independent and identically distributed with $N(0, \sigma_v^2)$; u_{it} represents nonnegative random error term and is technical inefficiency in production, independently and identically distributed with $N^+(m_{it}, \sigma_u^2)$. According to the above definition, technical efficiency can be expressed as

$$TE_{it} = \frac{E(Y_{it}|u_{it}, X_{it})}{E(Y_{it}^*|u_{it} = 0, X_{it})} = \exp(-u_{it}) \quad (2)$$

where TE_{it} represents technical efficiency of hog production, and it is a value between 0 and 1, with 1 referring to the unobserved frontier. Y_{it} represents the actual net increase in hog; Y_{it}^* represents the maximum possible net increase in hog at a given input level; X_{it} represents the inputs of hog production; u_{it} represents a technical inefficient term.

4. Results and Analysis

4.1. The Impact of the ASF Epidemic on Costs of Hog Production

4.1.1. Rising Feed Costs

After we deflated the feed costs using the national average Feed Price Index of China, the annual feed costs of hog production of different scales in China from 2011 to 2020 are shown in Figure 1. In 2012, the average feed costs of hog production in China increased by 3.1% year-on-year; from 2013 to 2017, the average feed costs decreased by an average annual rate of 0.7%, mainly due to continuous improvements in hog production technology that led to a continuous decline in the feed-to-meat ratio of hogs (Figure 2). From 2018 to 2020, the feed costs of hog production in China showed an upward trend, and the average feed costs of hog production in China increased by 0.4%, 0.9%, and 8.0% year-on-year, respectively. The main cause of this phenomenon is the impact of the ASF epidemic. Ensuring feed safety is one of the key measures to prevent and control African swine fever [60], and many hog farms under epidemic prevention and control ensure feed safety by high-temperature granulation, fumigation disinfection, sealed transportation, and selection of safe feed raw materials [61], but this also increases feed processing costs and transportation costs, thereby jointly raising the total feed costs. It is worth noting that, in 2020, the average feed costs of hog production in China increased significantly, with a year-on-year increase of 8.0%. This increase is in part because the epidemic prevention measures on feed safety had been fully implemented in hog farms throughout China in 2020, which significantly increased feed costs. It is also because the long incubation period of ASF made some farms unable to eliminate sick pigs in time, which led to the sick hogs consuming feed every day yet not being able to effectively gain weight. This can also be proven by the 0.7% year-on-year increase in the average feed-to-meat ratio of hog production in China in 2020, and the feed-to-meat ratio in large-scale hog farms increased by 1.5% year-on-year, hardest hit by the epidemic. By scale, small-scale hog farms had the highest level of average feed costs from 2011 to 2020 (mean value of CNY 849 per head), followed by medium-scale hog farms (mean value of CNY 848 per head) and large-scale hog farms (mean value of CNY 805 per head), and our results are consistent with the theory of economies of scale.

4.1.2. Decreasing Labor Costs Steadily

After we deflated the labor costs using national average the Rural Consumer Price Index of China, the annual labor costs of hog production of different scales in China from 2011 to 2020 are shown in Figure 3. The average labor costs of hog production in China from 2011 to 2017 showed a trend of first rising and then slowly declining, reaching the highest point in 2016 and declining in 2017. From 2018 to 2020, the labor costs of hog production in China showed a slight downward trend, with average labor costs per hog of CNY 156.30, CNY 156.93, and CNY 154.63, down 1.1%, up 0.4%, and down 1.5% year-on-year, respectively. The main reason for the increase in labor costs from 2011 to 2017 was the continuous rise in labor prices, but, after 2017, with continuous development of productivity, the trend of China's hog farming labor force being replaced by capital and

technology became more and more obvious, so the labor costs of hog production showed a steady and slight decreasing trend. Overall, the impact of the ASF epidemic on the labor costs of hog production is relatively limited. In terms of scale, the larger the hog farm, the stronger the capital and technology and the stronger the substitution effect of capital and technology for labor, so the labor costs of hog production are sorted from low to high as large-scale, medium-scale, and small-scale, and our findings are consistent with the theory of economies of scale.

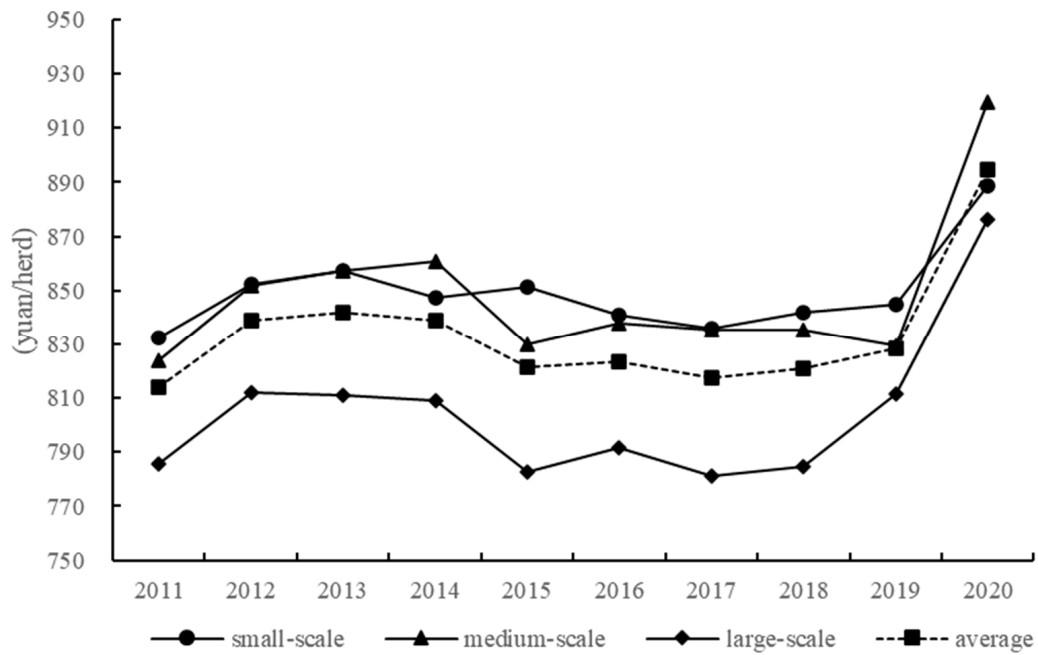


Figure 1. Annual feed costs of hog production of different scales in China from 2011 to 2020.

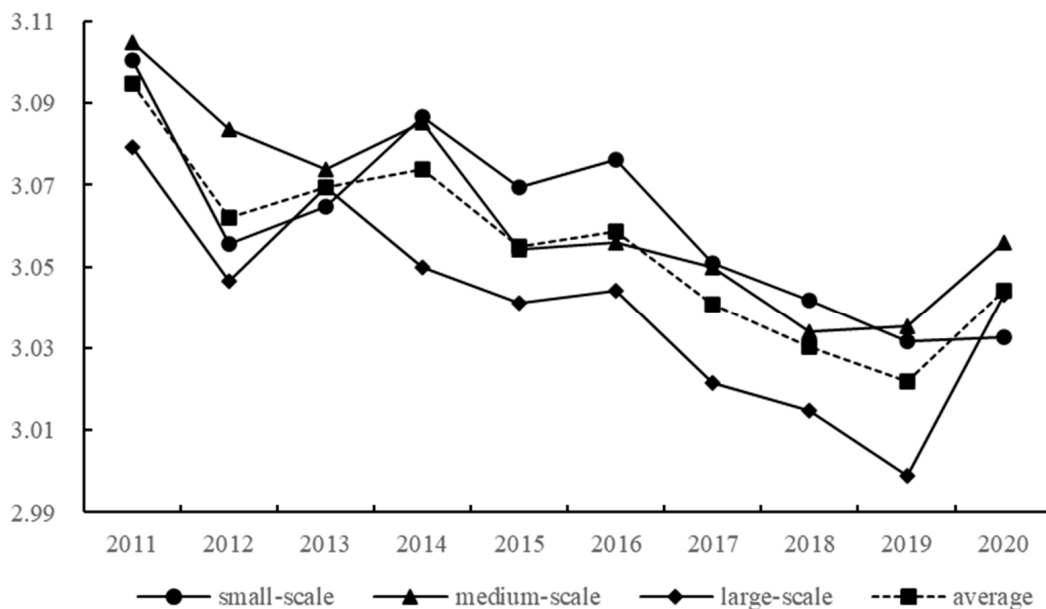


Figure 2. Annual feed-to-meat ratio of hog production of different scales in China from 2011 to 2020.

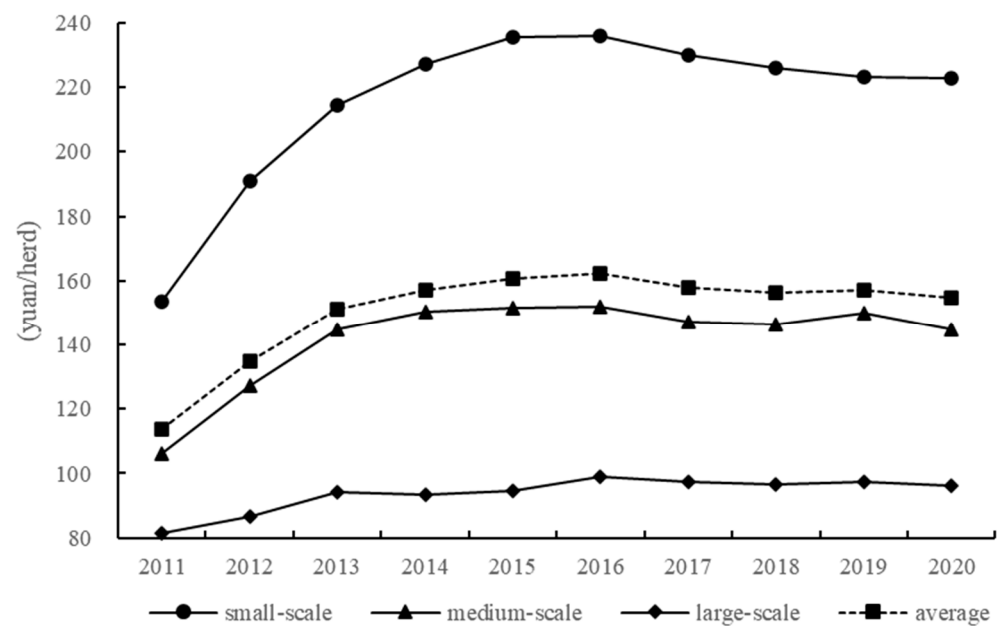


Figure 3. Annual labor costs of hog production of different scales in China from 2011 to 2020.

4.1.3. Climbing Medical and Epidemic Prevention Costs

After we deflated the medical and epidemic prevention costs using the national average Price Index for Other Means of Agricultural Production of China, the annual medical and epidemic prevention costs of hog production of different scales in China from 2011 to 2020 are shown in Figure 4. The medical and epidemic prevention costs for pig production in China were relatively stable from 2011 to 2017, and, after the African swine fever outbreak, the medical and epidemic prevention costs for pig production climbed significantly, and the average medical and epidemic prevention costs per pig produced in China were CNY 17.52, CNY 22.03, and CNY 24.47 in 2018–2020, respectively, up 0.6%, 25.8%, and 11.0% year-on-year, respectively. The reason for the low increase in medical and epidemic prevention costs in 2018 is it had been only five months since the outbreak occurred in August of that year and farmers' understanding of the ASF epidemic in such a short period of time was still very limited. In addition, the focus of China's epidemic prevention and control was to cut off the transmission chain and prevent the epidemic from spreading widely across the country; for example, the MARA issued "Circular of Prevention and Control of African Swine Fever and Strengthening the Supervision of the Movement of Hogs", "Circular of Subsidies for Compulsory Culling of African Swine Fever", and "Circular of Further Strengthening the Supervision of Cross-Provincial Transfer of Live Hogs and Their Products" in August and September 2018, so there were relatively few measures taken by hog farmers to prevent and control the epidemic. However, with China's more comprehensive knowledge of ASF's pathogenesis, transmission routes, and prevention and control measures, in 2019, the MARA, The Center for Animal Disease Control and Prevention of China (CADPC), General Office of the State Council of China, and the National Hog Industry Technology System of China successively issued the "Emergency Implementing Program for African Swine Fever (2019 Edition)", "Biosafety Manual for Prevention and Control of African Swine Fever in Scaled Hog Farms (Breeding Farms) (For Trial Implementation)", "Opinions on Strengthening the Prevention and Control of African Swine Fever", "Nine Key Technologies to Restore Hog Production for Prevention and Control of African Swine Fever", respectively. The medical and epidemic prevention costs for hog production were significantly higher year-on-year in both 2019 and 2020 due to the need of hog farms to implement the documents' ASF prevention and control requirements. In terms of different scales, medical and epidemic prevention costs are positively correlated with scale of hog production, which is because, the larger the scale

of hog farms, the higher their farming density and the greater the risk of loss in the event of an ASF epidemic, so large-scale hog farms will pay more attention to epidemic prevention and control. The finding is also consistent with current literature (Huang et al. [43]; Yan et al. [44]). In addition, the ASF epidemic has also significantly enhanced the inputs in disease prevention and control for small-scale hog farms, with medical and epidemic prevention costs for small-scale hog farms increasing by 30.1% year-on-year and ranking first in 2019 compared with 20.1% for medium-scale and 26.6% for large-scale. Medical and epidemic prevention investment of large-scale pig farms continued to strengthen after the outbreak of African swine fever, and the year-on-year increase in medical and epidemic prevention expenses in 2020 was still as high as 15.4%, widening the gap with small- and medium-sized farms. Medical and epidemic prevention investment of large-scale hog farms continued to increase after the outbreak of ASF, and the year-on-year increase in medical and epidemic prevention costs in 2020 was still as high as 15.4%, widening the gap with small-scale farms and medium-scale farms.

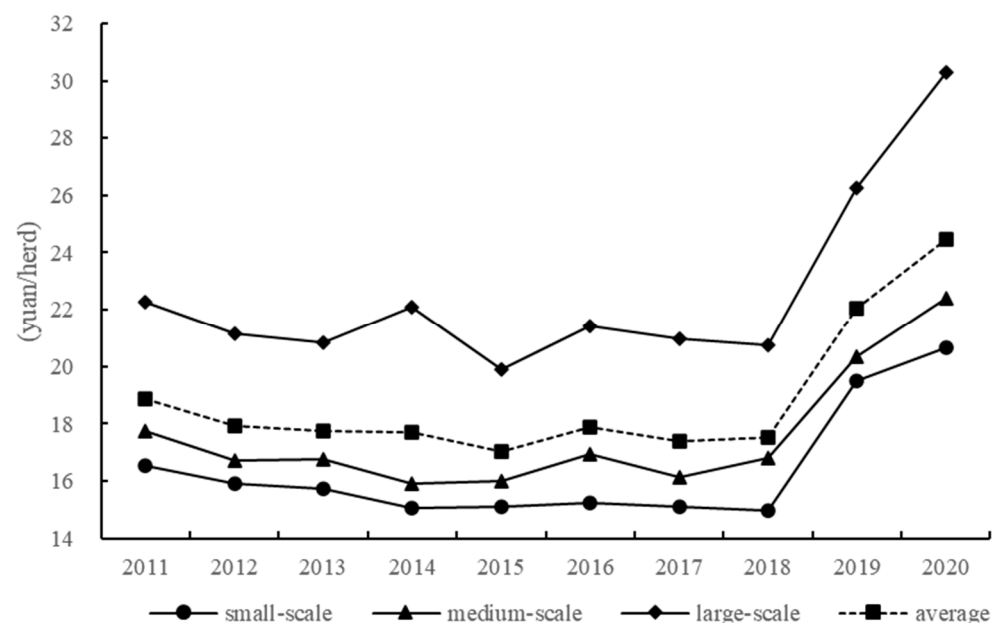


Figure 4. Annual medical and epidemic prevention costs of hog production of different scales in China from 2011 to 2020.

4.1.4. Rising Other Costs

Other costs in this study include water costs, fuel and power costs, tools and materials costs, and fixed assets depreciation costs. After we deflated the other costs using the national average Price Index for Other Means of Agricultural Production of China, the annual other costs of hog production of different scales in China from 2011 to 2020 are shown in Figure 5. Other costs of hog production fluctuated but remained generally stable in 2011–2017. After the outbreak of ASF, the average other costs of pig production were on the rise, and the average other costs of pig production in China were CNY 22.40, CNY 22.10, and CNY 24.37 per head in 2018–2020, respectively, up 2.8%, down 1.4%, and up 10.3% year-on-year, respectively. This is because, when hog farms strengthen epidemic prevention and control, besides increasing medical and epidemic prevention costs, they also need to increase renovation and upgrading of facilities, such as pig houses, so other costs, such as tooling and material costs, depreciation of fixed assets, fuel and power costs, and water costs, will also increase accordingly. By scale, large-scale farms have the highest other costs, followed by medium-scale farms and small-scale farms. This is because, the larger the scale of a hog farm, the more assets and equipment, tools and materials, and utilities it has. In terms of increase in other costs after the outbreak of ASF, the largest year-over-year increase was observed in 2020 for large-scale farms (16.8%), followed by

medium-scale farms (7.4%) and small-scale farms (4.0%), as larger farms require more per-unit inputs in terms of improving hog housing, etc.

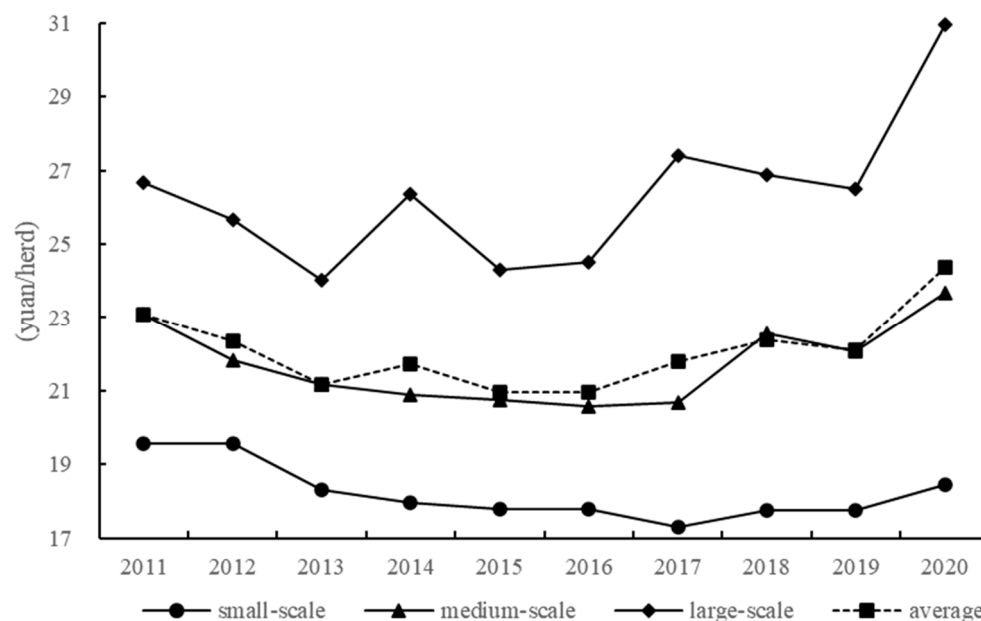


Figure 5. Annual other costs of hog production of different scales in China from 2011 to 2020.

4.1.5. Increasing Net Weight Gain

The trend in annual net weight gain of hog production of different scales in China from 2011 to 2020 is shown in Figure 6. From the overall trend, the net weight gain of hog production showed a continuous and steady increase. The average net gain in hog production from 2018 to 2020 was 104.72 kg, 106.80 kg, and 110.37 kg per head, respectively, representing year-on-year growth of 1.7%, 2.0%, and 3.3%, compared with an average growth rate of 1.4% from 2011 to 2017, which shows that the ASF epidemic had a relatively small impact on output of hog production. By scale, the average net weight gain for large-scale farms in 2011–2020 was 98.58 kg per head, the lowest level among the three scales, compared with 102.18 kg and 103.20 kg per head for medium-scale farms and small-scale farms, respectively. However, the growth rates of large-scale in 2019 and 2020 were faster, with 3.8% and 3.2% year-on-year growth, respectively, gradually approaching net weight gain of medium-scale farms and small-scale farms.

4.2. The Impact of the ASF Epidemic on Technical Efficiency of Hog Production

4.2.1. Model Test and Estimation

The results of the model estimation are reported in Table 2. The log likelihood value of the model was 1122.93 and the chi-square value was 2160.06, with a p -value of 0.000, indicating a good model fit. In addition, the estimated coefficients of the random error term and the technical inefficiency term in the model are significant at the 1% level, indicating that random factor disturbances and technical efficiency losses are prevalent in hog production, so the stochastic frontier production function is consistent with the actual hog production. Meanwhile, we tested whether the trans-log production function can be reduced to a Cobb–Douglas production function. The null hypothesis is that the coefficients of the second-order variables in the trans-log model are 0, indicating that the Cobb–Douglas function can well represent the data, which is, however, strongly rejected at a 1% confidential level. Therefore, it is more reasonable to use the trans-log production function.

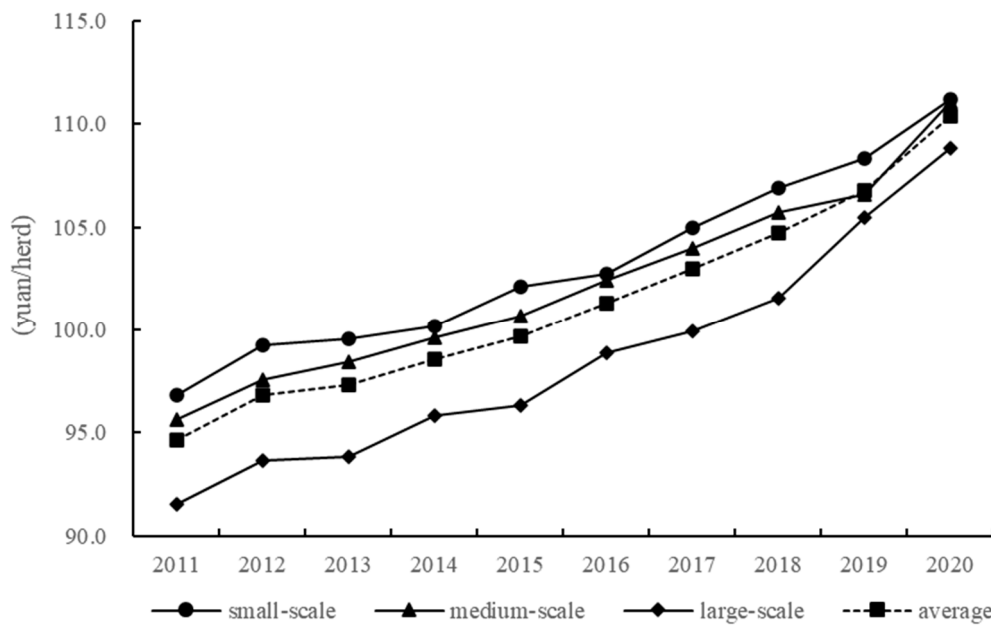


Figure 6. Annual net weight gain of hog production of different scales in China from 2011 to 2020.

Table 2. The estimation results of trans-log production function.

Parameters	Coefficients	Std. Err.	Parameters	Coefficients	Std. Err.
β_0	12.000 ***	−3.14	β_{13}	−0.081	−0.10
β_1	−3.017 ***	1.07	β_{14}	−0.044	−0.11
β_2	0.029	0.21	β_{23}	0.026	−0.02
β_3	0.076	0.35	β_{24}	0.093 ***	−0.03
β_4	0.129	0.37	β_{34}	0.087 **	−0.04
β_5	0.138 ***	0.03	β_{15}	−0.016 ***	−0.01
β_{11}	0.591 ***	0.18	β_{25}	0.004 ***	0.00
β_{22}	0.013	0.01	β_{35}	0.002	0.00
β_{33}	0.007	0.03	β_{45}	−0.002	0.00
β_{44}	−0.101 ***	0.03	sigma_u	0.178	0.30
β_{55}	0.0003	0.00	sigma_v	0.041	0.00
β_{12}	−0.061	−0.06			

*** $p < 0.01$, ** $p < 0.05$.

4.2.2. Analysis of Technical Efficiency of Hog Production

The trend of annual technical efficiency of hog production of different scales in China from 2011 to 2020 is shown in Figure 7. From the overall trend, the technical efficiency of hog production showed a decreasing trend from 2011 to 2013, and the average technical efficiency of hog production kept increasing, with an average annual growth rate of 0.1% from 2013 to 2017. Since the outbreak of ASF in August 2018, the trend of technical efficiency of pig production in China began to reverse, with large-scale hog farms bearing the brunt. The technical efficiency of large-scale hog production decreased by 0.01% year-on-year in 2018, which is related to the higher risk aversion of large-scale hog farms. At the beginning of the outbreak of African swine fever, large-scale hog farms preferred to invest more in feed costs and epidemic prevention costs to reduce losses, thus reducing their technical efficiency in hog production. The technical efficiency of small-scale hog production in 2018 increased by 0.04% year-on-year, which is, on the one hand, due to the African swine fever epidemic for the beginning of August of the year, only 5 months from the end of the year; the risk awareness of small-scale farmers was not yet high, and their adoption of epidemic prevention and control measures was less, so they were less affected by the epidemic. On the other hand, due to stronger environmental regulations from 2017, many small-scale

hog farms that did not meet environmental requirements were forced to shut down, thus eliminating some inefficient small-scale hog farms and improving the overall technical efficiency of small-scale hog production, as also evidenced by a 0.22% year-on-year increase in technical efficiency of small-scale hog production in 2017. Technical efficiency of medium-scale hog production increased by 0.02% year-on-year in 2018, in between large-scale farms and small-scale farms.

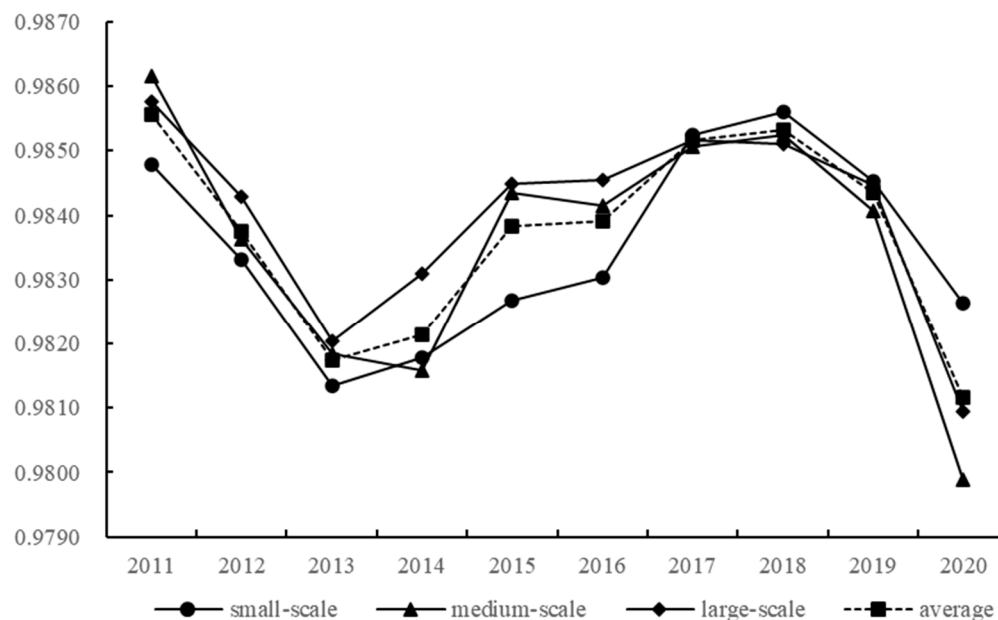


Figure 7. Annual technical efficiency of hog production of different scales in China from 2011 to 2020.

In 2019, with the rapid spread of the ASF epidemic across China and the increasing awareness of epidemic prevention and control in hog farms, there was an overall decline in the technical efficiency of hog production in China, with the average technical efficiency of hog production decreasing by 0.1% year-on-year. By scale, the technical efficiency of medium-scale and small-scale pig production decreased faster in 2019, with small-scale farms down 0.11% and medium-scale farms down 0.12% and large-scale farms down 0.06%.

In 2020, with prevention and control of the ASF epidemic being more widely accepted and implementation of prevention and control measures on hog farms becoming more standardized and stricter, the technical efficiency of hog production in China saw a more substantial decline, with the average technical efficiency of hog production decreasing by 0.32% year-on-year. By scale, the technical efficiency of medium-scale hog production in 2020 decreased by 0.43% year-on-year, followed by large-scale farms, down by 0.36%, and small-scale farms, down by 0.19%.

Looking at the average of the changes in technical efficiency of hog production in China in 2018–2020, the technical efficiency of hog production in China decreased by 0.14% on average during the three years. By scale, the technical efficiency of medium-scale hog production decreased the most on average by 0.18% in 2018–2020, followed by large-scale farms with a decrease of 0.14% and small-scale farms with a decrease of 0.09%.

4.2.3. Analysis of Technical Efficiency of Hog Production in Different Regions of China

According to the regional transmission characteristics of African swine fever outbreaks and the regional distribution of pig production in China, the 22 sample provinces were divided into six regions: Northeast China, North China, Northwest China, Southwest China, Central China, and Southeast China (Table 3). We analyzed the changes in technical efficiency of hog production in different regions of China after the outbreak of ASF, with a view to providing a reference basis for hog production recovery and technical efficiency improvement in different regions.

Table 3. Regional distribution of hog production in 22 sample provinces.

Regions	Provinces
Northeast China	Heilongjiang, Jilin, Liaoning
North China	Hebei, Shanxi, Inner Mongolia
Northwest China	Gansu, Qinghai, Shaanxi
Southwest China	Guizhou, Sichuan, Yunnan, Chongqing, Guangxi
Central China	Henan, Hubei, Jiangxi, Anhui
Southeast China	Jiangsu, Shandong, Zhejiang, Guangdong

The trend of annual technical efficiency of hog production in different regions of China from 2011 to 2020 is shown in Figure 8. In terms of the average technical efficiency of hog production from 2011 to 2020, the top three regions are Northeast China (mean value of 0.9869), North China (mean value of 0.9855), and Central China (mean value of 0.9850), which are the main grain producing regions in China, with sufficient feed and low transportation costs, and their technical efficiency is at a high level after promotion and application of modern hog production technologies. The results are in general agreement with the technical efficiency of pig production measured by Wang et al. [36]. In terms of the impact of the ASF epidemic in each year, the technical efficiency of hog production in Northeast China decreased by 0.01% in 2018, decreased by 0.04% in 2019, and increased by 0.02% in 2020.

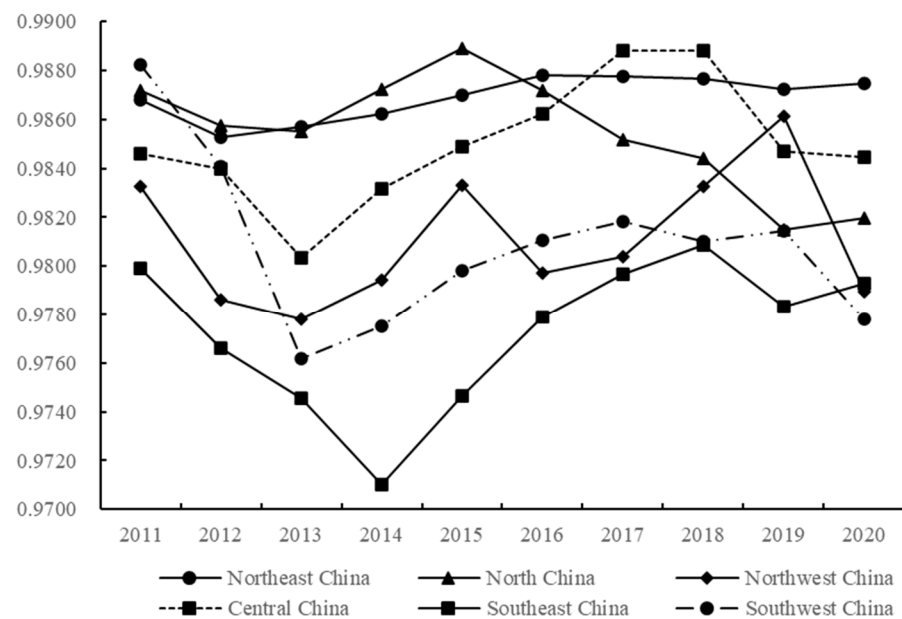


Figure 8. Annual technical efficiency of hog production in different regions of China from 2011 to 2020.

We found that the outbreak of ASF in China started in Northeast China, but the technical efficiency of hog production in Northeast China remained generally stable, probably because the technical efficiency of hog production in Northeast China was overall high before the ASF epidemic and the infrastructure and disease prevention and control capacity of hog production in Northeast China were also good, so the epidemic had less impact on Northeast China. Technical efficiency of pig production in North China decreased by 0.08% in 2018, decreased by 0.29% in 2019, and increased by 0.05% in 2020. North China was hit by the African swine fever epidemic mainly in 2019 and had started to return to normal and demonstrated growth in technical efficiency of hog production in 2020.

As can be seen from Figure 8, the technical efficiency of hog production in Central China was in a stable upward trend from 2013 to 2017, which was inseparable from

the abundant feed resources and application and promotion of modern hog production technology in the region. On the one hand, the four central provinces of Henan, Hubei, Jiangxi, and Anhui are the main grain producing areas; their feed costs are low. On the other hand, some hog enterprises in Central China, such as Muyuan in Henan Province and Zhengbang in Jiangxi Province, are developing rapidly, and the model of “company + farmers” established by them can promote advanced hog production technology to farmers well. After the outbreak of African swine fever, the growth trend of technical efficiency of hog production in Central China was reversed, and the technical efficiency in Central China was basically flat in 2018, with a significant decline in 2019 (down 0.41% year-on-year) but started to stabilize in 2020 (down 0.02% year-on-year).

Northwest China and Southwest China were slightly delayed by the impact of the ASF epidemic, and the technical efficiency of hog production in these two regions did not show a significant decline in 2018 and 2019 until 2020, when the technical efficiency of hog production in the two regions decreased by 0.73% and 0.37% year-on-year, respectively. This is because Northwest China and Southwest China are relatively remote, sparsely populated, and mountainous, which can play a certain role as a biosecurity barrier; they were relatively unaffected by the African swine fever epidemic in the early stage, but the impact of the epidemic in 2020 on the technical efficiency of hog production in both regions was obvious.

The average technical efficiency of hog production in Southeast China was relatively low at 0.9773 from 2011 to 2020. However, the technical efficiency of hog production in Southeast China grew rapidly at an average annual growth rate of 0.3% from 2014 to 2018 due to the developed economy and the obvious capital and technological advantages of Southeast China. The technical efficiency of hog production in the Southeast declined in 2019 (down 0.26% year-on-year) due to the impact of the ASF epidemic; however, the upward trend resumed in 2020 (up 0.10% year-on-year). The efficiency of hog production in Southeast China was able to recover quickly from the African swine fever outbreak mainly because the capital and technological advantages of Southeast China were exploited.

5. Conclusions

High production efficiency is one of the basic connotations of high-quality development of China’s livestock industry [62]. This study analyzed the impact of the ASF epidemic on the input–output and technical efficiency of hog production in China based on the data of China Agricultural Product Cost–Benefit Compilation using a stochastic frontier trans-log production function model and obtained the following conclusions.

First, feed, medical, and epidemic prevention costs and other costs of hog production in China increased significantly after the outbreak of ASF. Since the outbreak of African swine fever in China in August 2018, hog feed requires additional high-temperature granulation, fumigation and disinfection, and sealed transportation than before, thus increasing the processing costs and transportation costs of feed. In addition, the significant increase in feed-to-meat ratio of hog production in 2020 is also an important factor in the increase in feed costs. The medical and epidemic prevention costs for hog production in China are significantly higher after the ASF outbreak, especially in 2019 and 2020. Labor costs and net weight gain of hog production were relatively less affected by the epidemic, and their development trends were basically the same before and after the epidemic.

Second, the technical efficiency of China’s hog production decreased significantly after the outbreak of ASF. As the ASF epidemic significantly increased the input cost of hog production, the trend of technical efficiency growth of hog production in China was reversed. The average technical efficiency of scaled hog production in China increased at an average annual growth rate of 0.1% from 2013 to 2017, while it was essentially flat in 2018 and decreased by 0.1% and 0.32% year-on-year in 2019 and 2020, respectively.

Third, large-scale hog farms were the most responsive to and greatly affected by the ASF epidemic. The technical efficiency of large-scale hog production after the ASF outbreak decreased by 0.01% year-on-year in 2018, while small-scale farms and medium-scale farms

increased by 0.02% and 0.04% year-on-year, respectively. Feed costs and medical and epidemic prevention costs for large-scale hog production increased by an average of 3.9% and 13.6% year-on-year, respectively, in 2018–2020, both higher than for small-scale farms and medium-scale farms. This conclusion implies that the theory of economies of scale is not fully applicable to hog production. The larger the scale of the farm, the higher the market risk it bears, and moderate-scale operation should be developed.

Fourth, there are regional differences in the impact of the ASF epidemic on the technical efficiency of hog production. After the ASF epidemic, the technical efficiency of hog production in Northeast China was generally relatively stable; the technical efficiency of hog production in North China, Central China, and Southeast China mainly declined by a relatively large margin in 2019 but started to stabilize in 2020; Southeast China had the fastest recovery from the epidemic and its technical efficiency started to show growth in 2020; Northwest China and Southwest China were slightly delayed by the impact of the ASF epidemic, and the technical efficiency of hog production in both regions did not decline until 2020. This conclusion implies that different regions should develop hog farming reasonably according to their own resource endowments.

6. Policy Implications

At present, the ASF epidemic in China has been effectively controlled, but, under the situation of normalized prevention and control of the ASF epidemic, it is still difficult to reduce the increased costs of feed and medical and epidemic prevention in hog farms. If we want to improve the technical efficiency of hog production in the post-ASF era, we need to make efforts to improve the production technology level of hog farms. On the one hand, it is necessary to increase investment in R&D of hog production technology, promote enterprises, research institutes, and universities to jointly strengthen scientific and technological innovation, and focus on strengthening R&D efforts on pig genetic breeding, feed nutrition, feeding device system, and intelligent management of hogs so as to improve feed conversion rate, reduce production costs, and enhance biosecurity prevention and control capability and hog health level. On the other hand, it is necessary to enhance the technical promotion capacity of hog production. First, “company + farmers” and “company + family farms” need to be vigorously promoted to enhance the degree of organization of hog production and to enhance the timeliness and effectiveness of technical promotion of hog production enterprises and operational service organizations. Second, the Chinese government should promote reform and innovation of the grass-roots agricultural extension system, explore an integration mechanism of commonweal agricultural extension and business services, and support grass-roots agricultural personnel to enter hog producers to provide technical contracting, technical consulting, and other value-added services to obtain reasonable compensation.

After the ASF outbreak in China, the technical efficiency of large-scale hog farms declined the fastest and feed costs and medical and epidemic prevention costs increased the most compared to medium-scale farms and small-scale farms. Large-scale hog farms have absolute advantages in terms of capital and technology, but, because of their large scale and stronger asset specialization, their risk aversion will be higher and they will face greater adjustment pressure in case of unexpected events. Small-scale and medium-scale hog farms are more flexible and less costly in terms of epidemic prevention due to their smaller scale and relative independence. Therefore, development of hog production in various places should not overly pursue huge scale of farms but should choose the appropriate scale of production according to their own resource conditions.

Northeast China, North China, and Central China are the main grain producing areas in China, rich in feed resources, and have an overall high level of technical efficiency in hog production; Southwest China and Northwest China have more mountainous plateaus and lower breeding densities, which hinder the spread of an epidemic; Southeast China has the lowest technical efficiency, but, with their capital and technical advantages, they experienced rapid growth in technical efficiency from 2014 to 2018 and had the fastest

recovery from the ASF epidemic. Therefore, all regions should strengthen regional cooperation and communication and accelerate construction of a unified national market to optimize allocation of resources. Enterprises in Southeast China should be encouraged and supported to bring their capital, technology, and advanced farming management experience to Central China, Western China, and Northeastern China to promote overall improvement in the technical efficiency of hog production nationwide.

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