EXAMINING INTEGRATION, EFFICIENCY AND TECHNICAL CHANGE IN CHINESE PORK PRODUCTION

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Yongxia Tian

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Agribusiness and Applied Economics

July 2021

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Pork has been the main protein source for the Chinese millennia. Though China is the largest pork producer in the world, multiple challenges hinder development of pork production and hence demand are difficult to satisfy. Due to national food security strategy, imported pork may only play a minor role. Objective of this research is examining current production efficiency and technological progress in Chinese pork production and discuss comprehensive supply chain integration. This study presents theoretical analysis regarding consumer benefits and how they could be improved. Additionally, efficiency analysis is conducted across three hog production scales with results showing large-scale hog farms not as efficient as medium scale but have advantages in biosecurity and environmental control. This research also shows steady technological progress alone is not enough to satisfy the strategic plan the Chinese government has set forth for food security and structural changes in the industry are necessary.

ACKNOWLEDGMENTS

First and foremost, I would like to thank the holy God for his abundant blessings and guidance throughout this incredible journey. Without his Mercies and Grace, I would not come so far today. I know for sure he will continue shining in my life in the future.

I wish to express my deepest gratitude to my mentor, Dr. Bryon Parman for his continuous support and immense knowledge. I recall very clearly how he encouraged me to explore my research interests since when we first met at his office, he enthusiastically guides me into better understanding how to complete the thesis. Besides that, he also encourages me to pursue my potential career plan in the future. Additionally, I would like to thank my Committee Members: Dr. Saleem Shaik, Dr. Siew Lim, Dr. Lauren Hanna for their invaluable insights and guidance to help with this thesis. I also wish to express my appreciation to Dr. Thomas Wahl for his immeasurable advice and encouragements during my studies.

Special thanks to my families and friends for their support in my life. Their unconditional love is always the driving force pushing me to go ahead. The instructors and classmates at North Dakota State University gave me brilliant ideas and incredible support with the completion of my studies. May God bless each of you in your lives.

DEDICATION

I dedicate this work to my incredible father, Fuhua Tian; my amazing mother Ruilian Shen and my beloved husband, Xin Li.

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1. INTRODUCTION

1.1. Background of Pork in China (Mainland)

China is the largest country with respect to pork production, and pork consumption in the world. In fact, the Chinese Character “家” created 3,700 years ago contains two parts, the “home and family” is a house by adding the roof shown in this character to the pig’s symbol on the bottom portion. Pork is playing a significant role in Chinese people’s lives, and it is the main protein source for the Chinese people since ancient times. There are many famous Chinese recipes made by pork such as Sweet and Sour Pork (Gu Lao Rou), Large Meatball (Shi Zi Tou), Braised Dongpo Pork (Dong Po Rou), Double Cooked Pork Slices (Hui Guo Rou), and Braised Pork Belly (Hong Shao Rou) which are very popular to the Chinese consumers. Centuries before the economic reforms of the late 1970s, Chinese consumers were only able to eat pork once or twice a year for Chinese Lunar new year. Despite stress on self-sufficiency, grain production and agricultural output barely kept pace with the population growth (Lin, 1992). The Three -year Great Chinese Famine (1958-1961) and the Ten-year Cultural Revolution (1966-1976) brought the state’s reform on agri-food. Pork has been the central reform focus to increase meat production, especially the pork production so that consumers’ needs can be met which would raise public trust for the government. This notion is recognized by the Chinese government and has been one of their work focuses. “Let consumers be able to eat pork and eat pork safely”, government officers from the ministry of agriculture and rural affairs talked about how to guarantee the pork supply before the new year in 2020（Control Rural Work Conference, 2019）

To have steady and abundant supply of affordable pork is important to maintain the social stability since 65% their animal protein is from pork (USDA report, 2010). Pork production has dramatically increased after reforms based on the data issued by the Chinese ministry of agriculture and rural areas in 2018. Total meat production reached 85.17 million tons on the mainland, while pork production equaled 54.05 million tons of pork which accounted for 63.4 percent.

To have a better understanding of the cultural and historical significance of pork in China, it is a key to understand the general modern hog industry in China, and the significance of trade.

1.2. Pork Production

Based on the U.S Livestock and Poultry estimates by the United States Department of Agriculture (USDA) Foreign Agricultural Service, total pork production was 113.940 million metric tons in 2018, the top countries for pork production in that year were China, EU, U.S, Brazil, Russia and Vietnam with 48%, 21%, 11%, 3%, 3% and 2% respectively. China as the largest pork producer and consumer in the world, it produces half of the world's total output, and 4.52 times as much as that of U.S (see Figure 1.2)

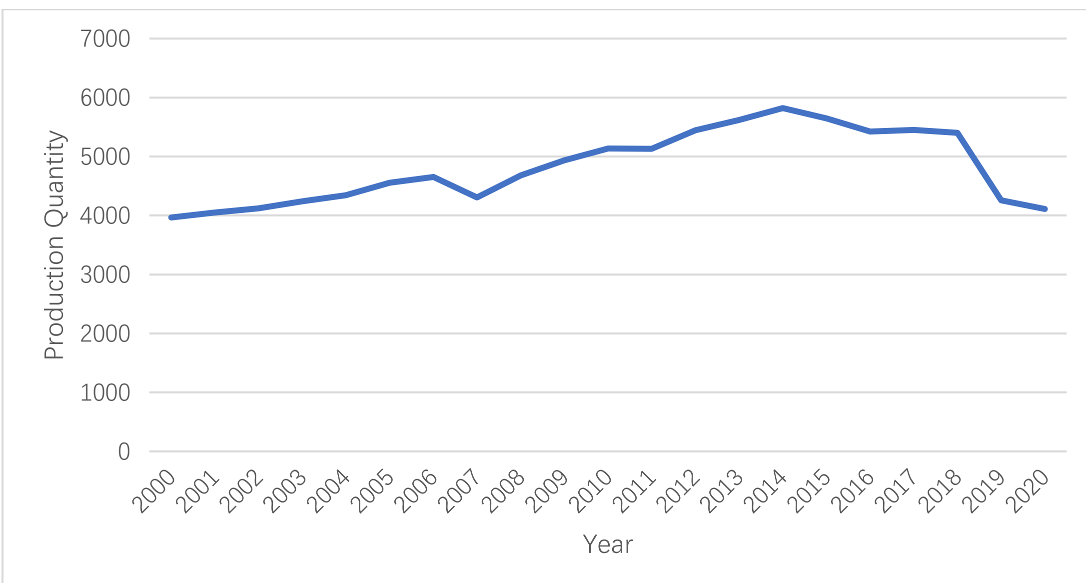

Figure 1.1: Pork Production (in 1,000 metric tons)
Source: NBS (National Bureau of Statistics in China)

Pork production in China has been increasing during the period 2000 to 2020. In 2014, pork production reached a plateau of about 58.208 million metric tons. In August 2018, ASF

(African swine fever) entered China and rapidly spread across the entire country which resulted in devastating impacts on pork production (Zhao at al, 2019). Consequently, its production dropped from 48% in 2018 to 39% of the total. However, China still maintained a dominating role in the world's production.

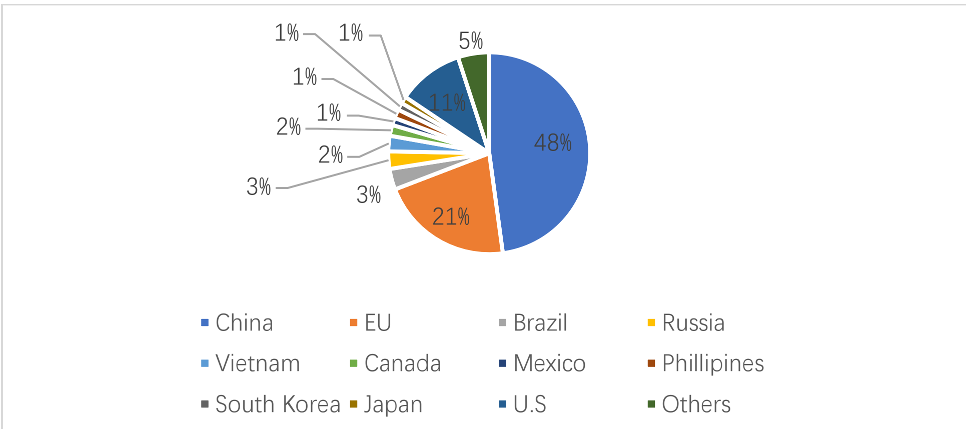

Figure 1.2: Top Pork Production Countries in 2018
Source: USDA Foreign Agricultural Service (2021 Livestock and Poultry)

1.3. Pork Consumption

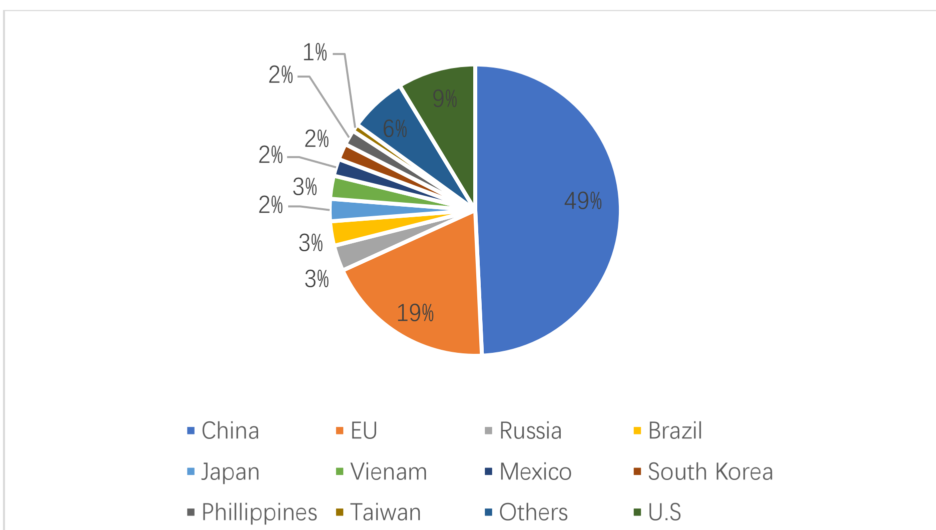

Figure 1.3: Top Pork Consumption Countries in 2018
Source: USDA Foreign Agricultural Service (2021 Livestock and Poultry)

The USDA Foreign Agricultural Service in 2018 reported total world pork consumption was 112.23 million metric tons. China consumed 55.295 million metric tons of pork accounting for 49% and 5.6-times more than that of U.S. (See Figure 1.3) In 2019 and 2020, record pork prices after the epidemic of ASF caused consumption to decline about five percent points, from 49% to 44%% of the world's total.

Pork consumption per capita in the urban areas is steady from 1990 to 2019, even though there is a slight decline in the first decade (1990-2000), there is a steep increase from the lowest point of 16.73 and then moved to 20.73 kg. After small fluctuations, it arrived at 21.23 kg in 2012 and 22.7 kg in 2018. Beef and mutton consumption remained steady while there was a dramatic increase in poultry. Poultry increased from less than 5 kgs in the 1990's to 10.75 in 2012, or 115%. (See Figure 1.4).

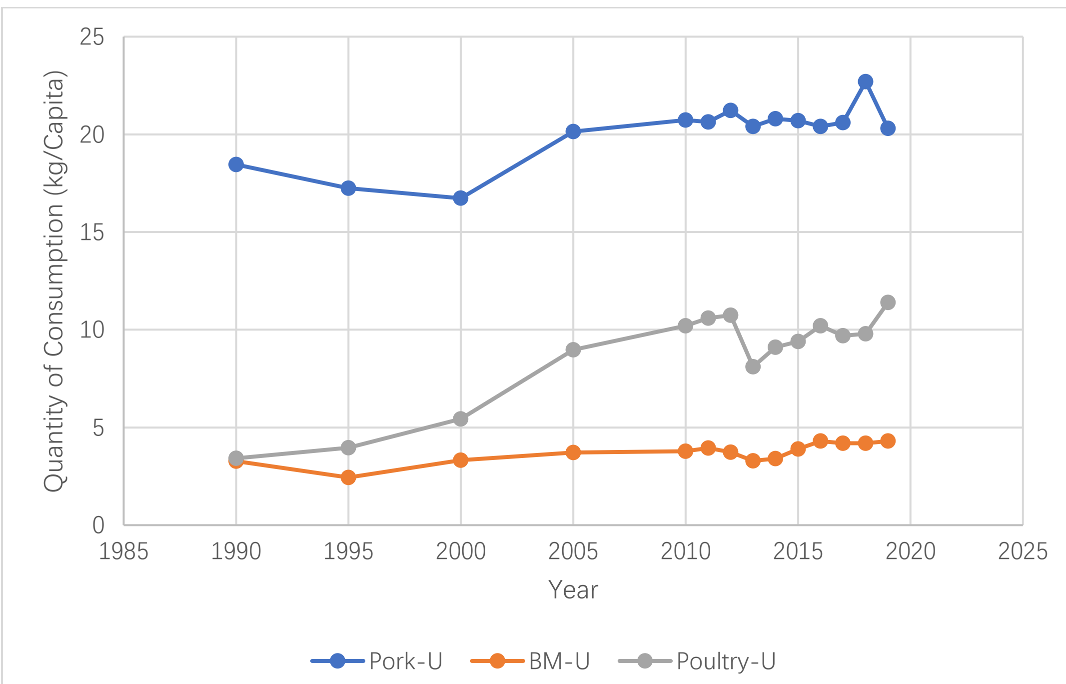

Figure 1.4: Urban Meat Consumption
Note: Pork-U: pork consumption in the urban area; BM-U: beef and mutton consumption in the urban area; Poultry-U: poultry consumption in the urban area.
Source: NBS (National Bureau of Statistics in China)

Total pork consumption declined from 73% to 56% in 2018 showing half of meat consumed by urban residents is still pork. Beef and mutton consumption maintains around 10%, while the poultry consumption increases largely from 14% in 1990 to 32% in 2019, up 18% (See Figure 1.5).

In contrast, rural pork consumption per capita increased steadily from 10.54kg in 1990 to 20.2 in 2019 or a 91.65% increase. Beef and mutton consumption per capita changed little while there was a very large increase for poultry (See Figure 1.6). Pork consumption in rural areas decreased from 84% in 1990 to 62% in 2019 (See Figure 1.7) though the majority of meat consumed is still pork.

The pork consumption gap between urban and rural residents was narrowing in 1990. Pork-R (pork consumption per capita in the urban areas) was 57% of Pork-U (pork consumption per capita in the rural areas) while in 2018, the Pork-R was almost the same as Pork-U (Pork-R: 23 VS Pork-U: 22.7). The percentage of pork relative to total meat consumption was in decline over the last few years (See Figure 1.5 and 1.7). As observed by Wang et al (2019), this indicates the focus of the pork industry switching from quantity to quality and food safety.

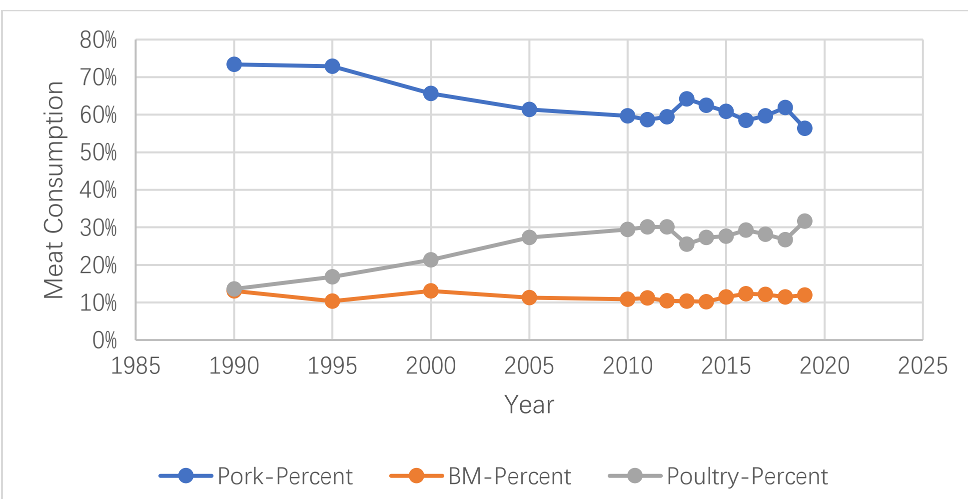

Figure 1.5: Urban Meat Consumption (%)
Source: Compiled using data from NBS (National Bureau of Statistics in China)

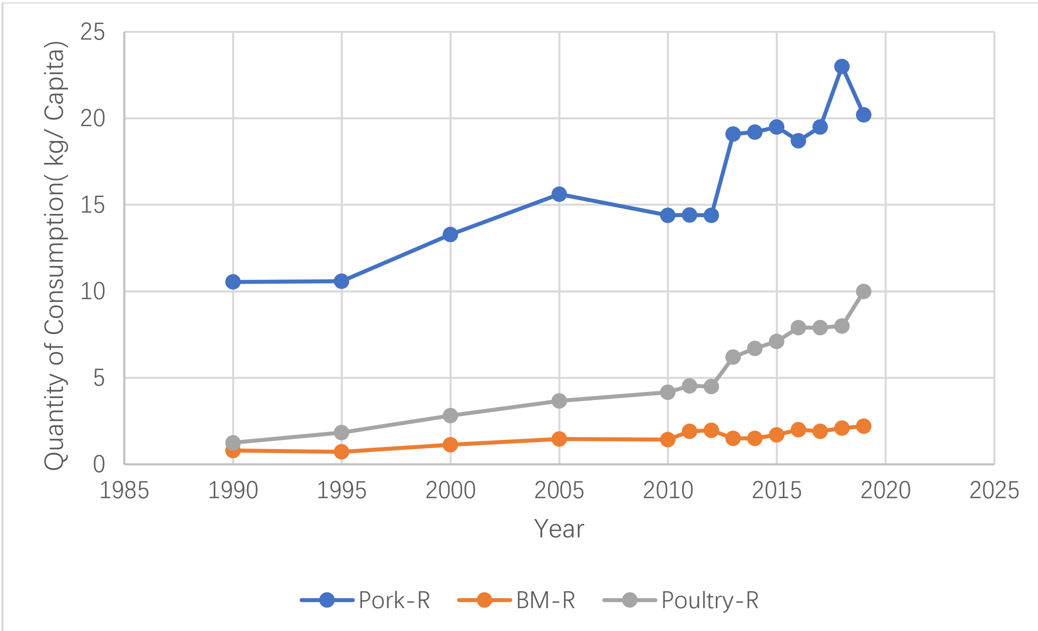

Figure 1.6: Rural Meat Consumption
Note: BM-R: beef and mutton consumption in rural areas; Pork-R: pork consumption in rural areas; Poultry-R: poultry consumption in rural areas.
Source: NBS (National Bureau of Statistics in China)

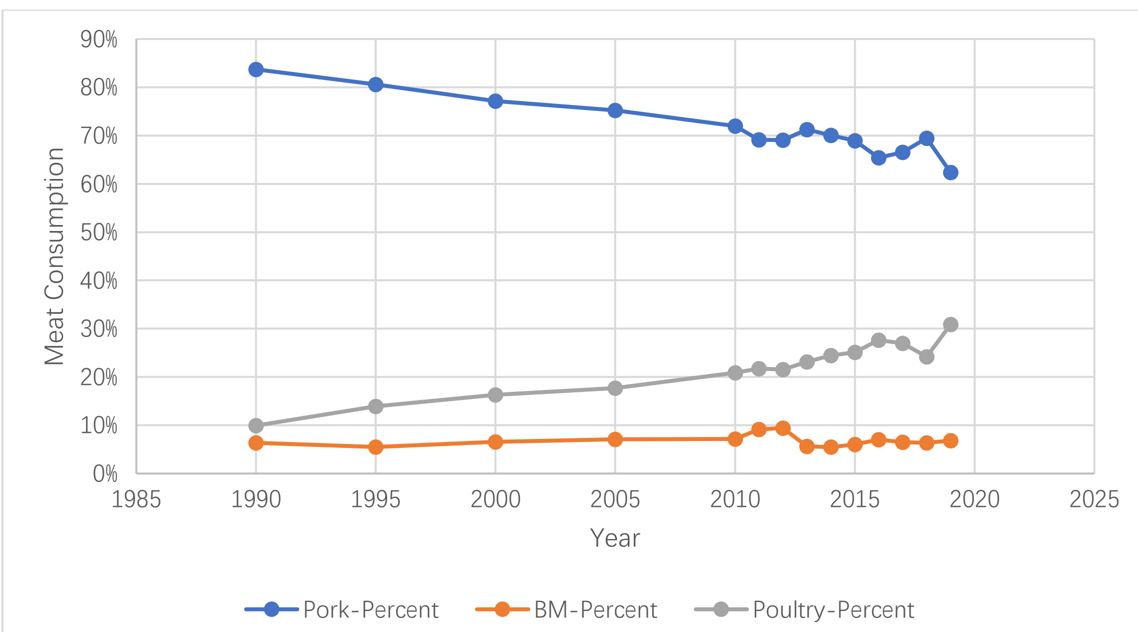

Figure 1.7: Rural Meat Consumption (%)
Note: BM refers the beef and mutton.
Source: Compiled using data from NBS (National Bureau of Statistics in China)

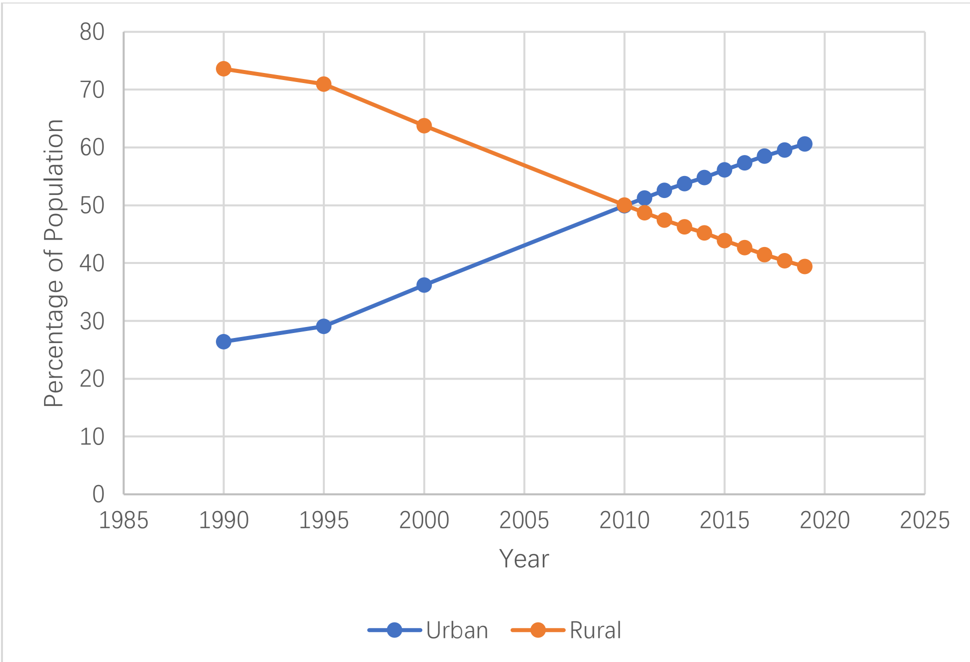

Figure 1.8: Urban and Rural Population Composition
Source: NBS (National Bureau of Statistics in China)

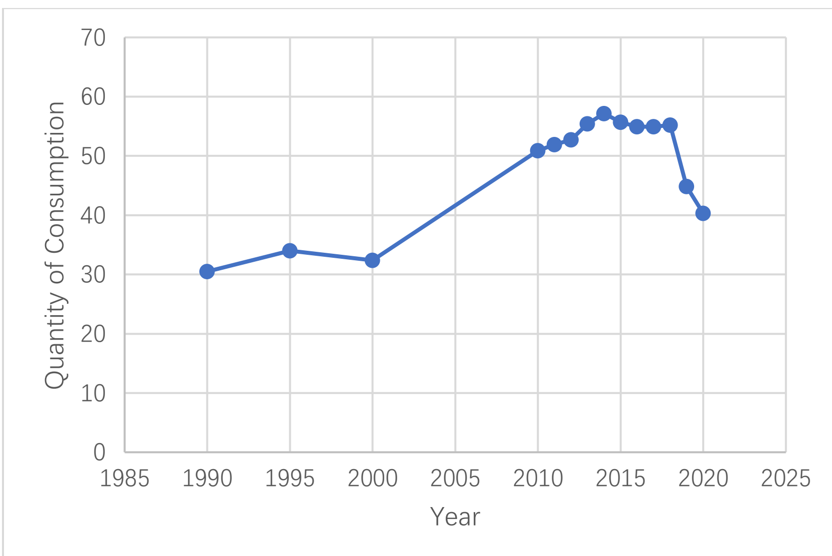

Figure 1.9: Total Pork Consumption Estimation (Million tons)
Source: Compiled using data from NBS (National Bureau of Statistics in China), USDA Foreign Agricultural Service (2021 Livestock and Poultry)

With respect to the urban and rural population composition (see Figure 1.8), the urban population percent increases from 26.41% in 1990 to 60.6 percent in 2019 while the rural population percent drops from 73.59% in 1990 to 55.162 percent in 2019. This explains very well how China's urbanization process makes progress. This accordingly mirrors the increasing trend of pork consumption because of the increasing purchasing power of the Chinese consumers. The overall consumption was increasing and reached the zenith in 2015. Since 2016, total consumption has declined as there were only 44.8667 million tons of pork consumed in 2019. It decreased by 13% over the previous year due to the outbreak of ASF (See Figure 1.9). With the transition and upgrading of the domestic consumption market, consumers started to adjust the dietary structure and are inclined to eat health consciously. As a result, demand for pork has slightly weakened. In addition, the consumption concept of urban residents is gradually changing. For example, the expenditure of dining out has increased rapidly since 2010 as the average expenditure per capita of urban residents on outdoor dining and drinking is 1,019 Yuan ($155.21) which represents an increase of 67.9% compared to 2005. This yields an average annual increase of 10.9%. Additionally (NBS: 11th Five-Year Plan Achievements,2011) outdoor consumption of pork has increased accordingly.

While pork is still the major protein source for the Chinese consumers, the impacts of ASF outbreaks and the change of consumers' consumption preference raises the question: is pork likely to be substituted by other meats such as beef, mutton, or poultry? One major hurdle to increase the alternative meat is first the cost. Given the higher price of beef and mutton, consumers are reluctant to replace the pork with them especially for the consumers who are price sensitive. This also explains why for years the consumption of beef and mutton maintains the same level (see Figure 1.3 and Figure 1.4). Another key barrier is the outbreak of pandemics such as SARS in 2003 (severe acute respiratory syndrome) and H1N5 which resulted a serious consequence to producers, processors, and consumers (Pan, 2013). Consumer taste is critical, and pork is the staple meat with no real substitute, especially given its cultural significance.

1.4. Import Barriers

From the previous discussion, China consumes nearly half of the world's pork. This implies even if China could import all its pork needed from other countries, it might still be unable to meet the huge domestic demand. In September 2020, the Ministry of Agriculture and Rural Affairs makes very clear in the "SUGGESTIONS ON STRONGLY ENHANCING THE INDUSTRIALIZATIONS OF THE HOG INDUSTRY" to ensure a steady supply of pork, hog production is included in the national food security strategy. This is a long-term and priority policy in China's next Five-Year Plan (Cheng, 2020). China's emphasis on pork production is self-sufficiency. On December 30, 2020, the Conference of Directors of the National Department of Agriculture and Rural Affairs stress the goal of 14th Five Year Plan on pork production maintains about 55 million tons, nearly 33. 72% up from the current production (41.13 million tons).

Xin Guochang, the Chinese officer from Ministry of Agriculture and Rural Affairs claims the import of pork has been rising in the past decade, but the imports mainly play a role of regulating supply and demand. The quantity of imported pork accounts for less than 3 percent of the domestic production, and the pork supply is dominated by self-production (Guangming daily, 2019). Import of pork mainly works to tackle the tight domestic pork supply. Additionally, the majority of imported pork is frozen which is less preferred by Chinese consumers who think hot pork is fresher (Zhang et al, 2019). But this phenomenon is changing. In the 1st tier cities, consumers' focus is shifting from fresh pork to chilled and frozen pork products. Though in 2nd and 3rd tier cities, consumers still prefer fresh pork (USDA Foreign Agricultural Service, 2021).

1.5. Challenges for China's Hog Industry

1.5.1. Volatile Pork Prices and Unsteady Pork Supply

Retail pork prices in China have been increasing constantly compared to the U.S. With the outbreaks of ASF in 2018, the price differences have grown much wider as the 2018 pork price was 8.11 times the U.S price. In 2020, the pork price in China reached the highest point in history at $ 4.738 per pound. In contrast, U.S pork remains relatively steady at a comparatively lower level.

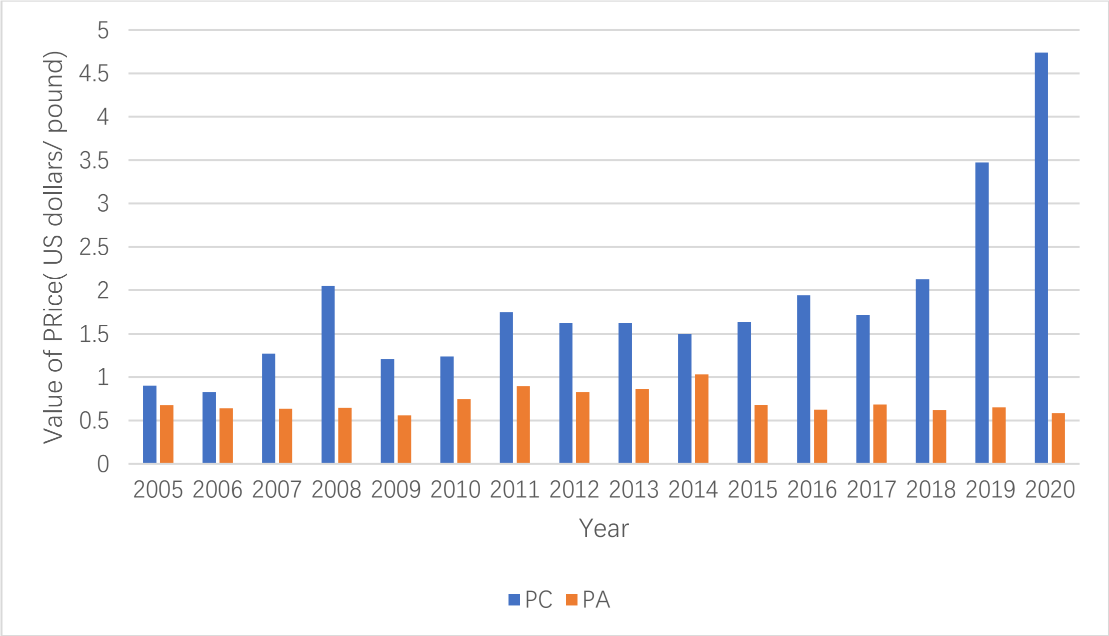

Figure 1.10: Average Retail- Pork Price of China and U.S (U.S dollars/ lb.)
Note: the pork price of China is converted into U.S dollars at official exchange rate. Prices are not adjusted for inflation.
Source: Average pork price of China calculated using data from EPS DATA (2005-2017), and Ministry of Agriculture and Rural Affairs of the China (2018-2020), the pork price data before 2005 is missing. Average pork price of U.S calculated using data of USDA ERS.

1.5.2. High Production Costs

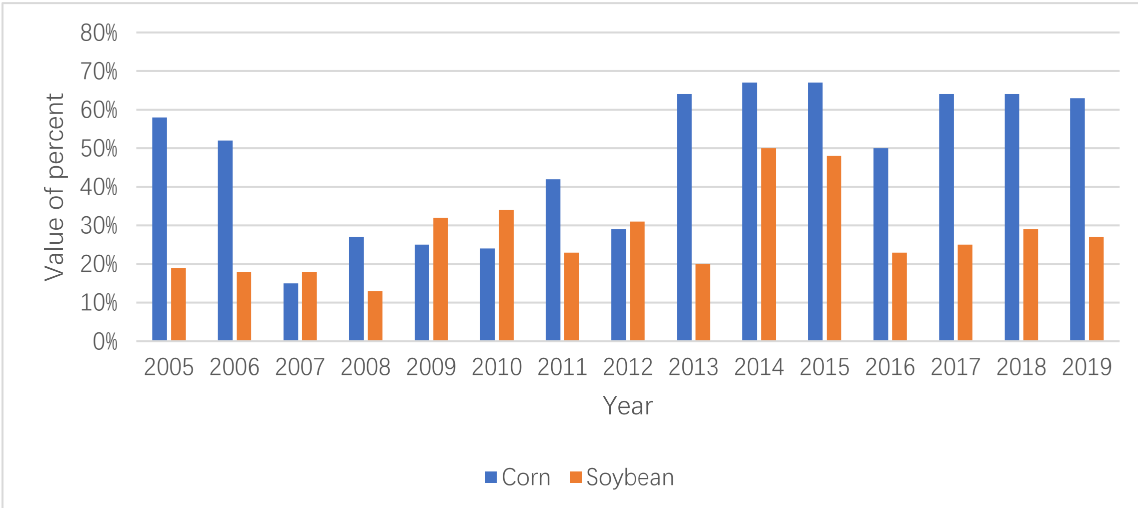

Figure 1.11: Soybean and Corn prices differences between China and U.S
Source: Data of Food and Agriculture Organization of the United Nations

Feed is the largest component of hog production cost in China (Gale, 2016). Of the feed ingredients, corn and soybeans account for 50%. We compare the two ingredient differences between U.S and China. China's price of soybeans are consistently around 20-35 percent while the average difference is 27%. The price difference of Corn in China and U.S is generally 30-60 percent while the average difference is 48%. This price shows why hog production in China has much higher feed costs than in the United States.

1.5.3. Low Concentration Rate

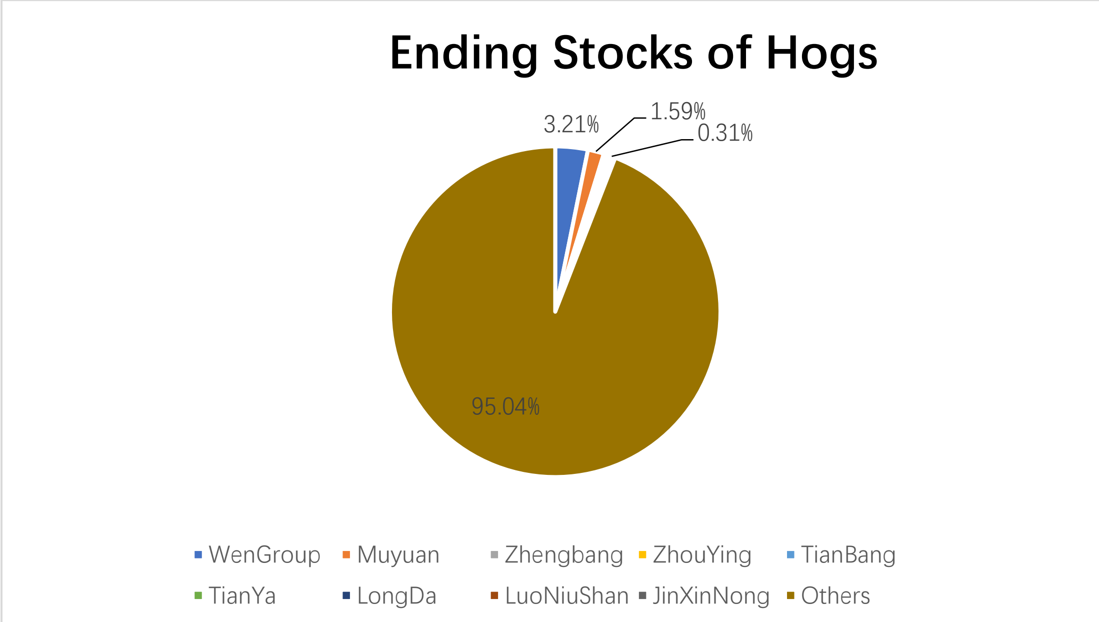

Figure 1.12: Top Public Listed Companies of Pork in China
Source: 2018 NBS (National Bureau of Statistics in China)

Concentration indicates the degree of horizontal integration. The U.S food industry has been increasingly integrated and concentrated since the last century (Hendrickson et al, 2014). Based on the data issued by NBS in 2018, there are 693.82 million head of hogs in China with the top public listed pork companies together accounting for 6.45%. The top five companies for pork ending stock in that year are WenGroup, MuYuan, ZhengBang, ZhouYing, TianBang with 3.21%, 1.59%, 0.33%, 0.33% and 0.31% respectively. This proves the hog industry still has a very low concentration ratio by comparison with U.S food system. “The top thirty Pork Powerhouses in 1994 owned 15% of all U.S sows in full production, the top thirty in 2004 had 45% of the total, with the top three alone comprised 21%” (Reimer, 2005). The market concentration rate has a positive relationship with the R&D, and might result in the lower level of environmental pollution control and biosecurity technology investment in China.

1.5.4. Food Safety

In the past decade, the reputation of China's food safety has been tarnished by several high-profile food safety crisis. The first one is the Sudan No.1 accident in 2005. Guangzhou TianYang Food Company was discovered using a banned, potentially cancer-causing colorant, to produce a food additive. In 2008, the contaminated melamine infant formula was disclosed in the dairy giant Sanlu by the Ministry of Public Health of China. In the pork industry, one notable incident is the "Clenbuterol Case" discovered in Jiyuan Shuanghui, a subsidiary of Shuanghui International Group which is the dragon head enterprise pork processor. It had a reassured brand built over years but became seriously questioned due to the incident and its loss exceeded 12.1 billion Yuan. In order to restore its brand reputation, Shuanghui spent $7.1 billion to purchase the U.S pork giant Smithfield in 2013. With respect to the cause of the "Clenbuterol Case of Shuanghui", the first problem was issues in upstream production. Shuanghui's focuses on the slaughtering and processing stages and breeding is not its strength. It has the slaughter capacity of 20 million head of hogs. The majority of pigs needed to fill the facilities are from small hog dealers. The company's production capacity was less than 5% of what was needed to meet slaughter capacity in 2009 (Tong et al, 2011). Secondly, because of the large scatter scale of hog breeding, it is very hard for the administrators and governments to carry out very strict supervision. Additionally, the supply chains of pork production are unbalanced. The pork industry is developing rapidly in the processing stages but related industries such as feed and animal medication industries are still not modernized. Also, because of the costs of scaling up breeding and likely latent pandemic risks, the upstream stage of production is not expanding as fast as the downstream. The term "top heavy and light feet" is used to describe this unbalanced phenomenon of the supply chains of pork production.

Shuanghui is not the only company with such problems. In order to upgrade the scale production, improve the concentration rate of dragon head enterprise (agribusiness leading firms), the ministry of Commence has announced many plans to support the development of industrialization in the agriculture sector. The speed and scale change from small backyard to an industrialized scale was accelerated after 2006 as the government's attempts to solve the food safety issues by factory farming (Schneider,2014). For example, to stimulate the transition to larger size hog farms, the government offered subsidies of $366 million in 2009 to improve the facilities of hog production (USDA report, 2010). Additionally, the food safety crisis drove the consumers attitudes to change. Modern consumers have larger disposable salary and are more willing to buy the pork produced by the large-scale famers which they believe is free from illegal additives and other harmful materials to the health (Barcellos et al, 2013)

1.5.5. Biosecurity Concern and Environmental Pollution

At the 12th meeting of Chinese Central Committee in 2020, biosecurity was included as part of the national security system. In 2007, the outbreak of "Blue Ear Disease" (a variant of the porcine reproductive and respiratory syndrome), an acute and highly lethal disease all over the country resulted in the mass death of pigs. Without sufficient pigs available, the pork price skyrocketed.

In August 2018, the outbreak of African Swine Fever (ASF) in China began in Shenyang, Liaoning Province, and spread rapidly to all other provinces. Large areas of swine morbidity and death numbers and the speed of the ASF pandemic's spread was unprecedented. The data from the Ministry of Agriculture in China reported the pork production in 2017 was 54.518 million tons and in 2018, the production was 42.55 million tons. This shows a drop of 21.95%. In December 2018, the retail pork price was 41.75 Yuan/kg($6.2625/kg). In December 2019, the retail price was 67.99 Yuan/kg($10.1985 /kg) or an increase of 62.85% (Ministry of Agriculture and Rural Affairs of China data, 2019). The fatality rate of ASF can be as high as 100% on small farms resulting in total bankruptcy for the farmer. Also, the loss of farmers has a negative impact on rural poverty alleviation. ASF pushed the whole swine industry to accelerate structural shifts. Because decentralized hog farming is very hard for the government to supervise regarding pandemic prevention, the outbreak of ASF accelerates the small farming exit from the market (Wang, 2020). Large farmers invest in high-tech solutions to mitigate the biosecurity issues arising from ASF and other animal diseases. In addition, staff training is also followed to ensure biosecurity measures while small, and medium-sized producers are unable to afford such investments (USDA Foreign Agricultural Service, 2021).

Environmental pollution is also an issue from hog production. The 'floating dead pig' incident in March 2013, where a large number of dead pigs were found floating in the waters of the Songjiang Section of Shanghai's Huangpu river is an example. 16,000 head of dead hogs were spotted and traced to JiaXing of Hangzhou provinces through tags in their ears. This environmental crisis made the public increasingly concerned about potentially polluting drinking water. Though Shanghai's municipal water department confirmed there was no water pollution, the public's doubts have not quelled.

There are 130,000 hog famers in JiaXing, but 89% of them are small scale famers with less than 50 head. They generally have poor breeding conditions, and the piglet mortality rate is very high. "Proper disposal of the carcasses is key to prevent the infectious disease from spreading further and the remains from causing secondary pollution" (Qin, 2019). Qin (2019) discusses "the method of disposing of the huge number of carcasses either by chemical process, cremation, or deep burial". The first one is the most expensive method while the other two are more cost-effective based on the land availability. But considering land is also a scare resources, this method might become harder in the future. Unfortunately, many small-scale famers lack environmental awareness and are unable afford the expenses of harmless processing. Additionally, the massive increase of manure arising from the swine industry is the leading source of water pollution from livestock.

1.6. Research Objectives

The main goal of this research is to evaluate comprehensive integration for the Chinese pork industry given the multiple challenges and have substantial increase in the hog farms like in U.S. The successful practice of U.S hog industry is pushed by the pronounced structural changes (McBride and Key, 2013). More importantly, the US pork industry shows the transition from small to medium and then larger farms with more vertical integration.

In this research we will show this is happening in China when the hog farms are expanding further so that they can control every aspect of pork production, minimize risks, and at least partially control the market. In addition, it will become easier for the governments to have effective enforcement about potential biosecurity and environmental pollution issues.

To reach this goal, we have three specific objectives of this thesis:

I. To analyze the current state of pork production in China.

II. To examine the potential efficiency, increase after implementing comprehensive vertical and horizontal integration in the hog industry of China.

III. To estimate the efficiencies between different scaled Chinese hog firms.

In the empirical model, we will analyze large- scale firms which might not be the most efficient, however, they do have a lot of advantages, but due to lack of the relevant data, we are unable to test biosecurity measures and environmental pollution prevention.

The thesis is organized into six chapters. In Chapter 2, the relevant theories and literature are reviewed. This section discusses the advantages from the perspectives of transaction costs, market power, steady supply, lower risks and etc., The disadvantages of vertical integrations are also briefly covered in this section. In chapter 3, we present the three theoretical models. In chapter 4, the data and its sources, statistics analysis regarding the different scales of pork industry in China are presented for this study. In Chapter 5, the empirical model and analysis are discussed. In the final chapter, the conclusions and the policy implications of the results are stated.

2. THEORY FRAMEWORK AND LITERATURE REVIEW

2.1. Vertical Integration

Vertical integration is a corporate strategy that has been regarded as a key force in the development of high productivity in U.S and used to enhance the shareholder's wealth. (Chandler, 1977; Lubatkin, 1982). Chandler (1962) and Williamson (1971) believe that to build a large and successful company, vertical integration strategy is very crucial. D'Aveni and Ravenscraft (1994) indicate there is a substantial incentive for firms to vertically integrate. Firm's managers use vertical integration to increase profitability or decrease the firm's risk (Maddign, 1981). Though implementation of vertical integration strategies has been attacked, still some critics have not recognized vertical integration could be an effective strategy and a competitive weapon (Harrigan, 1984).

Regarding the definition of vertical integration, Coase (1937) introduced vertical integration involved without the price mechanism is the coordination of the various factors of production. Later, Blois (1972) explained "vertical integration is the organization of production under which a single business unit carries on successive stages in the processing or distribution of a product which is sold by other firms without further processing." Blois's definition does not include the selling function. Porter (1980) gave a more complete definition of vertical integration as being the combination of production, distribution, selling and other economic processes by one single firm. Firms utilize internal transactions instead of market transactions to complete the company's strategy goals and many vertical integration decisions are made mainly about "made" and "buy" decisions. Dabashi et al (1999) claims fully vertically integrated firms include all the value chains from breeding of pigs to the retail level of slaughtering, and retailing pigment, some might also get involved the feed milling for the pigs' feed.

2.2. Justification of Vertical Integration

2.2.1. Reduced Transaction Costs

Transaction costs are very important determinants of vertical integration as it can be used to effectuate a bilateral exchange (Frank et al, 1992). Vertical integration in response to the transaction costs would generally increase welfare **(**Schmalensfee, 1989). Regarding the impact of vertical integration on transaction costs, Williamson (1971, 1975) introduced extensively how vertical integration can help to reduce the transaction costs. Firstly, vertical integration can become attractive through common ownership, because joint profit maximization is obtained instead of individual firm profits. Secondly, with the help of vertical integration, more conflict resolution machineries such as fiat are more efficient to settle conflicts or reconciles differences. Thirdly, vertical integration is often defined as the linking of successive stages of production (Maddigan, 1981), therefore (Porter, 1980) integration may reduce the overall cost by gaining market information which can then flow more freely through states and the information is exchanged more efficiently.

2.2.2. Less Vertical Externalities and Information Asymmetry

Jokowi(2010) remarks that: "Vertical integration is a response to inefficiencies that arise when there is market power in both the upstream and downstream markets." Also, vertical integration can efficiently avoid or reduce the negative effects of externalities by internalizing the externalities because the vertical externalities arising from double marginalization between successive monopolists are possibly eliminated (O'Brien, 2008).

When the firms at the upstream and downstream have independent production out of their own profits' maximization, they both add markup to the production cost or the retail price respectively. Double marginalization will raise prices of down streams higher than the maximized joint profits of integrating upstream and downstream firms require (Jokowi,2010). Additionally, because of information asymmetry between upstream and downstream firms, the downstream firms are unable to access the input quality supplied by the upstream firms, and the upstream firms do not have good knowledge about the demand of downstream firms. In the paper of "INFORMATION ASYMMETRY AS A REASON FOR GOOD INDUSTRY VERTICAL INTEGRATION", Hennessy (2002) suggested information externalities is one reason why vertical integration is being used to circumvent the market failure concerning the nature of food quality and problems in detection quality.

2.2.3. Less Uncertainty and More Stability of Supply

Given the stable relationship of upstream and downstream stages, integrated firms can operate more efficiently compared to an independent supplier facing the competitive risk of being dropped or squeezed by the other party. Additionally, the integrated firms can more easily ensure a consistent supply during tight periods. (Porter, 1980).

Despite costly capital requirements to reach this goal, many organizations think it is worthwhile to implement vertical integration given these advantages. Chandler (1964) claimed the motivation for business expansion and vertical integration is to have consistent supply and higher demand for assured supply which is more likely to lead to vertical integration (Malmgrem 1961). Backward integration could work as one way of reducing risk by vertically integrated firms and assure steady inputs as well. (Carlton,1979) (Lieberman, 1991). Forward integration may eliminate the impact of uncertainty from downstream firms on buying (Bernhardt,1977).

2.2.4. Economies of Technological Innovation

Armour and Teece (1980) used the data of the U.S petroleum industry during the period from 1954-1975 and demonstrated vertical integration can enhance innovation by facilitating the implementation of new technology. A majority of studies on the correlation between market concentration and R&D have been examined and found a positive relationship since firms required the expectation of increased market power to have the incentive to make investment (Schmalensee, 1989). Integrated firms have the potential of tapping into technology to gain a better understanding and control of the industry. Regarding the effects of the firm size and monopoly on R&D, large firms have advantages in securing, financing for risky R&D projects given the availability and stability of internally generated funds. Additionally, the returns are higher, and R&D is more effective in larger firms.

2.2.5. Monopoly Power and Foreclosure

Despite the advantages of vertical integration, there is still considerable discussion concerning some of the disadvantages. Williamson (1975) considered the indirect effect of vertical integration on market concentration which says latent monopoly power is mobilized and have the concentrating effects which might raise the capital requirements and force the small firms to exit from markets. “Vertically integrated competitors use foreclosure to squeeze out nonintegrated firms from the market by denying them access to materials, markets, innovations, intelligences, or other competitive advantages via price competition” (Harrigan, 1983).

Another potential incentive of vertical integration attacked is vertical foreclosure which “can be used strategically soften competition in the short run by raising rival’s costs or in the long run by increasing the costs of entry to foreclose rivals that might otherwise enter the market”, Joskow argued in his paper only when “there is a monopoly power over the supply of bottleneck resource input” which might hinder the competing firms access need attention, however, by charging a monopoly price for the essential facility, firms can extract the monopoly rents (Joskow, 2010). Whether there is an overall welfare gain or loss to the society often depends on the welfare criteria used (Antonovitz et al ,1996). As long as there is no collude between monopoly firms to charge a higher price than in a competitive market or restrict the output quantity in the market, the monopolistic competition can still benefit the consumers, the U.S airlines industry is one example. Large fixed costs make the airlines to have economic incentives to grow very large because of economies of scale and it results in a handful of very large airlines dominating the industry, "between 2005 and 2015 the airline industry underwent a series of mergers and decreased from nine major airlines to just four: American, United, Delta, and Southwest, these airlines controlled 80 percent of the U.S. market in 2015" (Wolla et al, 2018). Though few numbers of airlines in the market, however, there is still room for new airlines to access in the airline industry. Chipty (2001) discussed the effects of vertical integration in the cable television industry finding that integration results in market foreclosure, however, does not harm but might benefit consumers' welfare due to the associated efficiency gains.

2.3. Vertical Integration in China

2.3.1. The Rapid Development of Scattered Scale Hog Farming

Under the national conditions of a large population and limited land, China has formed a stable rural economy dominated by small-scale family farms (Huang, 2020), which is supported by the fundamental institutional structure of an agriculture system called" the household responsibility system" (HRS). By the end of 1983, HRS was fully adopted in rural households by contracting land to individual households on an egalitarian basis, allowing the farmers to rent their lands to others but restricted not to sell. After "Fulfilling procurement quota obligations", farms are permitted to sell the surplus products (Lin, 1997). Lin (1992) employed the province-level data to evaluate the contributions of HRS "decollectivization" on productivity and concluded HRS contributed to agricultural growth by 20.54%. HRS as the fundamental institutional system sustains plays a significant role in the agricultural development of China.

China's 13th Five-Year-Plan requires the stability of the family contract system. With the implementation of HRS spreading all over China, small-scale farms that combines farming with breeding livestock is developing very quickly. The traditional model continues to raise one or two pigs in a family and feed the pigs with swill and grain. However, with small scale farms it is hard to standardize production, disseminate technology, and establish a traceability system. It is also difficult to detect if there are any harmful substances in the food given the small scale of livestock production (Gale, 2011). In essence, while food safety issues are a big concern, ways to monitor and eradicate disease are essentially impossible to implement.

2.3.2. Agriculture Industrialization in China

Small-scale livestock farming requires modernization to deal efficiently with the transport, storage, processing, and market issues necessary for growth. Agricultural industrialization is the basic characteristics of modern agriculture, which is the only way to develop into a strong agricultural economy (Li, 1997). The term "industrialization of agriculture" popularized by Tom Urban (Boehlje,1996), refers the trend toward large production and vertical integration and coordination among the various stages of the food industry (Antonovitz et al ,1996). In 1998, the agricultural industrialization policy was approved by allowing more "dragon head[1]" enterprises and hence they developed rapidly. This policy has improved the farmer's income and increased the agricultural product quality (RCRE, 2010).[2]

[1] Dragon Head enterprise originates from one Chinese traditional dance which is called "dragon or lion dance". This form of dance normally is performed by several dancers, one of whom takes the lead while others make movement accordingly. In industry, the leading "head" company has the demonstration effects upon the industry , and hence others follow their direction.

[2] The report is available on http:// Oxfam.org.hk/en/f/news and publication/1402/Content 8565en.pdf

The agricultural industrialization in China yields a diversified classification system. Nie (2012) discussed the industrialization of the pork industry: 1st is "Farmer-Market" which permits the farmers to enter the market and trade with others, this is a temporary contract relationship; 2nd is "Dragon Head Enterprises-Farmer" :one industrialized company signing the long-time contracts with multiple farmers. Since farmers make production decisions based on the contract orders, this model is also called" contract farming"; 3rd is "Dragon Head Enterprises-Farm": companies rent the farm and hire farmers to work for them while the dragon head enterprises are responsible for production, processing and selling.

Gale and Hu (2011) have similar classification about an industrialization model. One is a loosely coordinated "Company- farmer" model which is encouraged to develop modern slaughter processing facilities. However, this link with producers is very weak and processers are unable to control the production of those highly dispersed hog famers and pork safety is unassured in this model. The exposure of the "lean meat powder" accident in 2011 is one example. Another model is the "Farmer-Supermarket Linkage" model that was intended to address the shortcomings of diffused networks of small farmers. The idea was to build direct correlation with producers and improve the horizontal integration with farmers while the supermarkets are inspired to link directly with farmers reducing transaction costs and the information exchange is more fluid. Though some are reportedly successful in the early stage of this model, a lot of producers are unable to meet the standard requirements supermarkets set which indicates the transmission of market and technical information from retailers to producers is not sufficient in China.

2.3.3. China's Vertical Integration

In 1998, the central government claimed the main way to achieve the agricultural modernization objectives is to implement vertical integration which refers production expansion and integrating with processing and marketing as it increases technology investment and helps farmers get access to the markers. The driving engineering of vertical integration is “dragon head enterprise policy” (“more government policy support, easier to access loans”) (Schneider and Sharma, 2014). “Dragon Head Enterprise” is called by some scholars as China’s “vertical integration”. Its goal is to promote the agricultural development by linking the farmers between upstream and downstream processes which is different than the definition of vertical integration in other counties, in the Chinese version, the first part is regional scale expansion; the second part is processing and marketing integrating within a single firm or an entire commodity system (Schneider and Sharma, 2014). The dragon lead enterprise generally runs the business via contract farming “Company-Farmer”. Then, agricultural companies sign long-term contracts with farmers and clearly defines the rights and obligations of both parties. Contract arrangements can reduce transaction costs and diversify the operation risks for the companies. They can also help farmers to circumvent the volatile price risks and sales risks (Wan, 2008).

China’s “Company – Farmer” model started in the early 1980s by Wen Group in the poultry industry. Wen Group contracted with farmers to expand and standardize the broiler processing and production. Today, this 1980’s start-up firm is one of the largest domestic agribusiness firms in China and contract farming is now widely used across the agribusiness sector (Schneider and Sharma, 2014). Wen’s model can be summarized as 1st: quasi – factory management, those cooperated farmers are not employees of Wen Group, but independent entities and they have to take the possible risks on their own. 2nd: clearly states “livestock property rights are owned by Wen Group”, the company provides piglet, feed, vaccines and etc. and they are the property of the Wen Group.” (Wan, 2008).

This model is very successful; however, contract farming is still restricted by the incompleteness of contracts, opportunistic behavior, and other risk factors (Zhang, 2010). In the Wen Group example, the farmers who signed the contract with Wen Group are not part of the company but an independent entity. They have to bear all the risks from production which is also the majority of the risks of hog production. The partnership between farmers and companies are basically" Contract of Commission Processing" (Wan, 2008), there is no real "benefit sharing, risk sharing" community of interests (Zhang, 2010). This model brings a lot of challenges for the farmers, especially small famers, as a lot of failure cases of contract farming can be attributed to the imbalance of benefits distribution and the farmers are the risk taker. Small famers have to wholly depend on the companies to sell the products as they do not have much bargaining power and lack a good understanding of legal contracts (Schneider and Sharma, 2014).

In addition, the loss of an effective supervision system in China also results in the risk of production because any system is designed based on a certain social environment. With respect to any biosecurity and environmental pollution issues, it is difficult to regulate and enforce on this scale. To effectively avoid such relevant issues, Wen Group choose to sign the contract only with farmers who have a certain scale but are unable to grow into a separate entity (Wan, 2008). Some researchers define contract farming led by dragon head enterprises in the hog industry as China's vertical integration, while others such as Sheng (2001) and Wan (2008) instead believe "firm-famer" is neither vertical integrated nor marketization, but a medium form called "quasi- vertical integration".

Dragon head enterprises also choose to merge with international hog producers. In the case of Shuanghui acquiring Smithfield, many researchers began to investigate this international acquisition. The exposure of "lean meat power" accident in 2011 accelerated Shuanghui's pace to restore its reputation. Because of unsupportive polices out of environmental concern, the plan of building new hog farms was rejected by the local governments. Shuanghui decided to acquire Smithfield Foods to obtain the comparative advantage in environmental regulation and hog production and processing of U.S hogs (Tao and Xie, 2015). Zhang et al (2019) discussed it does not bring a fundamental change to Shuanghui either in upgrading the existing processing capacities or importing more branded pork. However, its product brands and company image are indeed promoted such that this acquisition has made Shuanghui more competitive and profitable.

2.3.4. Contribution to the Literature Review

In this paper, the author tried to make contributions in the following:

Firstly, this paper has a more complete introduction and history of the Chinese hog industry where future researchers can continue with the foundation work to address the multiple challenges.

The significant achievements of dragon head enterprise either by contract farming with more domestic farmers or integrating with international brands is pronounced. Though the descriptive analysis or case studies of vertical integration in the previous literature does provide a foundation for the relevant research, the conclusions lack support from proven theories and comprehensive data analysis. Additionally, the research is normally done from a specific point of view. For example, Gale and Hu (2011) mainly target the food safety pressures, Tao and Xie (2015) mainly focus on the acquisition case of Shuanghui and Smithfield, Ortega et al (2009) discussed the consumer preferences for imported pork while Wei et al (2015) reported biosecurity and disease management issues. Very few research papers comprehensively discuss the integration application outside of Schneider and Sharma (2014). However, their research lacks the data. In this paper, we will fill the gap by using a proven model and data to discuss why " dragon head enterprise" model + comprehensive integration is a fundamental solution for the challenges facing the swine industry of China. The comprehensive work provides the necessary theory foundation for the further development of dragon head enterprises and is needed for Chinese government policy design to attract or stimulate the farmers' more progressive investment activities in the hog industry while pursing economic profits or better efficiency.

Thirdly, this is the first-time efficiency research is discussed with the biosecurity issues and food safety and environmental pollution to evaluate the scale of hog farms and efficiency change with potential advantages in biosecurity measures and environmental control.

Finally, to the beast of our knowledge, this is the first study to group the efficiency studies using the regions from policy-oriented groupings including Key Development Area (KDA), Restricted Development Area (RDA), Potential Development Area (PDA) and Moderate Development Area (MDA) instead of the traditional classification of regional division such as West, Middle, and East. The policy makers can evaluate how effective the policies might be and adjust the existing regional policies based on the efficiency conclusions of different regions.

3. THEORETICAL MODEL AND METHOD OF ANALYSIS

Some researchers use vertical merger when they analyze vertical integration. While they are not exactly the same, there are indeed some similarities between merger and integration. With globalization, merger and acquisition has become not only a method of external corporate growth, but also a strategic choice of the firm enabling further strengthening of core competence (Lee, et al, 2005). A merger is a combination of two or more business using simple algebra and can be symbolized by A + B = C (Singh, 1971) or represented by A + B = A or B or C (Hampton, 1989). Merger can either happen when a big company takes over one or more small-size companies, or a combination of two similar size companies. (Liu, 2006). Merger includes vertical, horizontal, and complementary mergers. Merger activities can often happen together with acquisition. Merger and Acquisition (M&A) can expand the production scales, and/or reduce the production costs to realize economies of scale. Meanwhile, it can also improve the market power of the buyer.

Vertical integration as a corporate strategy has long been a key force in the development of high productivity (Chandler, 1977) and worked as key engines of enhancing shareholder wealth (Lubatkin, 1982). Vertical integration can occur by internal growth or by merger (RIORDAN,2008). Tao and Xie (2015) analyzed how Shuanghui International paid $7.1 billion acquired Smithfield. Shuanghui's strength lies in hog slaughtering, pork processing and pork distribution instead of hog production because the local governments denied the plan of building new hog farms. By acquiring Smithfield, the merger combines Shuanghui's advantage in supply chain with Smithfield's reliable contract regarding hog production.

Given the close correlation between merger and integration, we will analyze how the possible welfare benefits could be obtained after merging using Williamson's tradeoff model. This model compares economies of scales after merger and the influence of market power on social welfare (Liu, 2006). The effects on resource allocation of a merger that yields scale economies but extends market power are investigated in the partial equilibrium (Williamson, 1968)

Even though vertical integration is mainly targeted in the paper, there are other areas of analysis. Koller (1950) noted that vertical integration is not always of the so-called simple or pure type, but there are joint, horizontal, and vertical integration in one firm. Many integrated firms actually are a combination of vertical, horizontal, and complementary integration. " Vertical integration is able to give the tightest control among all the different types of vertical relationships", however, there are situations in which vertical coordination is preferred depending on the relative cost of governance" (Antonovitz et al, 1996)

3.1. The Williamson's Tradeoff Model

The Williamson Tradeoff Model compares the difference between the deadweight loss caused by merger and the cost savings due to scale economies. After merging or transaction cost declines, the average cost AC_1 drops to AC_2. The market share or market power increases, $P_2 > P_1$. Q_1 is the production before integration, due to the price increases after integration, the quantity of production decrease and hence $Q_2 < Q_1$. Social welfare net gain is A_2 (Cost Savings) - A_1(Deadweight loss). Then we can conclude, only when A_2 - A_1 > 0, the social net welfare is benign.

Efficiency (cost Savings):

$$A_2 = (AC_1 - AC_2.) * Q_2 \tag{3.1}$$

Welfare loss because of merger (3.2)

$$A_1 = \frac{1}{2}(P_2 - P_1)(Q_2 - Q_1) \tag{3.2}$$

$$\text{Also } P_1 = AC_1 \tag{3.3}$$

The positive net economic effect will be:

$$(\Delta\text{AC})\ Q_2 - \frac{1}{2}\Delta\text{P} * \Delta\text{Q} \quad > 0 \tag{3.4}$$

The elasticity of demand is

$$\eta = \frac{\Delta\,\text{Q}/Q_1}{\Delta\,\text{P}/P_1} \tag{3.5}$$

Dividing by Q_2, combined with (3.5) and (3.3). Equation (3.5) can be rewritten:

$$\frac{\Delta\text{AC}}{AC} - \frac{1}{2} * \eta * \frac{Q_1}{Q_2} * (\frac{\Delta\text{P}}{P})^2 > 0 \tag{3.6}$$

When equation (3.6) = 0, the merger is neutral.

Williamson (1968) in his model explains a relatively modest cost will be sufficient enough to offset relatively large price increase with different elasticities of demand, if the post price increases by 20 percent, and η is equal to 2 and a cost reduction of 4 percent will be sufficient to offset the effects due to the price increase.

Therefore, we conclude the merger will possibly improve the social welfare and efficiency by meeting certain requirements. Using the same method, when there is market power before merger, we will have similar conclusion and it just requires having larger cost reduction or smaller price increase.

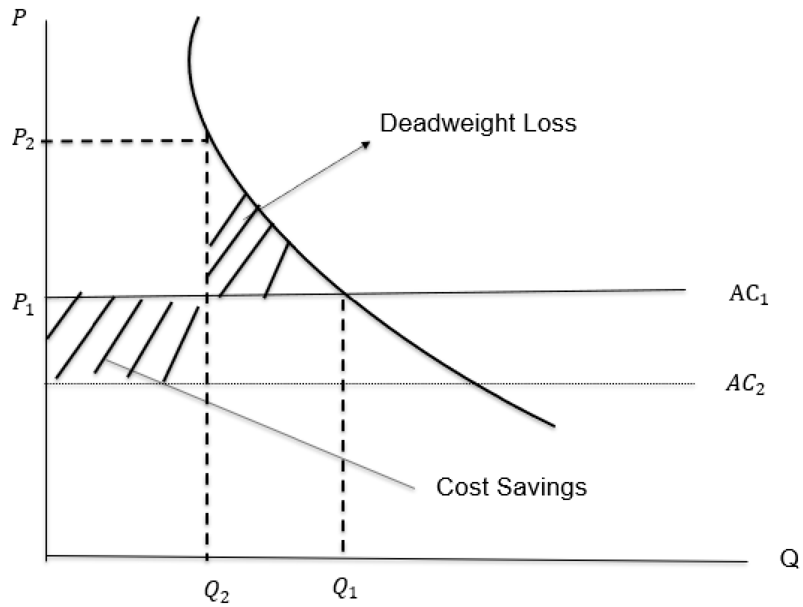

Figure 3.1: Williamson's Tradeoff Model
Source: Williamson (1968)

The above model only describes the scenario of price increase. Firms' maximizing behaviors assumes the post-integration price exceeds the pre-integration level. Actually, the integration activities do not always suggest the product price will go up. Hortacsu and Syverson(2007) used cement and plant data with a span of over 34 years in the U.S and concluded vertical integration led to prices declines and quantities to rise for consumers. This can happen because of the efficiencies and productivity increase in order to strengthen the marketing competitiveness or improve the concentrate rate. Essentially the companies can decrease the prices and increase outputs. Social welfare should be determined instead of only consumer surplus. Loertsher and Reisinger (2014) in their studies are concerned that if integrated firms utilize the shifted capacity less intensively, aggregate costs of production will increase with vertical integration. This might eventually result in less social welfare even when there is producer surplus enhancing.

This will require the integrated companies to expand the business in order to obtain the scale economics so that the shifted capacity is intensively used. This will possibly result in the production costs to decrease and eventually improve efficiency.

3.2. Business Expansion and Social Welfare

Vertical integration is not a costless strategy (Harrigan, 1984). Song et al. (2006) claim the transfer from consumer surplus to producer surplus because of price increase after integration is a dynamic process. If operation cost C is not considered, this transfer itself will not lead to any change in social welfare from a static point of view. However, from a dynamic perspective, the integrated profits can be applied to enlarge production which distributes social welfare across periods. Whether the total social welfare is increased or not depends on whether the productivity of integration is higher than the average one of other enterprise (Qiu,2008).

Ni and Hu (2014) discussed from the perspective of consumer surplus, first consumer surplus are seized and transferred into the monopoly profits and they are divided into several parts and some are distributed within and outside the firms, the monopoly firms do not surely have negative influence on the social total benefits, further, monopoly behavior might be able to increase the social welfare by meeting some conditions. We define integration profits as a producer as W_C and it can be divided into two parts: one is increased tax (T), and another is increased profits(P).

$$W_C = \mathrm{T} + \mathrm{P} \tag{3.7}$$

Tax can be redistributed as social benefits after subtracting the relevant operation cost(c). Eq. (3.7) can be rewritten:

$$W_C = \mathrm{T} + \mathrm{P} - \mathrm{C} \tag{3.8}$$

Increased profits either can be used as dividends of shareholders (D) or as capital (B) for future expansion.

$$P = D + B \tag{3.9}$$

When B=0, all the increased profits are distributed as dividends. In this case, according to the law of diminishing marginal utility, there is a social welfare loss. If most of the shareholders are wealthy, the increased unit utility obtained by the increase of dividends is smaller than unit utility loss of income for the ordinary consumers which is called transfer utility loss. Therefore, under this scenario, this transfer also leads to the loss of social welfare (Comanor & Smiley,1975).

Alternatively, when B > 0, and part of the profits are allocated to enlarge economies of scale, when D is allocated as dividends of shareholders, from previous discussion, we know there will a transfer utility loss called M2.

$$P = D + B - M2 \tag{3.10}$$

Vertical integration by investment in new productive assets usually expands markets, and therefore presumably does not raise competitive concerns (Riordan 2005). Take the case of New Hope Group, China's largest feed producer and one of China's largest agricultural and animal husbandry enterprises. Its business includes feed production, agricultural science and technology, and food processing, etc. The horizontal and vertical integration have greatly increased the scale of this company. One strategy of this company is "New youth" which means training a young and technical management team. Another strategy is "New Technology" which suggests research and development investment. This company utilizes the new breeding model which combines sciences, modernization, and pro-environment together. Implementing filtering air of pig farms across all the branches of this company is one example of this model (Liu, 2019).

Increased profits may also be used to train the technical and management team, and to improve the technology.

$$P=D+B1+B2-M2 \tag{3.11}$$

Where B1 is investment within the company which can also be divided into two parts. One is B11 for training the current employees with regards to the new technology. B12 is for hiring new technical workers. And these two investments will be transferred outside the company as part of social welfare. B2 is to purchase and improve new technology, especially the bio-security technology against the pandemic outbreak and environmental pollution for the hog industry in China.

$$P=D+B11+B12+B2-M2 \tag{3.12}$$

The inputs B11, B12, and B2 are not lost but temporarily used for expanded production. In another words, part of the integration profits is being invested and this will create new social welfare called W1.

$$W1=(B11+B12+B2)*\lambda \tag{3.13}$$

where λ is the efficiency ratio of integration and companies without integration. The higher the efficiency of integration, the higher the new created social welfare will be.

Assume there is deadweight loss (M1) because of integration, operation cost (C) from Eq. (3.8), and transfer utility loss (M2) from Eq. (3.10).

In order to evaluate the total social welfare after vertical integration called W, we have to use the newly created social welfare to subtract the relevant welfare loss such as deadweight loss, operation cost and transfer utility loss.

$$W = W1 - M1 - C - M2 = (B11 + B12 + B2) * K - M1 - C - M2 \tag{3.14}$$

From equation (3.2.8), as long as W >0, we can conclude the total social welfare is increased after vertical integration.

When $\mathrm{W} > 0$, we have $(\mathrm{B11} + \mathrm{B12} + \mathrm{B2}) * \mathrm{K} > \mathrm{M1} + \mathrm{C} + \mathrm{M2}$

$$K > \frac{\mathrm{M1} + \mathrm{C} + \mathrm{M2}}{\mathrm{B11} + \mathrm{B12} + \mathrm{B2}} \tag{3.15}$$

when (B11+B12+B2) is large enough, equation (9) will hold. Though production of an integrated firm may temporarily be inefficient, it will eventually benefit not only the company but also the society.

This might also hold in the real business operation. Due to the ASF outbreak in 2018, according to the data released by the national bureau of statistics, the Chinese hog industry is suffering huge losses with the pork output at 42.55 million tons. This was down 25% from a year earlier. New Hope Group instead benefited from the ASF. When analyzing the reasons why the company is still profitable, the founder of this giant group, LIU Yonghao, attributes it to the application of the new breeding model. This model combines science, modernization, and pro-environmental activities. For example, they utilized filtering air in pig facilities before the outbreak of ASF. The investment expense is transferred from the increased profits, and it eventually benefits this company against the impacts of ASF. Similarly, at Wen Group, one of the largest agriculture companies and quasi-vertically integrated (Wan, 2008), in 2019 the company sold 18,516,600 pigs and the sales revenue of pork increased by 20.03%. Wen's emphasis on technological investment of livestock and poultry breeding and emphasis on pandemic prevention helped this company to make profits under the attack of ASF.

The first two models are mainly talking about how social welfare can increase after vertical integration or business expansion. Some models are not so clear on social welfare change between different stages among supply chains. Next, we will use a small model to show how possible it is to improve the social welfare after merging between upstream and downstream companies.

3.3. Vertical Integration between Different Stages

Consider the model in the hog industry. Two companies A and B respectively are the downstream and upstream of pork production. A sells the feed (X) at the price of F to firm B. The production function of B is Y(Q)= f(X) with inverse demand function P= a- b*Y. To calculate conveniently, we assume the feed company A is equal to

$$X = (1/K) * Y$$

K>0, Y is the amount of pork produced by B.

Before integration, firstly consider pork producer B:

For simplicity purpose, feed cost is only included in the model.

Profits of B:

$$B = P * Y - F * X = (a - b * Y) * Y - F * (1/k) * Y \quad (3.16)$$

By taking the first derivatives to obtain the maximum profits,

$$Y = \frac{a}{2b} - \frac{F}{2b * K} \qquad P = \frac{ak + F}{2K} \quad (3.17)$$

Go back to the company A, its revenue $R = F * t * X$

t*X is the total feed amount of A made, t>1.We have

Revenue of A,

$$R_A = F * t * X \quad (3.18$$

Using equation (3.3.2),

$$F = a * K - 2b * k * Y \quad (3.19)$$

Plug (3.3.4) into equation (3.3.3),

$$R_A = (a * k - 2bkY) * t * X \quad (3.20)$$

Plug $X = (1/k) * Y$ into (5)

Using the principle of MR = MC to obtain the maximum profits of A

$MR = -4btk^2X + a * k * t = MC = C$ (Assume the marginal cost of B is C)

Then we have

$$X = \frac{c - akt}{4btk^2} \quad (3.21)$$

Feed producer A will produce the feed based on this conclusion to maximum their profits. Suppose feed producer A and hog producer B are vertically merged to form a vertically integrated firm A&B.

Still, assume we have the same inverse demand function $P_1 = a - b * Y_1$, to compare the prices and quantity of output before and after integration.

To have the maximum profits of new integrated company A&B:

$MR = a - 2bY_1, = MC = C_1$(Set the new marginal cost of feed production = C_1)

$$Y_1 = \frac{a - C_1}{2b}, P_1 = \frac{a + C_1}{2} \quad (3.22)$$

$$Y_1 - Y = \frac{C_1 * K - F}{2k * b}, \quad P_1 - P = \frac{C_1(K - F)}{2K} \quad (3.23)$$

We can find out after vertical integration, as long as K=$\frac{\boldsymbol{F}}{\boldsymbol{C_1}}$>0, the ultimate product quantities are higher for consumers; when F<K, the post-integration price is lower than the previous level could improve the consumer surplus and social welfare. Pindyck(2011) explained why this is the case, the vertical integration avoids the problem of double marginalization. When the two firms are not integrated, each one pushes the price above the marginal cost. To do this,

each firm must contract its output. However, vertical integration can lead to lower marginal costs, lower prices and higher quantities because of production efficiencies increasing.

4. DATA AND VARIABLES CONSTRUCTION

4.1. Data Source

Given there is no vertical integration data available in China's hog industry, in this paper we will not do empirical work on vertical integration but consider efficiency and technology progress on small-scale, medium-scale, and large-scale hog farms in China. The logic being that large scale hog farms in China are more vertically integrated and therefore, by proxy we can evaluate efficiency gains from vertical integration as well as scale efficiency and technological progress. The data related in this paper is selected from the China Agricultural Product Cost-Benefit Compilation (CAPCBC) issued by National Development and Reform Commission of China (NDRC). Within each province, a three-stage random sampling procedure is adopted to determine sample counties, villages, and finally individual farms. The hog production cost-benefit data is collected from individual farms including backyard farms, small-scale farms, medium-scales farms, and large farms (Zhou et al, 2015). The size of farms (Q) is determined by the average number of hogs in one year. (Q= (breeding stock at the beginning year + breeding stock at the ending year) /2, Q<30: backyard hog households; if 30≤ Q <100: small-scale farms; if 100≤ Q < 1000 then it is a medium-scale farm; if Q > 1000: large-scale farms (CAPCBC definition). Provincial data was used for individual farms in this paper.

Due to some incompleteness in the data with respect to the three assigned sizes of hog production, this paper did the analysis with 18 provinces for 13 years from 2006 to 2018. Some provinces are excluded due to the missing data such as Fujian, Jiangxi, Guizhou, Ningxia, Xinjiang, Chongqing, and Tibet.

4.2. Variable Selection

The composition of the cost of pork production in China is shown in Table 4.1. Generally, the total cost includes production cost and land cost while the production cost is decomposed into material service and labor costs. The material service contains direct costs including newborn animal cost, fine feed, green feed, feed processing, water, fuel and power, medical and epidemic prevention. Indirect costs are mainly the fixed asset depreciation, tax, insurance premium management and financial expenses.

The table 4.2 below listed several scholars who have done productivity analysis with regards to the hog industry in China. The research using mainly are DEA Malmquist. Some also used applied SFA (Wang et al, 2011).

The previous research has the output either pure product (the weight of a live finishing hog minus the weight of newborn pigs) or the main product (the weight of a live finishing pig). The common input variables include piglet weight (kg), Labor workdays (days), medical expenses (Yuan), water and fuel expense (Yuan), and fine feed (kg). Wang et al (2011) and Wang et al (2014) have the variables of indirect expenses (Yuan), Chen et al (2008) and Ji et al (2012) have the fodders (Yuan), Ning et al (2010) has death expense in the model also.

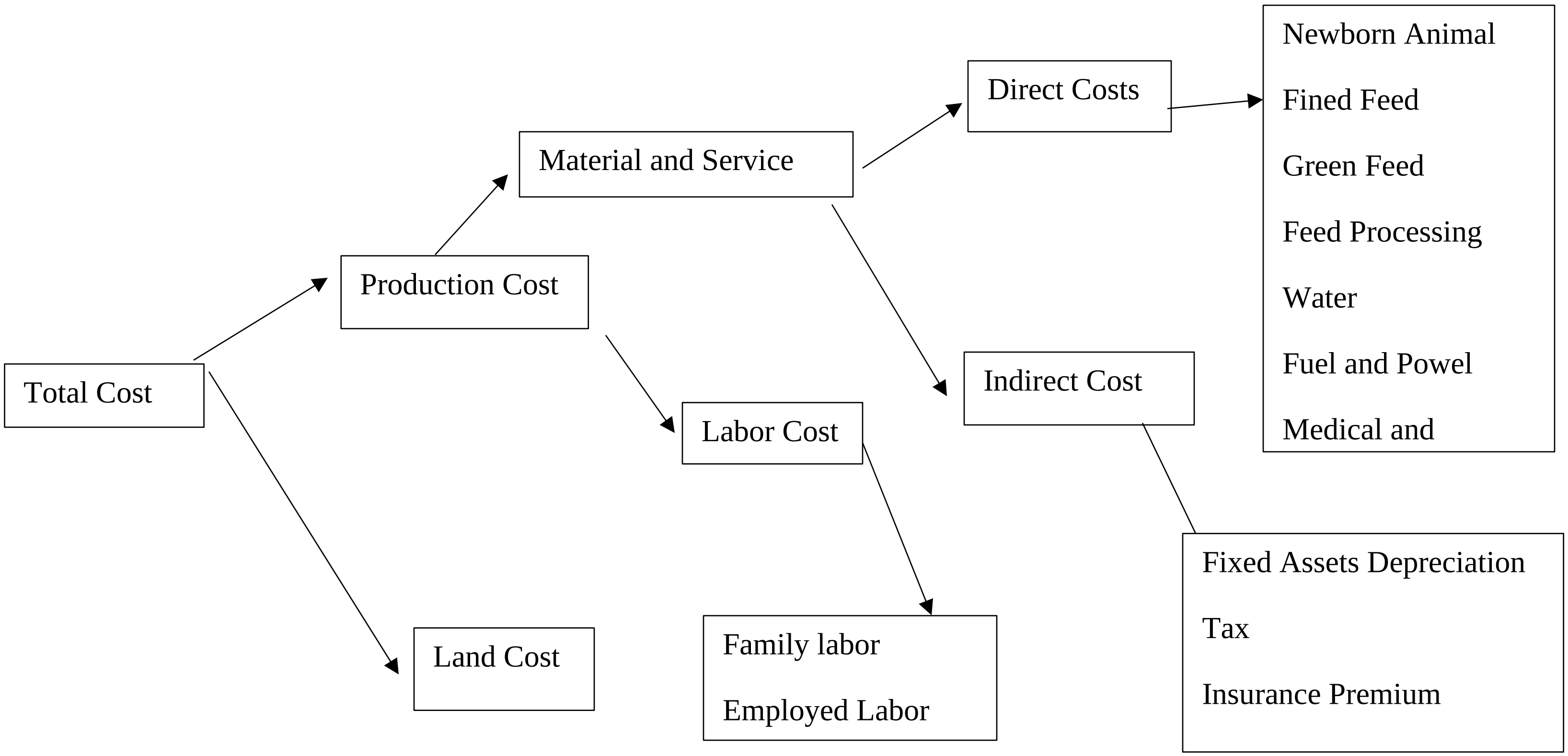

Figure 4.1: Composition of the Cost of Pork Production
Source: China Agricultural Product Cost-Benefit Compilation (CAPCBC) issued by National Development and Reform Commission of China (NDRC)

Table 4.1: Variables Selection by Scholars in the Previous Related Studies

Author	Method	Output	Input
Chen et al. 2008	DEA-Malmquist	Pure Product(kg)	Labor workdays(days), Concentrations (kg), Fodders (Yuan), Water, fuel expense (Yuan), Medical expense (Yuan)
Ning at al. 2010	DEA	Main product(kg)	Piglet weight(kg) and Price, Concentrations (kg) and Price, Medical expense (Yuan) and Price, Death expense (Yuan) and Price, Water, and Fuel Expense (Yuan) and Price, Labor workdays(days) and price
Yan et al. 2012	DEA	Main product(kg)	Piglet weight (Kg), Concentrations(kg), Medical expense(Yuan), Labor workdays(days)
Sun et al.2012	DEA	Main product value (CNY), By product value (CNY)	Piglet price(Yuan), Feed expense (Concentrations and Fodders) (Yuan), Labor expense (Yuan)
Wang et al. 2011	SFA	Pure product(kg)	Concentrations (kg), Labor workdays(days), Other expense including fuel expense, medical expense, and indirect expense.
Ji et al. 2012	DEA-Malmquist	Main product(kg)	Labor workdays(days), Feed expense including Concentrations, Fodders, and feed processing (Yuan), Water and fuel expense (Yuan), Medical expense (Yuan)
Wang et al. 2014	DEA-Malmquist	Main product(kg)	Piglet weight(kg), Concentrations (kg), Labor workdays(days), Water and fuel expense(Yuan), Medical expense(Yuan), Indirect expense(Yuan)

In this paper, we are consistent with the previous research including the pure main product as the output, the labor workdays, the fine feed, the water, fuel power expense, the medical epidemic prevention expense, and the indirect expenses as the input variables. Since the last three variables are measured in values, here we add them together and call it " invests" which agrees with Wang and Li (2011).

Table 4.2: Variables Selection in this Paper

	Variables	Description
Output	Main product(kg)	The difference between the weight of a live finishing pig and piglet
Input	Labor workdays per hog(days)	Total work hours (hired and family labors) / 8 (hours)
Input	Fine Feed(kg)	Grain, beans, compound feed, mixed feed, bran, bean cake, oilseed cake, feed additives, etc.
Input	Water, fuel power expense (Yuan)	The water, coal, oil, electricity, lubricants, and other power used in the production process
	Medical, epidemic prevention expense (Yuan)	Expenses related to the vaccination and medical usage
	Indirect expense(Yuan)	Depreciation of fixed assets, insurance expense, management expense, accounting expense, and sales expenses

4.3. Construction of "Value" Variable into "Quantity" Variable

Färe (1994) claimed distance functions require the multiple outputs and inputs in quantities. Consequently, we need to convert the "value" variables into" quantity" variables. Some authors such as (Sun et al, 2012; Yan et al, 2012) estimated the variables without adjusting the "value" variables. Given the different prices of different provinces, the estimated result might be biased due to the price impacts.

In this paper, the four "value" variables of water, fuel, utilities, medical and epidemic prevention expense, and indirect expenses are required to be converted into "quantity" variable using the corresponding price index variables from Price Indices of Agricultural Means of

Production by Category and by Region (2006-2018) so that the different price influences of provinces can be reduced.

Before we adjust the “value variables”, considering that there is missing price indices of some categories and provinces, we set the price index variables in 2006 as the base constant price. The price index from 2007 to 2018 of the different provinces are recalculated and price index deflator of agricultural production by category and by region is obtained. In addition, since the index varies by province, the base province is the national average. Hence, year base is in 2006 and province base is the national average in 2006. There is no corresponding price index regarding water, fuel power expense, medical epidemic prevention expense and indirect expense. Hence, we consider using other agricultural means of production as the price index of the new created variable “invests” which refers others excluding feeds and labor in the model. Then the adjusted quantity variable “invests” are measured accordingly.

4.4. Descriptive Statistics of Data

From the Table 4.1 to 4.3, the total observations are 234 which tells there are 18 provincial data over 13 years. The provincial data is the average of each province. The average pure weight of live pigs after subtracting the weight of piglets across the country over the period is 97.782 kg per pig for the small scale, 97.840 kg for the medium scale, and 93.433 kg for the large scale. Obviously, the medium scale has a relatively bigger pure weights of the live pigs, the average pure weight of large scale is smaller than those of the other two-scale production size which might be due to the shorter breeding days and higher turnover. For example, in 2006, the medium scale has an average of 143 days, , the small scale has an average of 145 days while the large scale has the average of 134 days. In other words, the large scale may be trading kilograms of pork per pig for volume.

With respect to the variable of labor, there is an obvious difference between scales. The average labor of large scale is 1.481 days, much lower than the average of small scale of 3.6 days and medium scale of 2.435. Large-scale hog farming has an advantage of labor hours when it expands its scale production. The usage of fine feed sees no significant difference across the three scales however the small-scale hog farmers gradually give up the traditional feeding using swill. Another important input on the hog production is the water, fuel power, medical, epidemic prevention and indirect expense. The large scale increases it invests on the biosecurity and environmental pollution technology and therefore, the overall average invest is bigger than those other two scales.

Table 4.3: Descriptive Statistics of Small-Scale Hog Production

Variable	Observations	Mean	Std.DeV	Minimum	Maximum
Main Output (KG/ head)	234	97.782	12.305	66.1	140.23
Labor (Days/ head)	234	3.629	1.421	1.52	10.81
Fine Feed (KG/head)	234	298.524	37.533	136.4	416.48
Invests ("Quantity"/head)	234	26.846	7.616	13.724	53.495

Note: As the new created variable invests is a loose" quantity" variable, there is no specific unit

Table 4.4: Descriptive Statistics of Middle Scale Hog Production

Variable	Observations	Mean	Std.DeV	Minimum	Maximum
Main Output (KG/ head)	234	97.84	11.953	64	135.94
Labor (Days/ head)	234	2.435	1.004	0.85	9.2
Fine Feed (KG/head)	234	301.627	36.549	216.4	395.31
Invests ("Quantity"/head')	234	29.612	9.644	9.186	71.369

Note: As the new created variable invests is a loose" quantity" variable, there is no specific unit.

Table 4.5: Descriptive Statistics of Large-Scale Hog Production

Variable	Observations	Mean	Std.DeV	Minimum	Maximum
Main Output (KG/ head)	234	93.433	11.722	63.4	141.91
Labor (Days/ head)	234	1.481	0.718	0.42	4.11
Fine Feed (KG/head)	234	287.713	33.324	202.5	389.82
Invests ("Quantity"/head')	234	37.646	15.514	7.625	104.91

Note: As the new created variable invests is a loose" quantity" variable, there is no specific unit.

4.5. Statistical Analysis

4.5.1. Change in Different-Scale Hog Production

This table 4.4 can tell us how the proportion of different hog scales changed between 2005 and 2018. The hog industry is developing in scale production. Especially in the scale of 500-2,999 hogs. There is an increase of 5.673 percentage points, and the proportion of large-scale farming is increasing dramatically. In contrast, the small scale (50-99 hogs) is shrinking from 96.766% to 59.63% during that period.

Table 4.6: The Proportion of Different-Scale Hog Farming (%)

Scale / Year	50-99	100-499	500-2999	3000-9999	10000-49999	Over50000
2006	96.77%	22.11%	3.79%	0.35%	0.09%	0.00%
2018	59.63%	29.74%	9.47%	0.94%	0.20%	0.02%

Source: Statistical Yearbook of Animal Husbandry in China

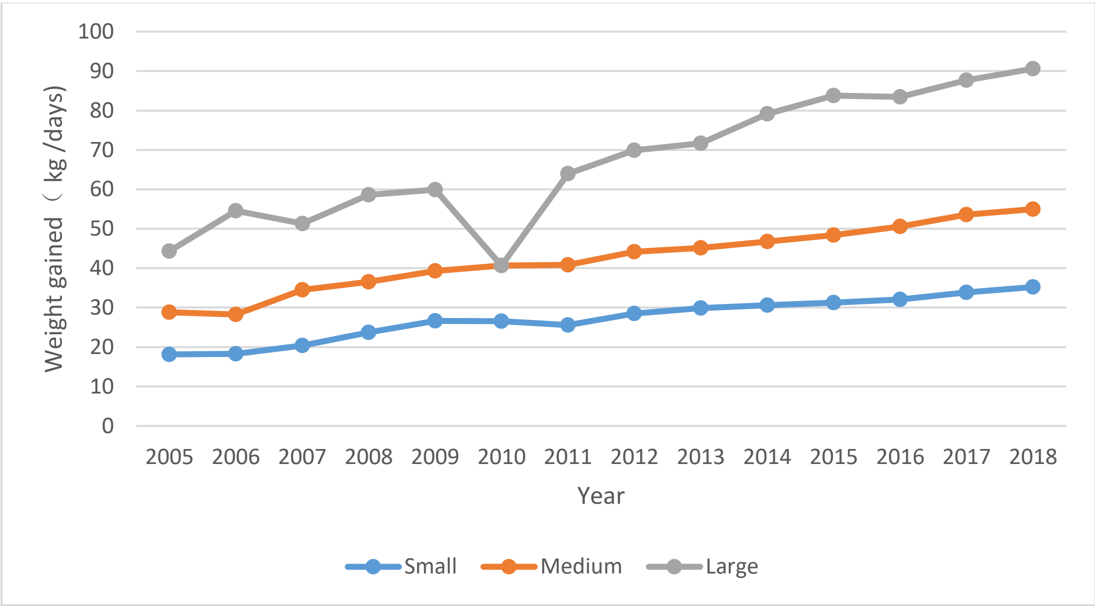

Figure 4.2: Labor Productivity per Hog (kg/day)

We next calculate the labor productivity which is the output obtained per day. The equation is: Labor productivity y= (main output – piglet weight) /(hired labor workdays + family labor workdays)

Figure 4.2 can tell us something about the increasing trend of the three-scale hog farms. By comparing those three scales, there is still a big difference. The average labor productivity for the small, medium, and large hog farms is 27.195kg/day, 42.328 kg/ day, and 67.11kg/day, respectively. Large-scale hog farming has the largest labor productivity though all three size categories have seen increases in productivity over the last 15 years.

4.5.2. Feed Conversion Ratio Comparison

Gale (2016) claims in his report the feed conversion ratio (FCR) is an indicator of the efficiency of feed use, the lower ratio implies greater efficiency.

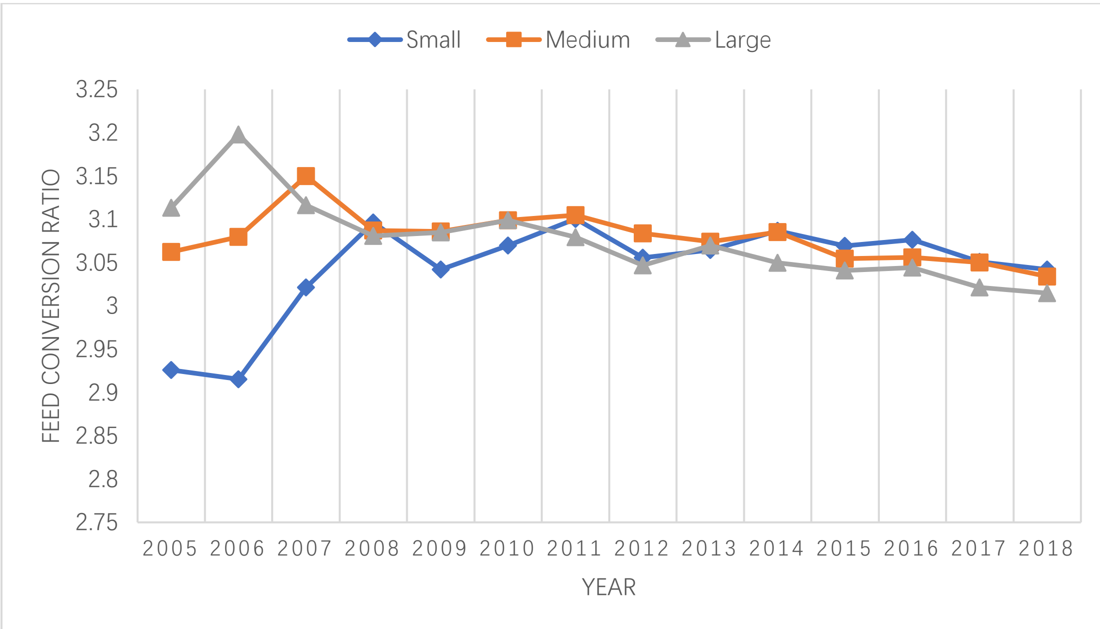

Figure 4.3: Feed Conversion Ratio

From figure 4.3, large-scale hog farming has gradually improved in feed conversion. Though in 2005 large farms had the highest ratio of the three scales, by 2018 it has the lowest feed conversion ratio. There are no significant changes with respect to the medium and small-scale producers. The different feed conversion ratios among the three scales can be partially attributed to the different feeds used. Small-scale farmers might feed the hogs using the green feed in order to save the production cost while the large-scale famers are more inclined to use concentrated rations, hoping to increase the hogs weight faster within a given period. In this paper, we only calculate the concentration feed conversion rate. The low feed conversion ratio for small farms initially may have been a function of not including some of the swill and grass feeding conducted by small farms 15 years ago.

4.5.3. Cost Comparison

Production cost here is calculated using the production expense given the pure hog weight. The equation is: Cost = (production expense) / (finished hog weight - piglet weight)

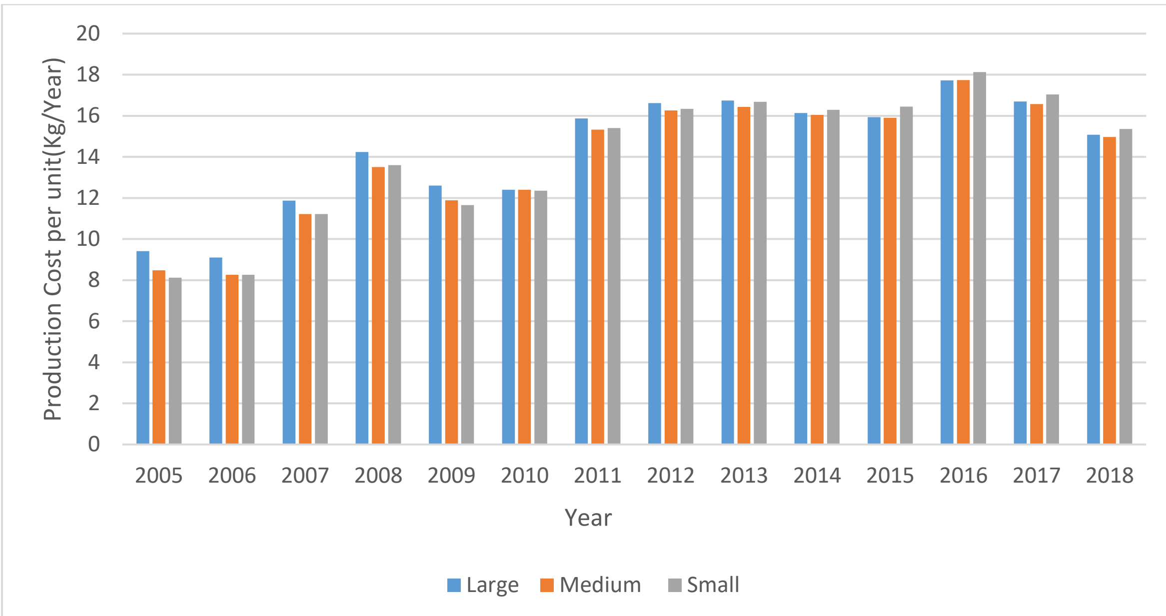

Figure 4.4: Unit Production Expense (Yuan/kg)

The average unit production expense for the three scales of farming are 14.04Yuan/kg for small-scale, 13.90 Yuan/kg for medium-scale, and 14.28Yuan/kg for large-scale. This shows an increase of 89.35%, 77.06% and 60% respectively in the past 14 years. Clearly large-scale hog farming has the slowest increase in unit production expense and costs are not rising as fast for large hog farms.

Figure 4.5 shows the total costs in the three scales. Costs have increased by 123.4% for small scale, 111.2831% for medium scale, and 104.732% for large scale, again showing an unequal cost increase across hog farms of different sizes. Since 2008, large-scale hog farming has the lowest total cost of the three scales. The differences between large-scale and small-scale changes from 13.24 Yuan to 110.56 Yuan while the difference of small and medium hog farming is from

14.77 Yuan to 58.35 Yuan. Compared to medium and small-scale hog farming, the large scale has advantages in the total costs.

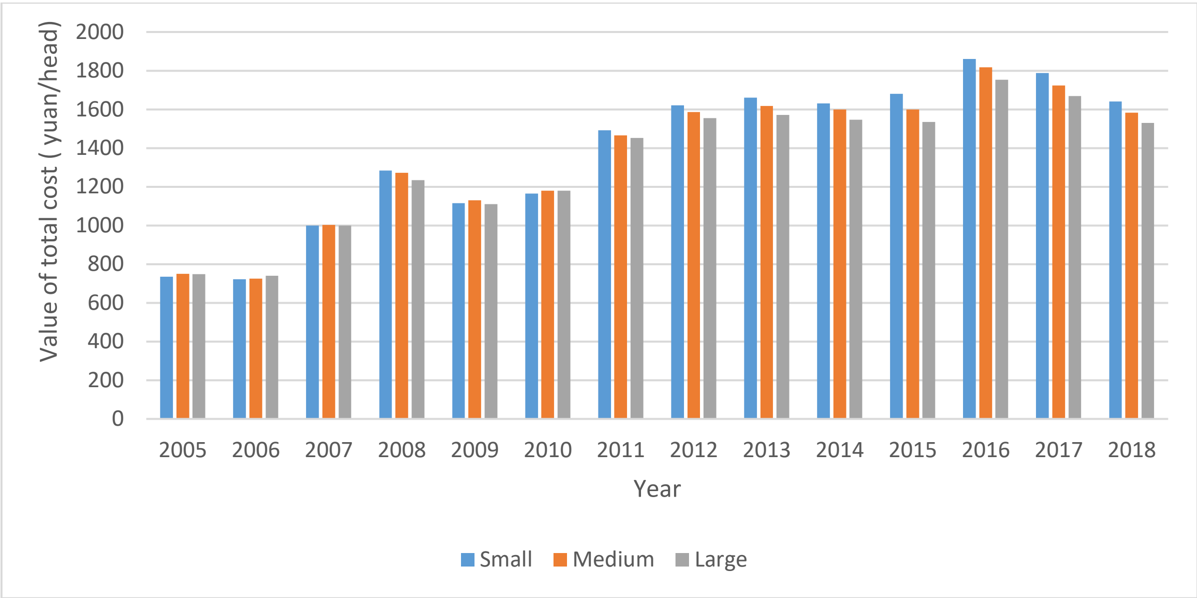

Figure 4.5: Total Cost (Yuan)

When looking at the profit differences of the three scales of hog farming, from the figure 4.6 the profits have had very large fluctuations over years. In 2005, 2006, and 2009, small-scale hog farming had the highest profits of the three scales. In 2007, 2008, 2011, 2012, 2013, and 2015, the profits of medium-scale hog farming are higher. Large scale's advantages in profits starts from 2014 onward. One key point is that compared to large and medium scale hog farming, small scale is more easily impacted by the other factors such as the ASF in 2018 due to no bio security and sparse medical care.

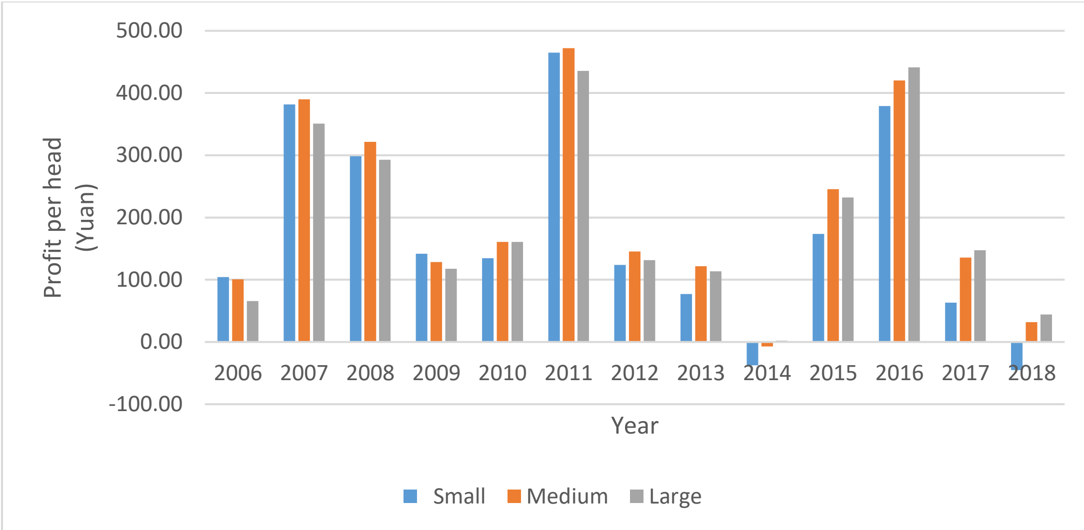

Figure 4.6: Total Profit

5. EMPIRICAL METHODOLOGY AND ANALYSIS

5.1. Methodology

The Malmquist Productivity Index, which was named after Steven Malmquist and introduced by Caves et al. (1982) is used to calculate total factor productivity (Fare et al, 1994) from output-orientation or input-orientation. Total factor Productivity (TFP) is the relation of proportionality (ratio) between the output and inputs. Let $y_t > 0$ denote the quantity of output produced during period, "t" and let x_t>0 denote the quantity of inputs utilized by the firm during period "t" for t=0,1 with 0 representing past year (t-1) and 1 representing current year (t).

$$\text{Productivity (t)} = \frac{y_t}{x_t} \; (A') \tag{5.1}$$

$$\text{Productivity (t} - 1) = \frac{y_{t-1}}{x_{t-1}} \; \text{(A)} \tag{5.2}$$

$$\text{Productivity Change from A to } (A') = \frac{TFP_t}{TFP_{t-1}} = \frac{\frac{y_t}{x_t}}{\frac{y_{t-1}}{x_{t-1}}} = \frac{\Delta y}{\Delta x} \tag{5.3}$$

Following Caves et al (1982), the Malmquist Productivity index compares the radical distances of input and output vectors in the period of t-1 and t associated with the reference technology, output-oriented Malmquist productivity index with respect to the technology in the period of t-1 is defined as shown in the equation (4) (Mizohuvhi, 2015)

$$OMP_0^{t-1} = \frac{D_0^{t-1}(x^{k,t}, y^{k,t})}{D_0^{t-1}(x^{k,t-1}, y^{k,t-1})} \tag{5.4}$$

Similarly, the output orientation Malmquist productivity index relative to the reference technology in the period of t is defined as:

$$OMP_0^{t} = \frac{D_0^{t}(x^{k,t}, y^{k,t})}{D_0^{t}(x^{k,t-1}, y^{k,t-1})} \tag{5.5}$$

Equation (5.5) measures the change from period t-1 to t when the base is the production possibility frontier at period t.

$$\mathrm{OPM}_{t-1}^{t} = \sqrt{\frac{D_0^{t-1}(x^{k,t}, y^{k,t}) \times D_0^{t}(x^{k,t}, y^{k,t})}{D_0^{t-1}(x^{k,t-1}, y^{k,t-1}) \times D_0^{t}(x^{k,t-1}, y^{k,t-1})}} \quad (5.6)$$

The output-based Malmquist productivity (OMP) 3is defined as the geometric mean of four output distance functions because taking the geometric mean of two periods is very close to the real value according to the Fisher index which is the geometric mean of Laspeyre's index and Paasche's index. In this paper it is based on current period, "t (1)"and previous "t-1(0)" period technologies for "k" DMUs (decision making units, in this paper it refers 18 provinces).

In equation (6), $(x^{k,t-1}, y^{k,t-1})$ and $(x^{k,t}, y^{k,t})$ refers the input and output vectors in year t-1 and year t respectively; D_0^{t-1} and D_0^{t} are defined as the distance functions in relation to the technology in year t-1 and year t. That is: $D_0^{t-1}(x^{k,t}, y^{k,t})$ shows the technology efficiency of period t in relation to the technology in year t-1; $D_0^{t-1}(x^{k,t-1}, y^{k,t-1})$ explains the technology efficiency of period t-1 in regard to the technology in year t-1; $D_0^{t}(x^{k,t}, y^{k,t})$ describes the technology efficiency of period t concerning the technology in year t; $D_0^{t}(x^{k,t-1}, y^{k,t-1})$ reports the technology efficiency of period t-1 in respect of the technology in year t.

[3] This depends on the objective function, if the objective is to maximize the output quantities without altering the input quantities used, then the output-oriented Malmquist productivity should be used. In contrast, if the objective is to minimize the input quantities without changing the output quantities produced, the input-oriented Malmquist productivity is used instead. In addition, if achieving the two objectives is the goal, the graph distance function should be implemented.

Equation (5.6) is multiplied and divided by

$$\frac{D_0^t(\, x^t \,,y^t}{D_0^t(\, x^t \,,y^t} \text{ and } \frac{D_0^{t-1}(\, x^{k,t-1} \,,y^{k,t-1}\,)}{D_0^{t-1}(\, x^{k,t-1} \,,y^{k,t-1}\,)}$$

$$\mathrm{OPM}_{t-1}^{t} = \sqrt{\frac{D_0^{t-1}(x^{k,t},y^{k,t}) \;\times\; D_0^t\,(x^{k,t},y^{k,t})}{D_0^{t-1}(\,x^{k,t-1}\,,y^{k,t-1}) \;\times\; D_0^t(\;\; x^{k,t-1}\,,y^{k,t-1})}} \;*\; \frac{D_0^t(\, x^t \,,y^t}{D_0^t(\, x^t \,,y^t} * \frac{D_0^{t-1}(\, x^{k,t-1} \,,y^{k,t-1}\,)}{D_0^{t-1}(\, x^{k,t-1} \,,y^{k,t-1}\,)}$$

Equation (5.6) can be rewritten as:

$$\mathrm{OPM}_{t-1}^{t} = (\frac{D_0^t(x^{k\,,t} \;\,, y^{k\,,t}}{D_0^{t-1}(\, x^{k,\;\, t-1}\,, y^{k\,,t-1}\,)}) \quad (5.7)$$

$$\times \sqrt{\frac{D_0^{t-1}(x^{k,\;\, t}, y^{k,\;\, t})}{D_0^t\,(x^{k,\;\, t}, y^{k,\;\, t})} \times \frac{D_0^{t-1}(\, x^{k,\;\, t-1}\,, y^{k,\;\, t-1}\,)}{D_0^t(\;\;\, x^{k,\;\, t-1}\,, y^{k,\;\, t-1})}}$$

Equation (5.7) is another distortion form of equation (5.4), and it says the Malmquist productivity index is discomposed into efficiency change (EC) which is the equation (5.8) and technical change (TC) which is the equation (9). Productivity growth is the product of efficiency change and technical change. Technical progress (TC) is measured by shifts in the frontier measured at the current period t and previous period t-1, EC is the change in efficiency over the same period (Andrew, 2000). In the figure 5.1, the movement from C to B is called efficiency change while the movement from B to A between two Production Possibilities Frontier is called a change in technology.

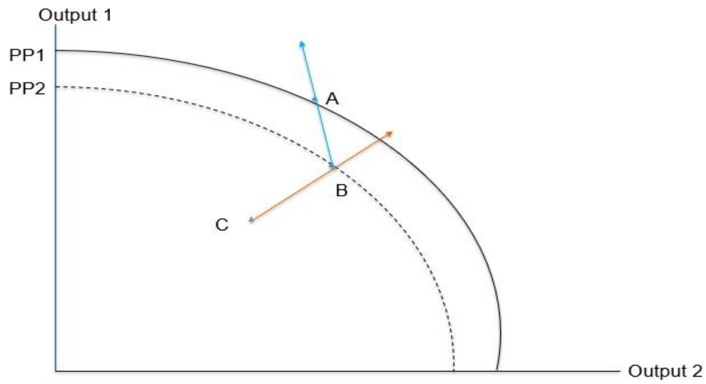

Figure 5.1: Technology Change and Efficiency Change

$$\text{Efficiency Change} = \frac{D_0^t(x^{k.\ t}, y^{k,\ t})}{D_0^{t-1}(x^{k,\ t-1}, y^{k,\ t-1})} \qquad (5.8)$$

$$\text{Technical Change} = \sqrt{\frac{D_0^{t-1}(x^{k,\ t}, y^{k,\ t})}{D_0^{t}(x^{k,\ t}, y^{k,\ t})} \times \frac{D_0^{t-1}(x^{k,\ t-1}, y^{k,\ t-1})}{D_0^{t}(x^{k,\ t-1}, y^{k,,\ t-1})}} \qquad (5.9)$$

This process can be interpreted using the Figure 5.2. The DMU A at period t and at period t-1 which is A′ under the two different frontiers, suppose under the condition the technologies are efficient, they have the inputs x^{t-1} and x^{t} respectively, in practice, they normally are unable to obtain the realized output Ry^{t-1} and Ry^{t} due to various reasons, and instead only reach the actual output y^{t-1} and y^{t}. When we move observation DMU A to the frontier t-1, the efficiency is measured. Same for A' moves to the frontier t, efficiency at period t is calculated. The distance between two frontiers captures the technology change. We calculate the efficiency methods for firm A and A', this will report the efficiency change in year t-1 and t which is shown in the equation (8). Second, temporal variation is considered. Here, DMU A in year t-1 in relation to its own frontier in year t-1 and new frontier in year t have to be calculated. The same for A' with its own frontier in year t and previous frontier in year t-1 to capture the technology change. Four distance functions are measured, and the square root is taken given the same method is used twice. This is the way we end with the equation (9).

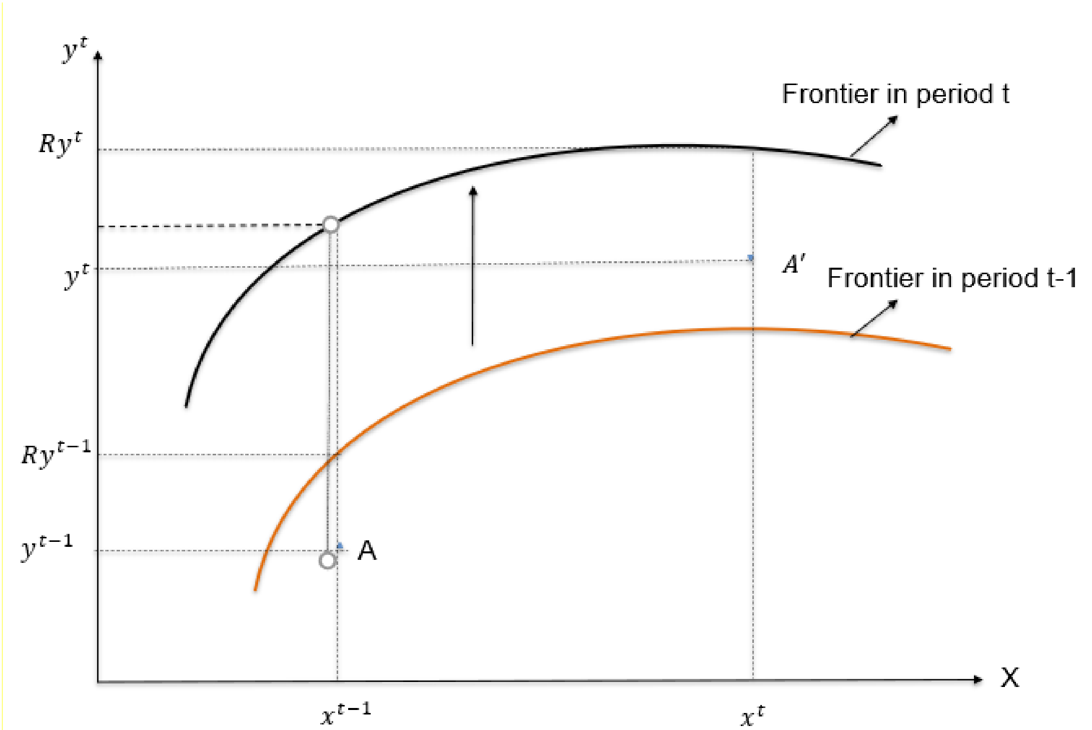

Figure 5.2: Decomposition of Total Factor Productivity

In addition, Fӓre et al (1994) decomposes efficiency change (EC) into pure technology efficiency change (PTE) and scale efficiency change (SE), when having the varied return to scales, that is:

$$\mathrm{EC}(x^{k,\ t-1}, y^{k,\ t-1};\ x^{k,\ t},\ \ y^{k,\ t}) = \frac{D_0^t(x^{k,\ t}, y^{k,\ t}\ |\mathrm{C,,S})}{D_0^t(x^{k,\ t-1}, y^{k,\ t-1}\ |\mathrm{C,S})}$$

$$= \frac{D_0^t(x^{k,\ t}, y^{k,\ t}\ |\mathrm{C,S})/\ D_0^t(x^{k,\ t}, y^{k,\ t}\ |\mathrm{V,S})}{D_0^{t-1}(x^{k,\ t-1}, y^{k,\ t-1}\ |\mathrm{C,S})/\ D_0^{t-1}(x^{k,\ t-1}, y^{k,\ t-1}\ |\mathrm{V,S})} * \frac{D_0^t(x^{k,\ t}, y^{k,\ t}\ |\mathrm{V,,S})}{D_0^{t-1}(x^{k,\ t-1}, y^{k,\ t-1}\ |\mathrm{V,S})}$$

$$= \frac{SE_0^{t+1}(x^{k,\ t},\ \ y^{k,\ t})}{SE_0^{t-1}(x^{k,\ t-1}, y^{k,t-1})} * \frac{D_0^t(x^{k,\ t}, y^{k,\ t}\ |\mathrm{V,,S})}{D_0^{t-1}(x^{k,\ t-1}, y^{k,\ t-1}\ |\mathrm{V,S})}$$

$$\mathrm{EC} = \mathrm{SE}(x^{k,\ t}, y^{k,\ t}; x^{k,\ t-1}, y^{k,\ t-1}) * \mathrm{PTE}\ (x^{k,\ t}, y^{k,\ t}; x^{k,\ t-1}, y^{k,\ t-1}) \qquad (5.10)$$

Where, (C, S) means the constant return to scale and (V,S) refers the varied return to scale, therefore,

$$\text{Malmquist productivity index} = \mathrm{TC}^* \ \mathrm{EC} = \mathrm{TC}^* \ (\mathrm{PTE}^* \ \mathrm{SE}) \qquad (5.11)$$

Malmquist productivity index is decomposed into three parts: technical change, pure technology efficiency changes and scale efficiency changes. To disaggregate the total factor productivity into those three parts is to explore the driving forces of structural change (McBride and Key, 2013). When technical change >1, it indicates the improvement in technologies which make the production frontier move upward while in contrast, when technical change < 1, it means there is deterioration in the technologies.

The last two are the decompositions of efficiency changes. Pure Technical Efficiency (PTE) measures how successfully the firms can utilize the given inputs to maximize the outputs. The technical efficiency measures the DMU's overall success at utilizing its inputs (Iqbal et al, 2015) when used the output-oriented measures, it answers the questions how largely the output quantities can be proportionally improved when the input quantities are unchanged while for the input orientation, it is about how large the input quantities can be proportionally decreased when the output quantities produced are maintained constant. In the Figure 5.3, ZZ' represents the production possibilities. Suppose the firm has the output sets q_1 and q_2. The distance AB refers the technical inefficiency and technical efficiency is measured by TE = $\frac{OA}{OB}$.

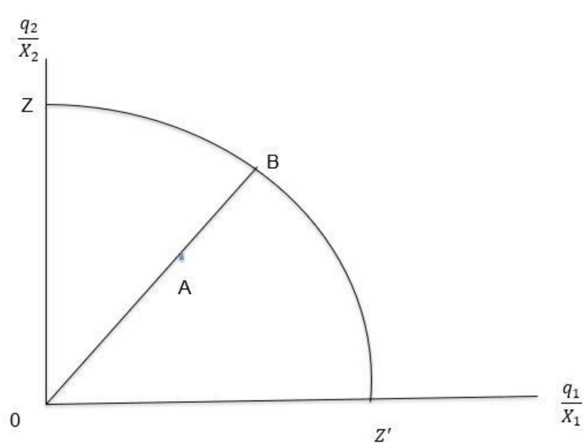

Figure 5.3: Technical Efficiencies from Output Orientation
Source: Coelli et al (2005)

Scale efficiency is the ratio calculated of the distance function under constant returns to scale and variable returns to scale. Scale efficiency is to assess the amount by which productivity can be increased by moving to the point of technically optimal productive scale (TOPS) or most productive scale size (MPSS) which is farm B in Figure 5.4, hog firms A, B and C are technically efficient because they are all on the production frontier, considering the definition of productivity which equals to the slope of a ray drawn from the origin through the data point A, B and C, they are not equally productive due to the effects of scale. (Coelli et, 2005). If SE <1, there are decreasing returns to scale and suggests even though firms may expand, SE will decline; if SE = 1, this indicates the firms are in constant return to scale. In contrast, SE > 1 implies increasing returns to scale and growth will cause average per-unit costs to decline. With respect to the Malmquist index, MI >1 (<1), this denotes improvements in productivity (regression or deterioration in performance). Furthermore, as noted in Fäare et al. (1994), when the efficiency changes or technology change is >1 (<1), it is also associated with the improvements or deterioration in the components. To disaggregate the productivity into technical change, efficiency change and scale efficiency can be helpful to understand the forces that drive the structural change (McBride and Key ,2013).

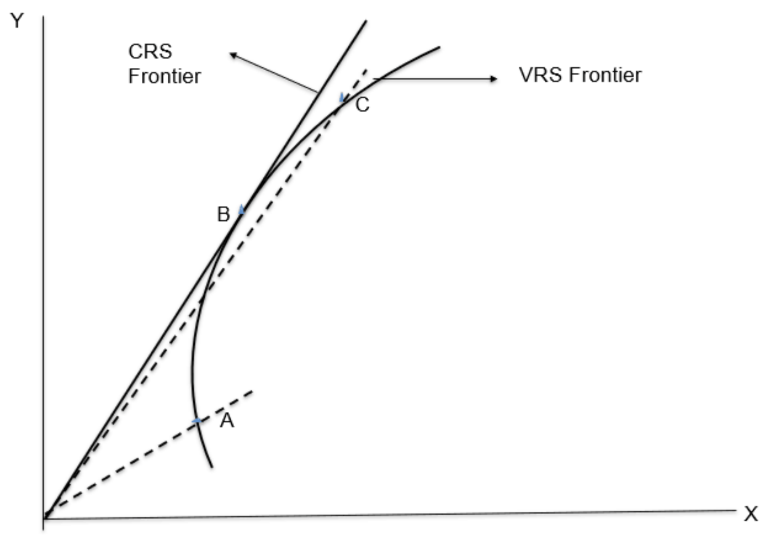

Figure 5.4: Scale Efficiency
Source: Coelli et al (2005)

There are several different methods which could be used to calculate the Malmquist TFP index such as SFA or DEA. SFA (Stochastic Frontier Analysis) is a model to examine the production relationships between input and output quantities and mainly used to estimate the technical efficiency (Shaik, 2015). The method we use in this paper is Data Envelopment Analysis (DEA) which is a non-parametric linear programming method used to construct the relative efficiency of DMUs. DEA utilizes multiple inputs and outputs in the programming techniques (Cooper, et al, 2011; Wang and Lan, 2011) via Malmquist Productivity Index. With regards to DEA, there are several advantages including (1) the nonparametric nature; (2) without requiring the price information, so the market conditions present no impact on the technical efficiency (Taib et al, 2018); (3) be able to handle multiple outputs and inputs (Ruggiero, 2007; Ludena, 2010) while SFA typically estimate single output with multiple inputs; (4) not having a functional form while SFA needs to specify the functional form; (5), can examine efficiency with a single years data (Lusk et al.). Therefore, DEA mostly is preferred because it easily converges since there is no need to estimate the functions, all that is considered is the distribution form. But because SFA can separate efficiency and noises while DEA does not accommodate noise, attributing the deviation away from the frontier to the inefficiencies (Theodoridis and Anwar, 2011), the stochastic frontier model can allow us to model the assumptions of both efficiency distributions and the functional form, hence we have more control over how we want to estimate the model to evaluate the relationship between the endogenous and exogenous variables.

In order to calculate the productivity of k DMUs requires solving four linear programming problems to measure the TFP changes between two periods (Coelli et al, 2005). Following Färe et al. (1994), the output-based Malmquist index of productivity change, assuming production technology (P) transforms the inputs vector $x^{k,\ t}$ into the output vectors $y^{k,\ t}$ given the period t=1(2006), 2, ...T (2018) for each province k=1, 2, …, K (18) (Shaik et al, 2012).

$$P(x^{k,\ t}) = \{y^{k,\ t} : x^{k,\ t} \text{ can produce } y^{k,\ t}\} \tag{5.12}$$

The optimal proportional change is measured by the output distance function in relation to the frontier at year t-1, the output set can be expressed using the output distance function as:

$$D_0^{t-1}(x^{k,\ t}, y^{k,\ t}) = \max\{\theta : \theta y^{k,\ t} \in P^t(x^k)\} \tag{5.13}$$

The distance functions and constraints at the same period and mixed periods are expressed as:

$$D_0^t\ (x^{k,\ t}, y^{k,\ t})^{-1} = \max_{\theta, z} \theta \tag{5.14}$$

s.t

$$\theta y_j^{k,t} \leq \sum_{k=1}^{K} z^k y^{k,t}$$

$$\sum_{k=1}^{K} z^k y^{k,t} \leq x_i^{k,\ t}$$

$$z^k \geq 0$$

$$D_0^{t-1}\ (x^{k,\ t-1}, y^{k,\ t-1})^{-1} = \max_{\theta,z} \theta \tag{5.15}$$

s.t $\quad . \quad \theta y_j^{k,\ t-1} \leq \sum_{k=1}^{K} z^k y^{k,t-1}$

$$\sum_{k=1}^{K} z^k y^{k,t-1} \leq x_i^{k,\ t-1}$$

$$z^k \geq 0$$

$$D_0^{t-1}\ (x^{k,\ t}, y^{k,\ t})^{-1} = \max_{\theta,z} \theta \tag{5.16}$$

s.t.

$$\theta y_j^{k,\ t} \leq \sum_{k=1}^{K} z^k y^{k,t-1}$$

$$\sum_{k=1}^{K} z^k y^{k,t-1} \leq x_i^{k,\ t-1}$$

$$z^k \geq 0$$

$$D_0^{t}\ (x^{k,\ t-1}, y^{k,\ t-1})^{-1} = \max_{\theta,z} \theta \tag{5.17}$$

s.t.

$$\theta y_j^{k,\ t-1} \leq \sum_{k=1}^{K} z^k y^{k,t-1}$$

$$\sum_{k=1}^{K} z^k y^{k,t-1} \leq x_i^{k,\ t-1}$$

$$z^k \geq 0$$

In the equations above, θ is is the decision variable, k is the number of decision-making units, j is the number of outputs, i is the number of inputs, and z^k is the intensity variables or weight constraints. The individual output sets are less than or equal to the efficiency frontier but when associated with the input sets, the observations are greater than or equal to the efficiency frontier.

In practice, the increase in TFP (Total Factor Productivity) while holding the inputs unchanged is often attributed to technological improvements. In the hog industry this could be the improvement of genetics, breeding, and pig feed formula. In China's hog industry, it also includes biosecurity and environmental pollution control technology implementation.

5.2. Empirical Analysis

To accelerate the transformation and upgrading of the hog industry and sustainable development and to ensure the stability of the pork supply, the Ministry of Agricultural and Rural Affairs of China in 2016 announced "National Hog Production and Development Plan" (2016-2020). This is the guideline for the hog industry to further enhance the production capacity, improve the production efficiency remain to be the pillar industry of the agricultural and rural economy. Especially given its cultural and economic significance.

By comprehensively considering the environment and resources capacity, consumption preferences and slaughtering and processing, the provinces are classified into key development areas (KDA), restricted development areas (RDA), potential development areas (PDA), and moderate development areas (MDA) (see Table 5.1).

Considering the differences of different scale (small-scale, medium-scale and large-scale) hog farming in China among different regions, 18 provinces have been selected which are classified into the corresponding regions based on the national hog productional regional distribution in Table 5.1. This is done to calculate total factor productivity.

Table 5.1: National Hog Production Regional Distribution

Areas	Provinces included	Area Features
KDA	Hebei, Shandong, Henan, Guangxi, Sichuan	Traditional production area accounting for 38.2% of the national output, the key area of stable pork supply in China, annual increase expected to expand by nearly 1% annually
RDA	Jiangsu, Zhejiang, Anhui, Hubei, Hunan, Guangdong	The production is 38.6% of the total output (2014), with the limited resources and environmental conditions in this region, the hog production and growth are limited and the total amount of breeding in this region will remain stable in the future
PDA	Liaoning, Jilin, Heilongjiang, InnerMongolia	The production is 18.6% of the total output, this area has good environmental conditions, great potential to expand further, and it is the main region resources are available to increase the pork production in China.
MDA	Shanxi, Shanxii, Qinghai	The production is 4.6% of the total output, and the region has rich land resources and good conditions for combining agriculture and animal husbandry, but the foundation of pig breeding is weak, and some provinces and regions are short of water resources.

5.2.1. Small-Scale Total Factor Productivity and Its Determinants

Table 5.2: Total Factor Productivity and Decomposition of Small-Scale Farms

Area	Province	TFP	EC	TC	PTE	SE
National Mean		1.012	1.002	1.01	1.002	1.001
KDA	Hebei	1.016	1.007	1.009	1.006	1.001
	Shandong	1.008	0.991	1.017	1.000	0.991
	Henan	1.011	1.009	1.002	1.007	1.002
	Guangxi	1.014	1.000	1.014	1.000	1.000
	Sichuan	0.975	0.999	0.975	1.000	0.999
KDA Mean		1.005	1.001	1.003	1.003	0.999
RDA	Jiangsu	1.020	1.000	1.019	1.000	1.000
	Zhejiang	1.023	1.004	1.019	1.003	1.001
	Anhui	1.018	1.011	1.007	1.005	1.006
	Hunan	1.009	1.001	1.008	1.001	1.000
	Hubei	1.017	1.013	1.005	1.005	1.008
	Guangdong	1.018	1.000	1.018	1.000	1.000
RDA Mean		1.018	1.005	1.013	1.002	1.003
PDA	Liaoning	1.005	0.993	1.012	0.995	0.998
	Jilin	1.005	0.995	1.025	0.997	0.998
	Heilongjiang	1.030	1.000	1.030	1.000	1.000
	InnerMongolia	1.026	1.006	1.020	1.000	1.006
PDA Mean		1.017	0.999	1.022	0.998	1.001
MDA	Shanxi	1.023	1.013	1.010	1.011	1.002
	Shanxii	0.979	0.993	0.987	0.996	0.996
	Qinghai	1.008	1.011	0.998	1.010	1.001
MDA Mean		1.003	1.006	0.998	1.006	1.000

The average TFP of all small-scale hog farming is 1.2%, the productivity has a positive increase: technical improvement is 1.01% and technical efficiency is 0.2%, this indicates the increase in productivity is mainly attributed to t technical improvement, since the average technical efficiency change is only 0.2%. PTE = 1.002>1, SE=1.001 =1, and this suggests the overall high level of technology upgrading and technical expansion, still some provinces such as Shandong and

Sichuan in the KDA, Liaoning and Jilin in the PDA, Shanxii in the MDA have decreasing return to scale possibly due to resource misallocation.

The region-level data tells us the average increase rate of TFP in KDA is 0.5% lower than the national average of 1.2%: technical improvement is 0.3% and technical efficiency is 0.1%. both are lower than the national level of 1.0% in TC and 0.2% in EC. The average increase rate of TFP in RDA is 1.8 % higher than the national average: technical improvement is 1.3% and technical efficiency is 0.5 %. The increase in productivity is mainly contributed by technical improvements. The average increase rate of TFP in PDA is 1.7%, higher than the national average: technical improvement change is 2.2% and technical efficiency change is -0.1%. Since technical improvement has a higher increase rate than the national average level, the decrease in the technical efficiency does not slow down the productivity growth. The average increase rate of TFP in MDA is 0.3%: the technical improvement is -0.2% and technical efficiency is 0.6%. It is the increase of technical efficiency which pushes the productivity growth further.

With the four regions in comparison, the TFP growth of small-scale hog farming tends to show: RDA (1.8%) > PDA(1.7%)> KDA(0.5%) >MDA(0.3%); Technical improvements: PDA(2.2%) >RDA(1.3%) >KDA(0.3%) >MDA(-0.2%); Technical efficiency:MDA(0.6%) >RDA(0.5%)>KDA(0.1%)>PDA(-0.1%)

By looking at the province-level calculation results, only TFP of Shanxii and Sichuan is in stagnation and the productivity is in decline of 2.1% and 2.5% respectively due to the decline in both technical efficiency and technical improvement. All other provinces have an increase in the TFP. With regards to the technical improvements in consideration, except Sichuan, Shanxii and Qinghai, all other provinces have the TC >1 which indicates most provinces are progressing with respect to technical improvements. However, Shandong, Sichuan, Liaoning, Jilin, Shanxii all have growth of TE <1 and this implies the technical efficiency is declining in those provinces.

In summary, from 2006 to 2018, the overall TFP of small-scale has had a positively increasing trend and the technical improvements contribute the most. The technical efficiency has had limited effects. Five provinces have stagnation regarding technical efficiency. Some provinces though suggest that a high level of technical upgrading and technical expansion is warranted, though the production scale of some small famers needs to be adjusted due to resource misallocation.

5.2.2. Medium-Scale Total Factor Productivity and Its Determinants

Table 5.3 presents the average productivity change and its decomposition for the 18 provinces between 2006 and 2018 for medium-sized hog farms in China. The average increase rate of TFP across the country is 2.8% which is mainly promoted by the technical improvement of 2.3%, the technical efficiency change is 0.5% and does not play a crucial role in growth. PTE= 1.005>1 and SE = 1.001 =1, and this indicates the majority of provinces are efficient with respect to scale as they are very near constant returns to scale.

Table 5.3: Total Factor Productivity and Decomposition of Medium-Scale Farms

Area	Province	TFP	EC	TC	PTE	SE
National Mean		1.028	1.005	1.023	1.005	1.001
KDA	Hebei	1.029	1.013	1.016	1.014	0.998
	Shandong	1.013	1.007	1.006	1.014	0.993
	Henan	1.013	1.015	0.998	1.008	1.007
	Guangxi	1.046	1.012	1.034	1.006	1.006
	Sichuan	1.022	0.995	1.027	0.997	0.998
KDA Mean		1.025	1.0084	1.0162	1.0078	1.0004
RDA	Jiangsu	1.015	1.011	1.004	0.995	1.016
	Zhejiang	1.046	1.008	1.038	1.008	1.000
	Anhui	1.027	1.021	1.005	1.015	1.006
	Hunan	1.024	0.991	1.034	1.000	0.991
	Hubei	1.040	1.005	1.035	1.005	1.000
	Guangdong	1.040	1.001	1.039	1.000	1.001
RDA Mean		1.032	1.006	1.026	1.004	1.002
PDA	Liaoning	1.012	1.001	1.010	0.999	1.003
	Jilin	1.038	1.002	1.035	0.999	1.003
	Heilongjiang	1.038	1.001	1.037	1.001	1.000
	InnerMongolia	1.013	1.006	1.007	1.007	0.999
PDA Mean		1.025	1.003	1.022	1.002	1.001
MDA	Shanxi	1.016	1.013	1.016	1.014	0.998
	Shanxii	1.033	0.989	1.045	0.996	0.993
	Qinghai	1.044	1.015	1.028	1.018	0.997
MDA Mean		1.031	1.006	1.030	1.009	0.996

With respect to the region-by-region results, we note that RDA has a TFP change of 3.2% on averae which is higher than the national increase rate at 2.6%. Almost all the increase is due to the improvements in technical change. Technical efficiency plays a minor role in growth in the region. Similarly, the growth rate of TFP in the MDA area at 3.1% is also mainly due to the technical innovation. PDA and KDA have the same average increase rate in TFP at

2.5%. Both the TC and EC work together to accelerate productivity growth, and technical innovation has the larger impact on the TFP increase in those regions.

By comparing the TFP increase rate of those four regions, RDA (3.2%) > MDA (3.1%) > KDA (2.5%) = PDA (2.5%). Concerning the technical innovation, MDA (3.0%) > RDA (2.6%) > PDA(2.2%) > KDA(1.62%). When we consider technical efficiency, clearly, the four regions all have a smaller increase rate.

Based on the province-by province calculation results, we find that Zhejiang and Guangxi have an increase rate of TFP as high as 4.6%, and technical innovation contributes largely to the growth. The province of Qinghai in the MDA has greatly accelerated its productivity at 4.4%, Similarly, it is mainly due to technical change. Other provinces such as Hubei, Guangdong, Heilongjiang, Jilin and Shanxii all have a growth rate of productivity higher than 3.0%. Still, the technical innovation plays the dominant role as far as contribution. Though almost 15 provinces except Sichuan, Hunan, and Shanxii present a positive increase rate of the technical efficiency, the effects are relatively smaller when compared with those of technical change.

In summary, in the period from 2006 to 2018, the nation has an average TFP increase rate at 2.8% in medium-scale hog operations and this is mainly due to technical innovation at 2.3% (technical efficiency at 0.5%). With respect to regional level results, RDA has the highest increase rate at 3.2%, next is the MDA at 3.1%, KDA at 2.5% and PDA at 2.5%. Most of the increase is due to technical innovation. In addition, the scale efficiency denotes most of the provinces are efficient to utilize their resources.

5.2.3. Large-Scale Total Factor Productivity and Its Determinants

Table 5.4 tells us the overall average increase rate of TFP in large-scale hog production is around 1.6% which is due to the joint effects of EC at 0.7% and TC at 0.9%. The PTE =1.002 >1 and SE=1.005>1. Overall technology upgrading, and expansion are high level and large hog farmers will become more efficient if the production scale is expanded further. The region level results present the comparison among the different regions.

The TFP increase rate of RDA at 2.0% is the highest among the four areas, higher than the national average level at 1.6%. Although EC and TC both contribute to its increase, the effects of technical efficiency are larger. PDA has an increase rate of TFP at 1.7% which is different from RDA. This increase mainly is due to technical innovation. KDA is similar to PDA, and its average increase rate is 1.5% which is contributed to by the combined effects of TC and EC. MDA is the only one with a deterioration rate of technical efficiency change at -0.3%. Therefore, though its TC at 1.2% is higher than other areas on average, the increase rate of TFP is still smaller when compared with other regions.

The ranking of the four areas about increase rate of TFP: RDA (2.0%) > PDA(1.7%) > KDA(1.5%) > MDA(0.9%); technical efficiency: RDA (1.2%) > KDA(1.0%)>PDA(0.5%)>MDA(-0.3%); technical change: MDA (1.2%) >PDA (1.1%) >RDA(0.9%) > KDA(0.5%).

Shanxi is the only province with a negative rate of TFP at -0.1%, and this is mainly the deterioration of technical effects at -0.2%. Hubei in the RDA has an increase rate as high as 3.8% which is much higher than the national average at 1.6%. This is pushed forward mainly by technical efficiency. Hebei's increase rate is at 3.3% and the same as Hubei which is also mainly due to technical efficiency.

To conclude, from 2006 to 2018, almost all the provinces except Shanxi has a positive increase of TFP. Especially the two provinces of Hubei and Hebei with much higher increase rates compared with others. This is contributed by the joint effects of TC and EC, though the technical efficiency plays a larger role of pushing the TFP forward. With regards to the region level results, RDA has the highest increase rate on average at 2.0% with PDA at 1.7% higher. KDA is 1.5% higher and MDA at 0.9%. Overall scale efficiency also suggests that large hog production could be expanded further in order to exploit economies of scale in some regions.

Table 5.4: Total Factor Productivity and Decomposition of Large-Scale Farms

Area	**Province**	**TFP**	**EC**	**TC**	**PTE**	**SE**
National Mean		1.016	1.007	1.009	1.002	1.005
KDA	Hebei	1.033	1.027	1.006	1.013	1.014
	Shandong	1.016	1.003	1.013	1.000	1.003
	Henan	1.010	1.023	0.987	1.005	1.017
	Guangxi	1.015	1.004	1.010	1.004	1.001
	Sichuan	1.001	0.995	1.007	0.995	1.000
KDA Mean		1.015	1.010	1.005	1.003	1.007
RDA	Jiangsu	1.020	1.010	1.010	1.000	1.010
	Zhejiang	1.011	1.019	0.993	1.004	1.014
	Anhui	1.017	1.013	1.004	1.008	1.004
	Hunan	1.024	0.997	1.027	0.999	0.998
	Hubei	1.038	1.029	1.009	1.003	1.026
	Guangdong	1.012	1.001	1.011	1.001	1.000
RDA Mean		1.020	1.012	1.009	1.003	1.009
PDA	Liaoning	1.019	1.006	1.013	1.002	1.004
	Jilin	1.012	0.995	1.017	0.997	0.999
	Heilongjiang	1.019	1.000	1.019	1.000	1.000
	InnerMongolia	1.016	1.020	0.996	1.010	1.010
PDA Mean		1.017	1.005	1.011	1.002	1.003
MDA	Shanxi	0.999	0.998	1.002	1.000	0.998
	Shanxii	1.011	1.000	1.011	1.000	1.000
	Qinghai	1.016	0.994	1.022	0.996	0.998
MDA Mean		1.009	0.997	1.012	0.999	0.999

5.2.4. Temporal Productivity Changes and Its Decomposition Comparison

According to temporal changes of Malmquist index across years (table 5.5):

1st period (2006-2007), the average productivity of medium scale increases at 3.6%, large scale increases at 1.2%, and small scale has a negative increase rate at -5.4%. Nevertheless, the increase of Malmquist index with respect to large scale is mainly due to technology change at 5.1% since technical efficiency deteriorates at -3.7%. This is different from large scale as the joint effects of technical efficiency and technical innovation promotes the increase of TFP for medium scale hog production. Though technical efficiency has a larger influence. In contrast to medium scale, TFP of small scale deteriorates due to the decline of both efficiency change and technology change.

2nd period(2007-2008), The TFP increase rate of small scale (9.0%) is higher than medium scale (6.3%) and large scale (2.4%). This is mainly driven by the mutual effort of technical and efficiency change. Though large scale has the highest increase of efficiency change at 8.8%, the deterioration of technical change slows the TFP increase. It is the same with the small-scale production, TC (1.4%) and EC (4.7%) work together to accelerate the TFP increase of medium scale production.

3rd period (2008-2009). The large scale maintains an increase trend of TFP (1.7%), which is mainly promoted by the efficiency performance (1.8%). Small scale has a slight increase of 1%. In contrast, there is a negative increase of medium scale (-3.8%) because of the deterioration of technical and efficiency change.

4th period (2009-2010), the large scale continues to increase at a faster pace at 7.5% compared with the small scale at 1.3% and medium scale at 2%, mainly from technical innovation at 7.3%. Because of a decline in the technical change for the medium scale and deterioration in technical efficiency, the increase rate of medium scale is smaller.

5th period (2010-2011). TFP of medium scale is growing at a faster rate of 2.7% than the other size categories. The technical change at 2.6% contributes more to this growth. The technical change decline of large-scale production results in the decline of productivity (-0.8%).

6th period(2011-2012). The productivity increase of large scale is as high in this period at 20.2% which is due to the dominating effects of technical improvements. Likewise, the small and medium scale also have a big increase in productivity at 3.6% due to the technical improvements at 3.9% though and they both have a decrease of in technical efficiency.

7th period (2012-2013). Different from the previous periods, large scale instead had large decrease of productivity (-13.3%) and it is the technical decline decreases the TFP. But the productivity of small and medium scale still sustains an increase of 1.3% and 0.7%, respectively.

8th period (2013-2014). Technical decline is reduced which helped to accelerate the productivity of large-scale hog production at 0.8%. The medium scale grew at 1.9%, faster than the large and small scale. Most of the growth is from technical efficiency. The small scale has a similar increase level with that of the large scale, but it is more due to technical efficiency.

9th period (2014-2015) Medium scale continues to grow at a similar speed (1.7%) mainly facilitated by technical innovation at 2%. Large scale continues to increase its productivity at 0.5% and this is mostly contributed by technical efficiency at 1.0%. The small and medium scale farms both have a decline in technical change, though the determinant roles are different

10th period (2015-2016). The productivity of large scale continues to increase at 0.6% and this is smaller than 1.4% of small scale and 0.8% of medium scale. The reason why the small scale has a higher growth rate than the other two scales is that the technical and efficiency change both grow positively.

11th period (2016-2017). Given the continuous growth of technical change for medium scale production, its productivity has a higher increase level even though the technical efficiency deteriorates.

12th period (2017-2018). Despite the decline of technical efficiency, the high amount of technical change at 18.6% results in medium scale continuing to have a high level of productivity increase at 16%. The small and large scale continue to grow at a relative smaller pace.

The average increase rates of TFP under the small, medium, and large-scale production are very different, the results across years have large fluctuations (see Figure 5.6). In addition, the determinants vary across the three-scale production categories. Therefore, in order to promote growth of TFP, there must be a diverse set of strategies to continue.

Table 5.5: Malmquist Index Summary of Temporal Changes of Hog Productions

Year	Small Scale			Medium Scale			Large Scale		
	TFP	EC	TC	TFP	EC	TC	TFP	EC	TC
2006-2007	0.946	0.996	0.950	1.036	1.028	1.007	1.012	0.963	1.051
2007-2008	1.090	1.028	1.060	1.063	1.047	1.014	1.024	1.088	0.941
2008-2009	1.010	1.009	1.001	0.962	0.986	0.975	1.017	1.018	0.999
2009-2010	1.013	0.993	1.020	1.011	1.022	0.989	1.075	1.002	1.073
2010-2011	1.008	0.999	1.009	1.027	1.002	1.026	0.992	1.005	0.987
2011-2012	1.036	0.997	1.039	1.036	0.998	1.039	1.202	0.998	1.204
2012-2013	1.013	0.998	1.016	1.004	1.002	1.001	0.867	1.022	0.848
2013-2014	1.007	1.010	0.997	1.019	1.019	0.999	1.008	0.988	1.020
2014-2015	0.999	1.000	0.999	1.017	0.998	1.020	1.005	1.010	0.995
2015-2016	1.014	1.001	1.012	1.008	0.992	1.017	1.006	0.989	1.017
2016-2017	1.003	1.004	0.999	1.006	0.995	1.012	1.010	1.005	1.005
2017-2018	1.010	0.995	1.015	1.160	0.978	1.186	1.005	1.005	1.000
Mean	1.012	1.002	1.010	1.028	1.005	1.023	1.016	1.007	1.009

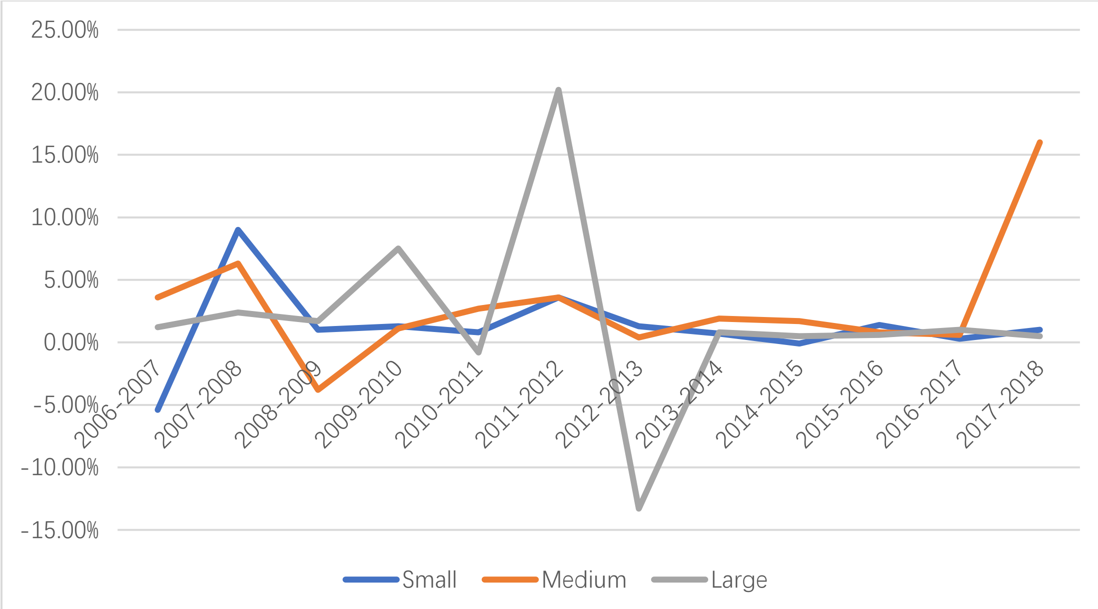

Figure 5.5: Temporal changes of TFP over Years

5.2.5. Statistics Test about the Robustness of Data Selection

In this section, our goal is to test the validity of data selection, in order to test the variation between the estimated value and real values of main output, we first have to make assumptions about the production functions. Here, we assume they are Cobb-Douglas, CRS (constant return to scale) and inputs are weighted differently (Andor and Hesse, 2011) as the below:

$$Ln(y_i) = \ln(\beta_0) + \beta_1 \ln(x_{1,i}) + \beta_2 \ln(x_{2,i}) - \ln(u_i) + \ln(v_i) \qquad (5.18)$$

Parameters of the production functions are set $\beta_0 = 1, \beta_1 = 0.75, \beta_2 = 0.25$. Here x_1 is the fine feed variable and x_2 is the invested variable, x_3 labor is relatively small when compared with another two variables, and hence it is not included in the equation. u is the deviations due to the technical inefficiency and v is random error. And u and v are presumable to be the half-normal distributions with the mean = 0, STD Dev =0.025, and normal distribution with the mean =0, STD Dev= 0.05, respectively. For test purpose, we only consider the data selection of the large-scale hog farming. y, x_1, x_2 are assumed to meet the normal distributions, according to figure 4.5 statistics description of large scale hog farms, we have $y_i \sim N(93.433, 11.722)$,

$x_{1,i} \sim N(287.713, 33.324)$, $x_{2,i} \sim N(37.646, 15.514)$. The exogenous variables are generated randomly based on the normal distribution for 1,000 times and the estimated endogenous variable y_i is calculated according to (18). The real value for the endogenous variable y_i is collected randomly based on the normal distribution with the mean and STD Dev set above. We then generate the histogram of real value and estimated value of the output, plus the scatter plot of them using R. The results are shown below. The scatter plot between the estimated and real values are shown in the figure 5.9 and they are clustered together with the mean = 4.612918 for the estimated value and mean = 4.525982 for the real value. Obviously, they are not all on the line 45-degree angle but considering their values with regard to the mean and omitted valuable of labor, the data selection is acceptable.

By looking at the distribution of the estimated and real values, we find out the real and estimated values are proximately the normal distribution, though the real values are slightly left skewed. The median of the estimated is 4.626448 while the median of the real is 4.533074, which seems very close. Hence, we can say the data selection is robust, and the empirical results will not vary largely by choosing the different data sets.

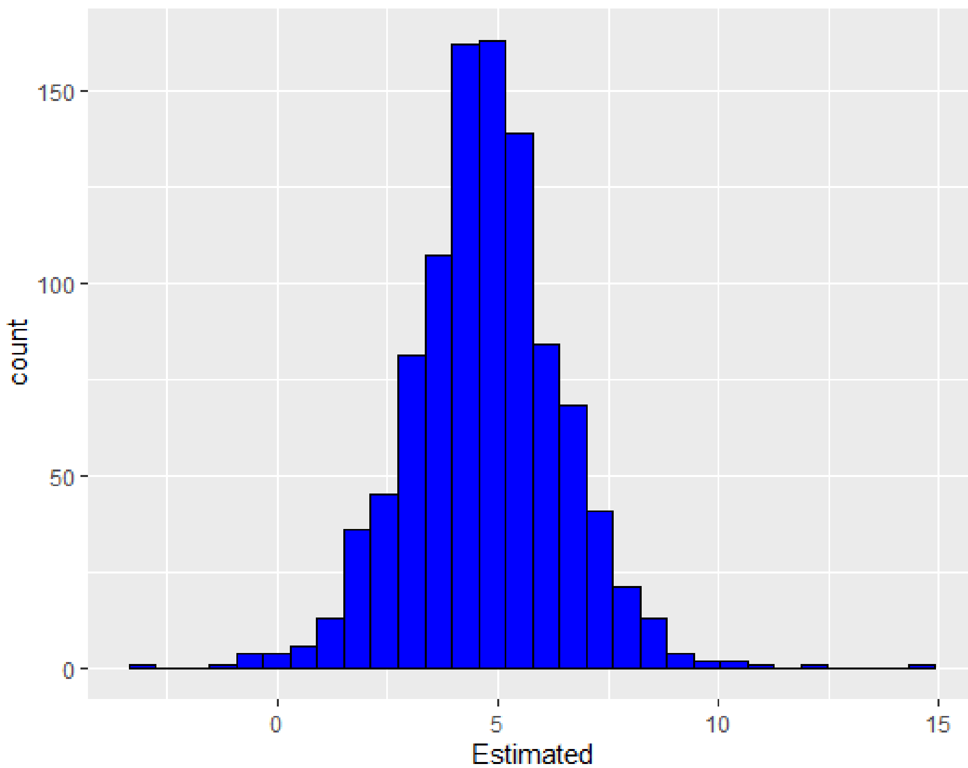

Figure 5.6: Histogram of Estimated Value of Main Output

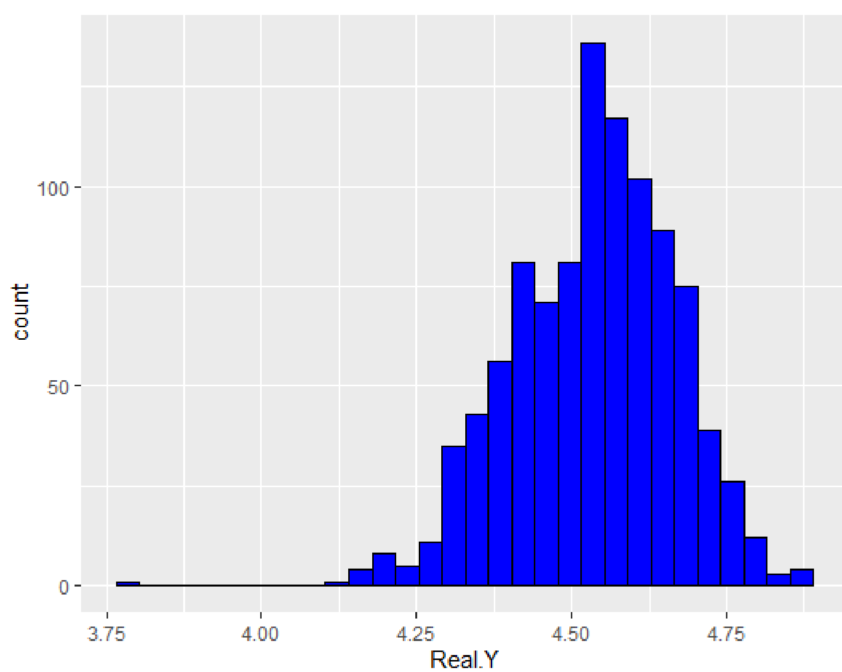

Figure 5.7: Histogram of Real Value of Main Output

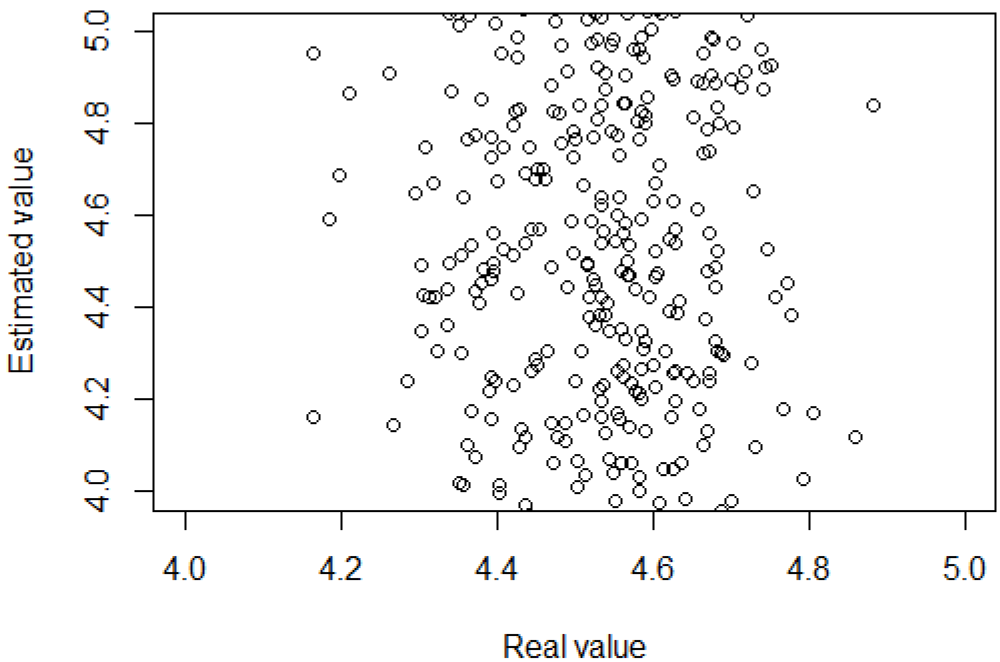

Figure 5.8: Comparison between Real and Estimated Value

6. CONCLUSION AND POLICY RECOMMENDATIONS

6.1. Summary and Conclusion

The statistical analysis shows the proportion of large-scale hog farming is increasing significantly while the percentage of small-scale is shrinking which is in-line with the initiatives set forth by the Chinese government. However, China's hog industry remains early in the transition from small-scale to the large-scale hog farming. The large-scale hog farms have the highest pure hog weight per unit (working day) and lowest level of feed required per kg of gain. Nonetheless, there is no significant difference in farm size with respect to breeding and weaned pig production. The unit production costs of large-scale hog farmers have the lowest increase rate given the sample period. Despite the fact the small-scale hog farmers still have advantages in costs and profits during certain periods, yet compared with the medium and large-scale breeding, it is more impacted by other factors such as the outbreak of ASF and wide swings in feed prices.

This paper used the Malmquist index, the input and production data from 2006 to 2018 measuring the TFP and the decompositions for the four characteristic regions. The empirical results show that:

From 2006-2018, the overall TFP growth of hog production in China is mostly determined by technical innovation, the effect of technical efficiency is smaller. The four regions including KDA, RDA, PDA and MDA all have very different growth rates of TFP under the three-scale production categories. RDA is a densely populated region and the production and consumption both are very high. It is also experiencing much faster growth than the other three regions. The RDA with respect to small and large-scale production both presents great potential for pork production because two areas have a bigger growth rate than the overall average of the country. KDA is China's traditional pig production area, and the pork demand is very high. In addition to meeting the consumption requirements of the local consumers, it also needs to offer a steady supply of pork to the consumers from costal provinces such as Shanghai, Jiangsu, Zhejiang, and Guangdong. The results show the KDA growth rate of TFP is smaller than the overall national level under small, medium, and large-scale production. Potential development area (PDA) is a key region needing additional investment for expansion. PDA is the area with rich land resources, and good combination of agriculture and animal husbandry. Due to good environmental conditions and development potential, it becomes the main area to focus on increasing pork production as demand exceeds supply when you also add the demand from Beijing, Tianjin, and other cities. Under the medium scale production, it shows a great advantage due to the advanced breeding technology. However, under large scale production due to the negative growth of technical efficiency, its development is still much slower than the national average level.

The empirical results of temporal changes of hog farms from 2006 to 2018 shows the overall average of medium scale hog farms has the largest growth rate at 2.8%, followed by the large-scale hog farms at 1.6% and then the small-scale hog farms at 1.2%. Except in 2006-2007, 2014-2015, TFP of small scale develops positively and still presents certain advantages. Hence, small scale hog farming continues to exist despite many of its limitations. Large-scale farms show that the growth rate reaches as high as 20.2% in 2012. However, in certain periods, the technical innovations deteriorate, and this largely slows down the productivity growth.

The results are in accordance with the concept of Minimum Efficient Scale (MES). MES is capacity beyond which firms are no longer to have the economies of scale linking different scales to operational efficiency as reflected by the average cost function (Kaselimi, et al, 2011). We can explain this theory using Figure 6.1. Binger and Hoffman (1998) explained very thoroughly the short-run and long-run average costs. The Long-run average cost function (LRAC) is U-shaped. If the products are produced at certain scale, the LRAC is declining because of economies of scale. Firms expand production as the costs per unit continue to decline. However, there is a limit to economies of scale. Eventually, firms reach point of constant returns to scale where the increase in output is met with a proportionate increase in costs. As overhead costs, inefficiencies, and other management challenges erode the savings from growth, firms reach the point known as diseconomies of scale. At this point the LRAC will increase rather than decrease.

After calculating the TFP, the MES of China's hog production can be obtained under the medium scale at which the average long run cost is the minimum.

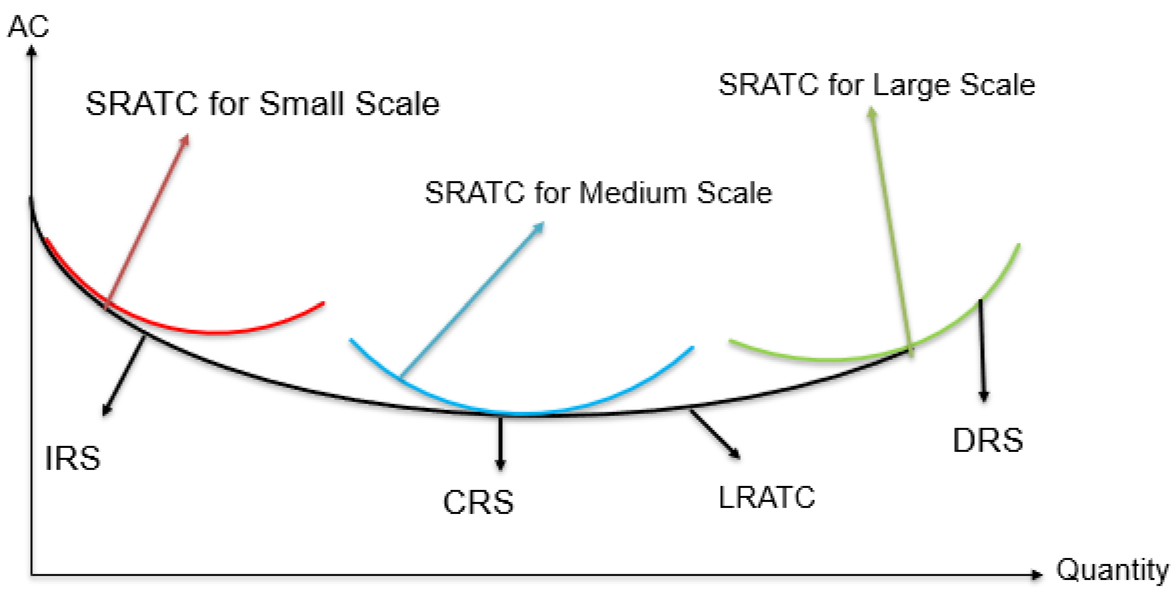

Figure 6.1: Short-run and Long-run Costs with IRS, CRS, and DRS
Source: Binger and Hoffman (1998), page 296-297

Despite the temporal declines in the TFP growth, admittedly, large- scale hog farms might not be quite as efficient as medium-scale hog farms, but large hog farms or dragon head hog firms do have a lot of advantages the small and medium scale hog firms might not have such as the biosecurity and environmental pollution controls.

6.2. Policy Recommendations

Since the reforms in China and incentivizing larger hog production systems, China's pork production has developed significantly, and standardized scale production has been continuously promoted. This effectively satisfies the consumption demand of urban and rural residents to an extent, especially in implementing the dragon head enterprises model in China's hog industry. However, the multiple challenges in China's hog industry persist including environmental challenges, limited resources, increasing production costs, outbreaks of animal pandemics, and general food safety concerns. Additionally, China relies on trade for much of its livestock feed supply. The development of the modern hog industry is a systematic project, any weak chain of this whole system will result in a potential business risk such as animal epidemics, manure disposal, breeding environmental issues and so on. The theory and practise prove the "dragon head enterprises" + " comprehensive integration" model is in line with the requirements of this systematic project about biosecurity and environmental protection. In order to promote this model, for the hog industry in China to achieve the sustainability and dependability it desires, it is very necessary to implement the corresponding measures. And the policy makers should make policies to encourage pork farms, feed producers, pork slaughtering, processing firms to extend the industrial chain and develop vertically integrated operation which are able to complete the feed production, genetics improvement of pig breeding, feeding weaned piglets, fattening live pigs, animal pandemics control, slaughtering processing and marketing and sales within one firm. In this way, the whole industry chain is well monitored and tracked. Implementation of standardized production to ensure pork quality and safety is a lot more tangible (Shen, 2012). The multiple challenges might be well tackled if the following recommendations are considered.

6.2.1. Structural Change to Accelerate the Growth of Productivity

We have discussed in the previous chapter 4 the hog industry has been in the transition from small scale to the large-scale hog farms, though the size of small hog farmers has been greatly decreased over years, the structural shift to make larger improvements in pork production as the current structure is still very slow in improving the productivity as seen in the chapter 5. Structural change in U.S agricultural have been attributed to various factors including technologies improvement in agricultural production, and without considering the structural impacts, the formulating policies will be severely hampered (Reimund et al, 1981). Therefore, there is necessary for the policy makers to accelerate the structural shift so as to improve the productivity to a larger extent.

Gillespie et al (2000) claimed three major trends in the livestock and poultry industry in relations to the evolution of the structural shift including the increase in farm sizes, technology, and production; increase in vertical coordination in the livestock and poultry industries; consumption patter change about meats. Boehlje and Schrader (1995) argue the rapid industry structural change lies in the transformation of pork products, upgraded facilities and plans for innovative technologies. Besides the technology forces, same with Gillespie et al (2000), Barkema (1996) also emphasized the consumers' consumption as a driving force for the structural change. In addition, Reimund et al (1981) discuss the adjustment to risk is also part of structural change in the process.

Obviously, the visible change due to the structural change is to have less hog farms in the market but larger size of hog farms. The U.S hog producers have made significant structural change in the structural shift about the market share while in the Chinese pork market, the concentration rate is still pretty low, and the impact of low concentrate rate and the corresponding policies are covered in the next section. Continued technology development is a very significant force to shift the overall structure of hog industry include genetically improved breeding, automated feeders, disease control improvement, environmental issues control, and monitoring herd performance using the computerized information systems, and so on, the application of technologies result in the exit of those who are unable to adopt but only to keep a subset of producers in the market. (Gillespie et al, 2000). Chinese hog industry also strengthens the livestock policies in speeding up of relevant technologies policies, but the process seems still slow which slows down the productivity progress of overall industry , this is because small-scale or medium scale hog farms are still playing large part of the pork production and do not have sufficient integrate between upstream and downstream.

In addition to accelerate the firm size, to speed up the integration of the overall industries and have vertical integration is a necessary trend, the longer supply chain of the pork production related farms have, the less business risk there will be. The policies makers should make more stimulative and progressive policies and encourage the upstream and downstream with strong capital strength to have vertical integration in the hog production. Meanwhile, the hog producer with capital advantages is encouraged to expand in the slaughtering and pork processing in the downstream to form a large hog farming group with a complete industrial chain of feed, breed, slaughtering and processing which are able to better handle the multiple challenges and achieve the long-term and stable profits. The rural areas in Quzhou city of Zhejiang province can work as one example. Within a few years, the city makes rapid progress in structural change of hog industry in the rural areas using a series of more progressive policies : subsidizing to demolish the piggeries of scatter or small hog farmers and decreasing the number of small or scatter hog farmers in the market by actively encourage them to shift to other ecological characteristics agriculture operation and at the same time 50 producers together in the Quzhou city form a joint group whose business covers in feed, breeding, food safety, slaughtering, illness monitor and waste harmlessly treatment and environmental control (Lan and Wang, 2014). This has effectively solved the problem of financing, epidemic prevention and control, food safety, environmental protection and greatly reduced the production cost. Thereby, the pork price in the local area does not rise but greatly decrease.

6.2.2. Increase the Productivity via Technological Improvement

The increase in productivity is mainly attributed to the development of technologies. We have analyzed the productivity of small, medium and large-scale hog farms and found out the hog industry has not made significant improvements in the overall technology development and popularization. At certain periods, the technology progress even stagnates or deteriorates. Even if the hog production is differentiated among small, medium, and large scales, there still exists imperfect market, for example, highly integrated larger firms will have more control about the pork market. Given the disadvantages in biosecurity and environmental control, the small or even the medium scale hog farms will eventually exit from the market. With regards to the large hog farms, it is very necessary to strengthen the innovation and application of technologies. In Chinese hog production, we have to focus more on pig breeding technology and feed processing technology.

Specially, it should focus more on improvement in breeding pigs' genetics, feed formulation process, breeding, and production technology. To be clear, though genetics is not included in the part of vertical integration like in US, in China, more than 80% of the commercial pigs are brought in from overseas. The sow fertility is closely linked to the economics welfare of the hog farms. To achieve high levels of reproductive performance and longevity for the sows is very critical and this is affected by a variety of factors including genetics potential, health status, nutrition levels, and environmental qualities. (Singleton Wayne, 2007). The reproductive performance and feed utility ratio are still far behind in China. For example, the average number of farrowing is 16, while in U.S is more than 22. The feed conversion rate of live pigs in China is 3.1:1, while it is 2.5:1 in U.S (Shen, 2012). The selection and breeding of well-bred sows is a comprehensive systematic project which requires to combine the traditional breeding technology with the advanced biological technology, the orderly introduction of superior breeds from abroad with the effectively utilization of the domestic pig breeding resources (Shen, 2012). Because different breeds of pigs are genetically different, the actual nutrient requirements to pigs will vary and they require different formula of feeds at different stages of feeding(Aillery et al, 2005), hence it may be necessary to accelerate the cultivation of feeds suitable to different regional conditions and different periods of pigs.

With promoting the new pig breeding technology, the technical efficiency of pork production should be accelerated, too. The reputable Wen Group' model (contract growing model) states they provide the piglet, feed, vaccines etc to the farmers. Wen Group or other dragon head hog firms can do more, for example, offering consulting service, working with the farmers with respect to disease control and prevention and help the farmers to make assessments of the associated risks in the procession of breeding so that farmers are able to prevent and control them effectively. This would help minimize the relevant risks and greatly reduce the farmers' losses. Moreover, they can also help the farmers bring or cultivate the sows, improve their fecundity and survival rate of piglets, and enhance the comprehensive production capacity. Training can be offered about the relevant technologies of waste treatment as well. Essentially farmers would willingly feed the hogs according to the requirements of those dragon lead hog firms.

6.2.3. Breeding Center Construction

Pork and relevant products are one of the food categories having the frequent food safety crisis in China and the incidents due to the inflow of sick or dead pigs into the market are on the rise. (Xu, 2016). Ensure to have the safe pork in the market involving breeding, slaughtering, processing, transportation, and marketing. But Breeding as the initial stage, normally controlled by small or medium hog farmers in China is the most fundamental and the weakest stage of hog production.

If the sick or dead pigs in the initial stage can be treated harmlessly, and this will help to avoid most of food safety issues. For large-scale pork processing firms, whether to have the trustworthy and steady pork supply makes a big difference. By controlling the original source of production upstream, the associated business risks will be greatly reduced.

In order to avoid a similar scandal Shuanghui used to have, one big change this company tried to do is to adjust their production structure and develop their feeder pigs in the upstream. They try to raise their breeding pigs and commercial pigs, and they also plan to have their own processing facility in operation. What is more, some other firms even have their own feed factories and milling to ensure traceability of any potential disease or contaminations (integration).

While building the breeding center, first and most important is to consider the environmental bearing capacities of different areas. For example, Fujian, Jiangxi, Sichuan, Gongdong and Hunan have the largest pollution load due to the manure polltuon brought by large scale hog farming, therefore, the relevant policies should be made to restrict the medium or large-scale farms to expand in those provinces to have less emissions of pigs' manure. (Zhou and Qing, 2017).

The national hog production regional distribution order issued in 2016 by Ministry of Agriculture can work as the guideline of building the breeding base for large hog firms. For example, the large hog firms can make use of the resource advantages in the potential development areas (PDA), build their own breeding bases in an area having a lower hog density, and become the integrated leading firms in both breeding, slaughtering, and processing. (No. 350 [2020]) Notice of the National Development and Reform Commission also makes the expansion of building the breeding base possible by ensuring reasonable land use requirements of the pig breeding base.

6.2.4. Concentration Rate Increase

The 12th Development Plan in 2012 issued by Ministry of Industry and Information Technology in China reports " small, scattered, low" patter in China's food industry still account for more than 90%, the low concentration of medium or large-scale enterprises, low level development of advanced production capacity and unreasonable organization structure in the food industry hinders the pace of industrial structure upgrading. Zhang et al (2014) did survey in Wuxue City of Hubei province and found 45.5% of sampled hog farms are small farms with less than 100 head. This also brings challenges to China's food safety management. Low concentration rate is another big challenge the hog industry also needs to address.

In China, one of the important policies regarding the low concentration rate is to utilize the limited resources into the fewer advantageous large enterprises and encourage those firms to grow bigger and stronger in the market. For example, the 12th Five Year Plan (2011-2015) requires adjusting and optimize the industrial structure to support the medium and larger firms grow bigger and stronger in hog industry by cooperating, merging, restructuring and obtain the goal of having ten large firms with over 10 billion Yuan and the production and market concentration of the top 20 firms arrives at 80%.

The market regulations and management by Chinese governments are different with the US and EU where the anti-monopoly policies are implemented to prevent the companies with dominating market shares obtain excess profits and ensure the consumer welfares are not harmed.

In China, the concentration level of markets is still very low at the current stage, the main goal of market regulation is to ensure food safety (Yu et al, 2015). The intensive breeding model advocated can lessen a series of problems caused by the scatter or small-scale hog farms and reduce the overall breeding cost (Zhu, 2018). The higher concentration rate of medium or larger hog farms will make the food safety supervision easier for the governments since the larger hog farms hold larger responsibilities and care more about their reputation.

6.2.5. Environmental Pollution Control

With the large scale and industrialization development of hog industry, the waste caused by the hog production is increasing, due to the backward in policy management, regulation construction and technology in pollution control. Pig production waste has become one of the most important environmental pollution. What is more, livestock excrement is also the main source of many pathogens that threaten human health, such as pathogenic microorganisms and parasitic worm eggs. Microorganisms in livestock waste may cause serious diseases. In addition, the fetid gas produced by livestock production contains many harmful components, which will seriously pollution the air and harm the human health. (Qiu, 2007). Hence, better control of pollution caused by pork production and reduction of the pressure on the environment is urgently necessary to be solved (Chen and Sun, 2019; Zhang, 2006) and would be easier to achieve with a higher concentration in the pork industry.

By analyzing the reasons for pork production waste, Cui (2018) did the statistical analysis in hog industry from 2011 to 2018 and found out, small and medium-scale pig breeding is very outdated in waste management which is the bottleneck restricting environmental governance of the hog industry. This is because the small-scale famers have weak awareness of environmental protection, and are largely scattered at rural and mountain areas, which are very difficult to have better control for the environmental governments. In contrast, large-scale hog farms are in accordance with the requirements for standardization pollution and waste disposal, having one or several joint disposal systems including the separation between wet and dry waste via machinery, high temperature anaerobium fermentation and three stages sedimentation tank. This system can largely minimize the relevant environmental pollution, but is too expensive for the small or medium hog farms to implement.

The environmental pollution is actually the negative externality generated by the hog production, from the optimal level of environmental pollution cost, the pollution is better controlled by equating the marginal revenue obtained by improving environment protection and the marginal cost brought by controlling the environmental pollution. To reach this goal, it seems the pollution level can be effectively reduced by controlling the amount of pollution created by scaled production, the governments can make controlled or stimulative policies to limit the amount of pollution (Shu, 2010). For example, the hog firms with outdated technology equipment and unable to meet the requirements of environmental pollution have to exit from markets (12th Five Year Plan, 2011-2015). More importantly, reduction in pollution can be obtained by bringing in the advanced technologies. The governments should make more stimulative policies and increase the investments in environmental pollution control through measures such as subsidies or subsidised loans for those hog firms who invests in feces treatment technology so that their cost-effectiveness advantage is still maintained. (Shen, 2012).

6.2.6. Biosecurity Measures

Besides the environmental pollution control, biosecurity issues are one of the most important issues needing addressed in hog production. The animal pandemics in China have become more complex and difficult to control and this poses a serious threat and risk to the hog industry but also the people's health. The reasons are 1st: small-scale hog farmers have a weak awareness of animal epidemic prevention, and do not have good measures of animal epidemic prevention and biosecurity measures, which increase the chances of the transmission of animal diseases; 2nd: the incomplete epidemic prevention systems. Many supportive policies and measures are adopted temporarily after the outbreaks of pandemics, and most of them are " remedial measures" instead of proactive measures. Moreover, those policies and measures are not completely implemented in all places, and it is very difficult to effectively prevent and eliminate the potential pandemics risks. (Lu, 2013).

The dead or sick pigs in Gao 'an City of Jiangsu province in 2014 flowing to multiple provinces including Guangdong, Hunan, Chongqing, Henan, Anhui, Jiangsu and Shandong, this outrages scandal make the consumers show much concern about the pork safety and quality and this shows lack of effective health quarantine supervision and loopholes of management of the local governments. (Huang, 2014). Comprehensive law enforcement in animal industry should be established and to clarify the enforcement responsibilities of departments and officers. Finally make more severe regulations and punishment for those who issue the certifications without quarantine inspections and result in the sick or dead pigs in the market.

More importantly, improvement in the ability to prevent and control animal epidemics mostly lies in the farmers from the original source. Many microbiological technologies do not require a large investment but a series of strict rules and regulations which require everyone involved to follow, that is to maximum the implementation of All-In–All-Out (AIAO) so as to avoid the transmission of different groups of pigs (Harmon, 2007). But this work better for the large, standardized hog farms. For those scattered distributed small farmers, it is very hard to regulate those behaviors very well. As with the disease control like ASF, to promote the prevention and control of ASF, it is also very important to make the famers better aware the importance of ASF control, have better understanding the ASF characteristics, and improve the diagnostic technology and control methods of ASF. The local governments need to make scientific training plans, build professional training teams, and improve the diagnostic technology and control methods of ASF. In order to have fast response to the outbreaks of pandemics like ASF, it is very critical for building forward and backward tracing potentially infected contacts to identify the potential spread of infection, but it is very hard to fully implemented in highly complex pork food system in China (Dixon, 2020). In addition, legal and illegal importation of infected live pigs, pork products or food waste should be avoided to reduce the virus spreading, but this normally depends on how well policy instruments are tailored to it (Dixon, 2020). This again requires the Chinese hog industry to enhance the integration level to fight against any potential biosecurity issues.

6.3. Limitation and Future Work

Considering the historical and cultural significance of pork to the Chinese consumers, the future research of pork production and consumption will likely continue to be hot topics to the researchers. From the practice either in biosecurity or environmental pollution, it is true the large integrated hog farms are better managed or monitored by the government and also, they are able to invest those advanced technologies to maintain their competitive market power and the brand image, but somehow, we are unable to empirically evaluate those advantages in addressing those challenges due to lacking relevant data. Future researchers can continue with this direction by doing survey to present how different the different scale hog farms are doing in the biosecurity and environmental control.

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APPENDIX

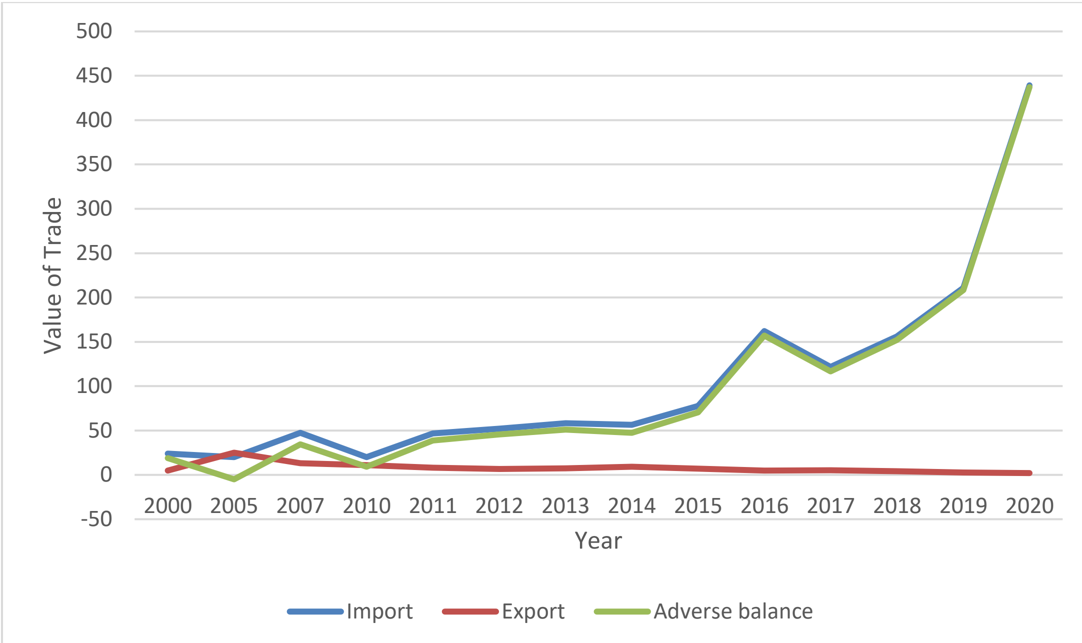

Figure A.1: China's Pork Trade (carcass weight, 1,000 pounds).
Source. Export data is from Agricultural Trade Statistics of China's Ministry of Commerce; import data is from NBS (National Bureau of Statistics in China)

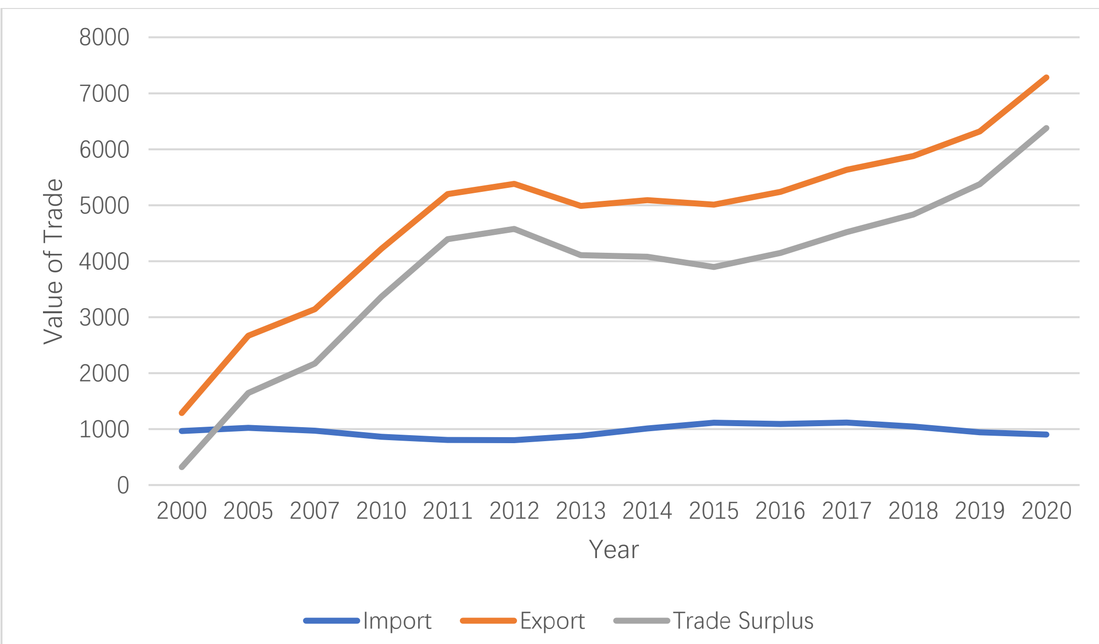

Figure A.2: U.S Pork Trade (carcass weight, 1,000 pounds)
Source: USDA, ERS data products

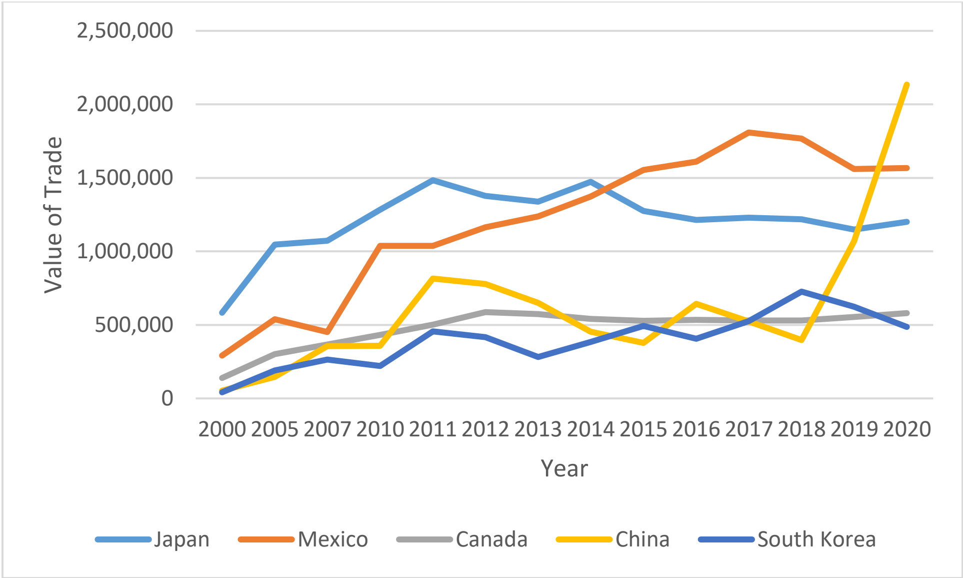

Figure A.3: Top Five Export Markets for U.S Pork (carcass weight, 1,000 pounds)
Source: USDA, ERS data products

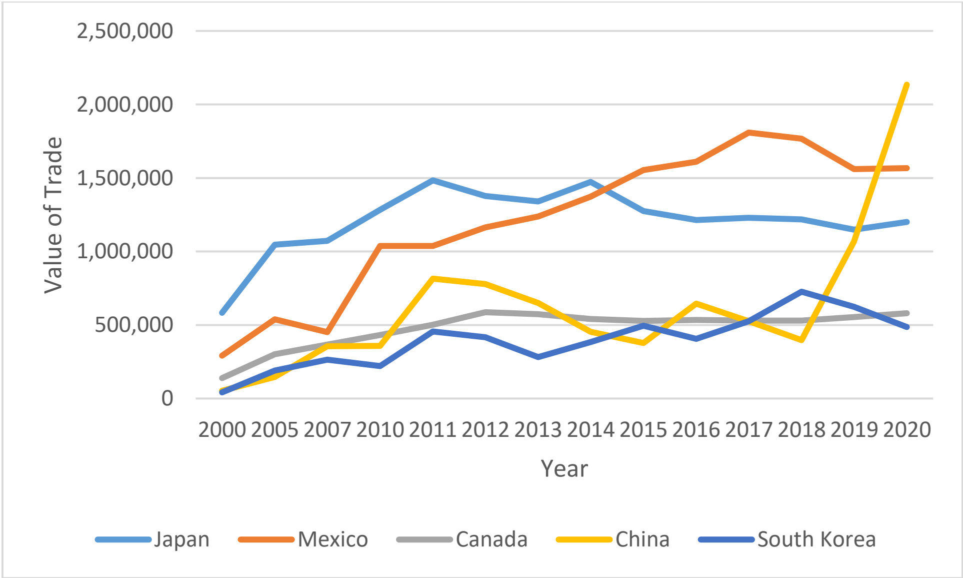

Figure A.4: Top Five Export Markets for U.S Pork (carcass weight, 1,000 pounds)
Source: USDA, ERS data products