Agricultural Development in China through the Promotion of Land Rental Markets and Agricultural Cooperatives

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Contents

Chapter 1

Introduction

With only 9% of the world's arable land and 6% of its water resources, Chinese agriculture has long supplied most of the food consumption of the world's largest population domestically (Chen et al., 2019; Zhu et al., 2019). However, as the national economy has grown over the years, Chinese agriculture, in particular, the feed grain sector, has completely lost its international competitiveness, which triggers grave concerns about the agricultural production capacity and national food security. Against this background, China's central government launched the National Rural Revitalization Strategy, which aims to modernize the rural economy and bring wealth to rural people through innovating new pathways for economic development in the countryside. A key institutional innovation envisaged in this strategy is the consolidation of fragmented farmland and the enlargement of small-scale individual farm size through the development of land rental markets (Kan, 2021).

The pressure of the growing population on the limited land has made the meager production structure unable to support China's sustainable agricultural development. Therefore, it is considered that improving the land use efficiency is indispensable for enhancing agricultural productivity, and thereby strengthening the production capacity. In this context, the issue of land exchanges has received considerable attentions recently, and China's central government has launched a series of policy programs to promote this movement. In 2010, the national average land rental ratio was 14.7%. However, the area of rented land has increased significantly over the years, reaching 35.47 million ha in 2020, equivalent to 34.1% of all contracted land.[1] A growing body of literature has addressed the driving force behind this rapid

[1] Contracted land is automatically granted to people born in rural China. Recently, the land contracted rights

development of land rental markets. Many empirical studies, such as Cheng et al. (2019), Ito et al. (2016), Kung (2002), and Yao (2000), demonstrate that rural out-migration and the security and transferability of land rights served the main catalyst of rising land rental activity. However, there remains much to be learned about land rental markets in rural China.

More noteworthy in the process of land exchanges is that the non-farm household producers (NFHPs), such as agricultural cooperatives (ACs) and dragon head enterprises[2], have increasingly entered into farm businesses by renting in land from farm households in rural China. ACs are organizations including those established by a group of farmers, a local government, and/or private entrepreneurs. Some agricultural cooperatives emerge as a result of collective action by farmers and are equity-based with open membership. Others are efficiency-based and have closed membership, thus behaving like investor-owned firms (Ito et al., 2012). These rural producer organizations provide various services, including the provision of high-quality inputs and access to profitable product markets, within the framework of their contract with participating farmers. Meanwhile, through vertical coordination, ACs establish large-scale agribusiness firms by renting farmlands from others and hiring locals as employees (Ba et al., 2019; Zhong et al., 2018). According to the statistic of basic operation in rural areas published by the Ministry of Agriculture of China, the rented land share of NFHPs increased from 31.3% in 2015 to 45.4% in 2020, with the share of farm households naturally decreasing. The central government of China also stimulated agricultural modernization and industrialization by promoting land usufruct accumulation in favor of large-scale farms and NFHPs since the early 2000s (Li and Ito, 2021; Ye, 2015).

There is an established view among agricultural economists that family farming has

have come to serve similar purposes to land deed or titles, except that they are not freely tradeable (Ito et al., 2016).

[2] Dragon head enterprises are agribusiness firms that have played a leading role in the vertical coordination of agricultural commodity chains in China (Yan and Chen, 2015).

efficiency advantages over NFHPs because family members, as residual claimants on farm income, have a strong motivation to work diligently (Allen and Lueck, 1998; Eastwood et al., 2010). Moreover, according to the well-established hypothesis of an inverse relationship between farm-size and productivity, farm size enlargement results in a decrease in agricultural productivity. However, Otsuka et al. (2016) posit that the inverse relationship may not hold in developing countries where the mechanization of agriculture has progressed due to an increase in wage rates. Therefore, it is worthwhile to analyze the development of land rental markets and the entry of ACs into agriculture in terms of land use and productivity efficiencies.

The aim of this thesis is threefold. First, it empirically analyzes the driving force behind the development of land rental market in rural China, with special emphasis on ACs' growing involvement in agriculture. Second, this study investigates the impact of land rental market development and ACs on farm production efficiency improvement. Third, this study evaluates the effect of ACs and their involvement into farm business as cultivators on biochemical (BC) and mechanical (M) technical efficiency separately. By doing so, we can gain a better understanding of the role of ACs on farm production efficiency and agricultural environment in rural China.

Considering the unbalanced economic growth and agricultural development, this study focuses on Gansu province. It is located northwest inland China, with lowest per capita GDP across the country. It is believed that although the agricultural development in western lagged behind other regions, western provinces are struggling to reduce the technology gap and to catch up with other leading areas during past few decades. The issue related to regional disparity of agricultural productivity will be analyzed in this thesis. Meanwhile, the province's land rental ratio was among the lowest in China (below 10%) at the beginning of the 2010s. However, it rose sharply thereafter, reaching 26% in 2017 (Li and Ito, 2021). Moreover, the land-use patterns in Gansu agriculture show a similar trend with the national average, which will be discussed below. Therefore, some meaningful policy implications can be drawn from the analysis, and the issues addressed in this study are likely to be of relevance to other parts of rural China characterized by similar underdeveloped rural societies.

The contribution of this thesis to the literature are twofold. First, this study collects county and village level aggregated data instead of household micro data when analyzing the factors that promote and impede the development of land rental markets. Most of previous studies on this issue explore the land exchange decisions of lessor and lessee and identify the household characteristics that determine their participation in rental markets (Kimura et al., 2011; Min et al., 2017; Shi et al., 2018; Tang et al., 2019). However, due to mismatches between lessors and lessees and high transaction costs, their rental behaviors may not directly lead to actual land transactions. Therefore, this thesis pays special attention to the land rental rates, which are viewed as the “market outcome”' of land exchanges, and clarifies their determinants. Second, ACs in China provide participants with various services, while most of previous studies focus on the provision of biochemical services (Ma et al., 2021). Since ACs’ entry into farm production by renting land may have conflicting consequences for improving BC and M technical efficiencies (Zhong et al., 2018), this research separately explores the impact of ACs and their involvement into farm sector on both BC and M technical efficiency, by estimating a production function in a special form called the separated Cobb-Douglas (SCD).

The reminder of this thesis is structured as follows. Chapter 2 discusses the background information of Chinese agricultural, from the perspective of the agricultural policy transformation in China, the farmland use policy, and the development of ACs in rural China. In this Chapter, information of Gansu province, research filed for following study, and its rural economy are also included. Chapter 3 analyzes the region differences and dynamic evolution of farm technical efficiency in China, by estimating a meta-frontier production function. Chapter 4 analyzes the factors that promote and impede the development of land rental markets in Gansu, by using 86 county level data from 2013 to 2017. Chapter 5 explores the relationship between land rental markets and the improvement in agricultural productivity, by estimating the stochastic frontier output distance function (SFODF) using 86 county-level data in Gansu province. Another important issue addressed in this Chapter is to examine farmers' crop choice rationality. Chapter 6 investigate the multiple roles of ACs in improving farm technical efficiency and promoting green agriculture by estimating the SCD production function, which allows us to figure out the impact of ACs on BC and M technical efficiency separately. Chapter 7 concludes the study with a summary of the findings and draws policy implications.

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Chapter 2

Agricultural reform and structural adjustment in rural China: Background information

Abstract

Following China's spectacular economic transformation over the past several decades, rapid growth in the non- agricultural sectors has been assisted by massive resource transfers out of agriculture, consequently, there is a declining share of agricultural in both GDP and employment, and the agricultural production has gradually lost its comparative advantages in the international market. Against this, China's agricultural sector has gone through tremendous changes, including institutional transformations, structural adjustment, technology advancement, etc. This chapter seeks to review the major changes in China's rural economy from several perspectives, including policy adjustment and institutional reforms.

Keywords: agricultural development; rural transformation; structural adjustment.

2.1. Introduction

According to an empirical rule detected by William Petty and Colin Clark, the relative importance of agriculture in terms of country's employment and Gross Domestic Product (GDP) always declines in the course of economic development. Figure 2.1 illustrates the per capita GDP, rural population percentage, and agricultural shares of employment and GDP in China between 1960 and 2019. Since 1978, when the visionary Deng Xiaoping initiated the reform and open-door policy, China has achieved unprecedented economic growth, with per capita nominal GDP (USD) growing at an annual growth rate of 10.7% between 1978 and 2019.[3]

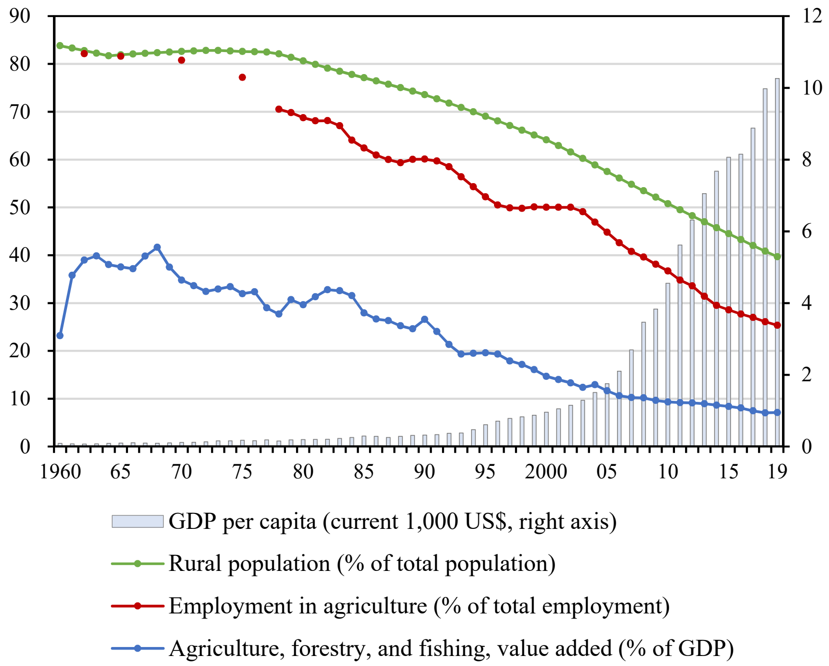

Figure 2.1. Agriculture and economic growth in China

Source: World Development Indicators.

In this process, the share of agriculture decreased significantly, consistent with the Petty-Clark law. As shown in Figure 2.1, although rural residents accounted for more than 80% of the

[3] Per capita GDP at 2010 constant price grew at an annual rate of 8.4% during the period.

national population during the 1960s and 1970s in China, the percentage consistently declined over the years. Until 2003, the employment share of agriculture dipped below 50% and decreased consistently thereafter, reaching 25.4% in 2019. Meanwhile, the GDP share of agriculture in 2003 was 12.4%, which fell to 7.1% in 2019. Hence, most modern-day Chinese live in a unique time of rapid urbanization and drastic transformation toward a post-agrarian society. However, this situation does not necessarily mean that agriculture and the rural society of China do not face serious problems. Rather, the situation presents new challenges manifested in various aspects that are worthy of careful examination.

The main objective of Chapter 2 is to illustrate the major agrarian challenges China currently faces. It covers a wide spectrum of economic and political issues related to Chinese agriculture, such as a decreasing ability to sustain food self-sufficiency, the implementation of an agricultural protectionist policy and its disestablishment, and the evolution of farmland use policy and the agricultural cooperative system. The final section overviews the rural society and agriculture in Gansu Province.

Ultimately, this Chapter is designed to complement subsequent works of in-depth economic analyses on related topics of academic and practical importance.

2.2. Evolution of policy instruments for food security in China

2.2.1. Cereal production and food self-sufficiency

Figure 2.2 shows cereal production, yield, and area harvested in China. We see from this figure that after reaching a record high of 456 million tons in 1998, cereal production fell to 375 million tons in 2003 (FAOSTAT, Production).[4] During this period, the cereal stock held

[4] Cereal comprises wheat (21.8%), rice (34.2%), barley, maize (42.6%), rye, oats, millet, sorghum, and others (figures in parentheses represent the component percentage of individual crop production in 2019). Cereal does not include legume and starchy roots in the FAOSTAT. The China Statistical Yearbook reports the production volume of grain as the total sum of production, such as rice, wheat, maize, beans, tubers, and other staples, by multiplying tubers production by 0.2. However, the FAOSTAT does not make such a

by the central government successively decreased from its peak level in 1999 to the lowest level in 2004 (Huang and Yang, 2017). Further, the loss of harvested area for cereal production accelerated considerably between 1996 and 2003, with the area decreasing by 15.3 million hectares (16.5%).

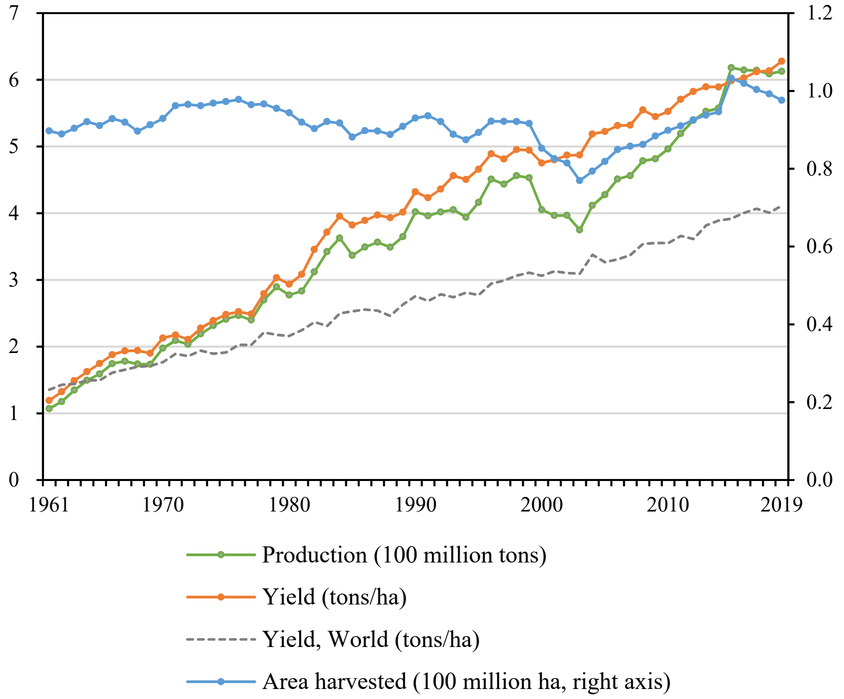

Figure 2.2. Cereal production, yield, and area harvested in China

Source: FAOSTAT

Confronted with these warning signs, the government introduced the producer subsidy program (PSP) in 2004 to boost cereal production. Soon after the PSP was implemented, the decreasing trend of harvested areas reversed dramatically, increasing by 20.7 million hectares between 2003 and 2019. Thus, cereal production also made a remarkable recovery during the period. The PSP was designed to promote cereal production while simultaneously enhancing farm income through direct payments to farm producers. The program comprises four

correction. Tubers consumed as vegetables, such as potatoes, are calculated as fresh vegetables and their output is not included in the output of grain in the China Statistical Yearbook.

operations: (a) general input subsidy, (b) direct payments to grain growers, (c) subsidies for adoption of certain improved seed varieties, and (d) subsidies for farm machinery purchases. In 2016, the PSP budgetary expenditures were approximately 6.8% of the general public budget expenditure at the central government level[5]. In addition to the PSP, the government has introduced the minimum procurement prices (MPP) program for rice and wheat since 2004 and 2006, respectively, and the temporary stockpiling policy (TSP) program for maize and soybeans since 2007 and 2008, respectively.

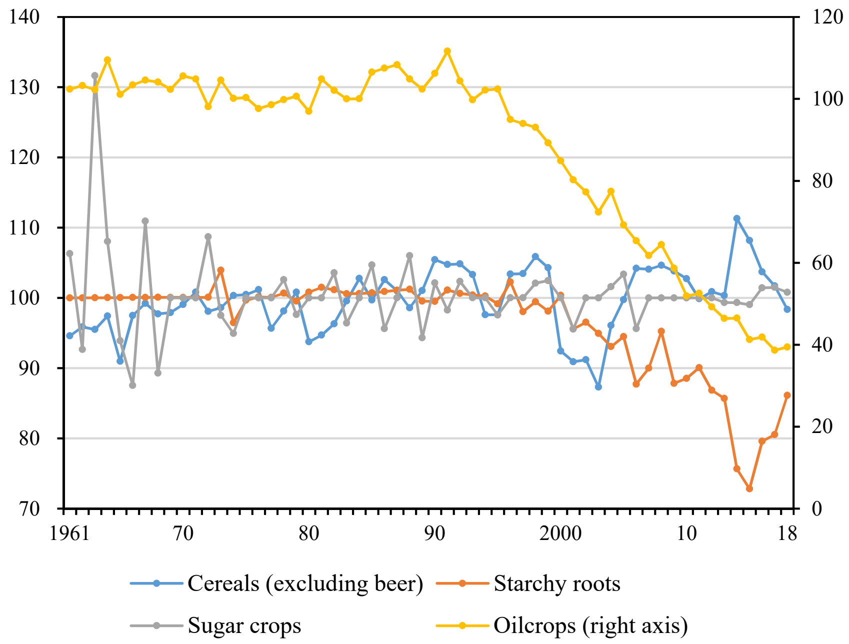

Figure 2.3. Self-sufficiency rates by crop (%)

Source: FAOSTAT

Despite remarkable progress in cereal production for the past several decades, China still faces the critical challenge of a declining food self-sufficiency rate. Figure 2.3 presents the self-sufficiency rates by crop, which is defined as the quantity of production divided by domestic supply quantity. From the figure, the self-sufficiency rates of oil-crops and starchy roots began

[5] The PSP changed its name to the farmland capacity conservation subsidy in 2016.

to decline from the early 1990s and 2000s, respectively, while the cereal self-sufficiency rate began to fall in 2000 and dipped slightly below 90% in 2003. From 2004, the self-sufficiency rate of cereals made a strong recovery due to a steep increase in the production quantity.

From 1996, China's central government set a national goal of maintaining the grain self-sufficiency rate at 95%. However, with the rapid growth of demand for non-food crops due to a change in the dietary habits of Chinese citizens, attaining the national goal was practically impossible. This phenomenon is not unique to China. Many Asian countries have followed a similar eating habit trajectory in recent years, shifting away from the traditional rice towards Western food (Ito, 2015). This situation stems mainly from rapid economic and income growth, urbanization, and globalization (Pingali, 2006). Moreover, modernization of the retail food sector and vertical integration of food supply accelerate such movements.

Against these backgrounds, instead of the 95% target, China's central government aimed to achieve near full self-sufficiency for rice and wheat, whose demands are expected to decrease for years to come. Regarding non-food crops, such as soybeans and maize, the government broken away from the 95% target; thus, excess demand for non-food crops will be met by imports from other countries (Huang and Yang, 2017). Ito and Ni's (2013) economic analysis reveals that attainment of the 95% self-sufficiency rate would be quite challenging for China unless the terms of trade in agriculture improve substantially in favor of farm producers. They conclude that China's policy makers must seriously reconsider whether adhering to the policy goal of grain self-sufficiency is worth the effort. In 2013, Chinese central government decided to partially relax its self-sufficiency target for grain, and moderate import is considered as a policy option for ensuring food security in China.

2.2.2. Policy shift from protectionists to structural improvement

Given a large fraction of the total world population and an ever-growing food consumption, maintaining farm production capacity at a certain level to ensure world food security, especially for the poor in least-developed countries, would be worthwhile for China (Otsuka, 2013). However, increasingly higher domestic grain prices in China relative to international market prices emerged from the mid-2010s, despite an increasing domestic production during the same period (Yu et al., 2019).

China adopts a two-tier tariff policy instrument in which imports are permitted up to a predetermined quota level at a low in-quota tariff rate of 1%. Imports exceeding the tariff quota are permitted in unlimited amounts with a much higher tariff rate. The ever-widening price gap between domestic and international markets is predicted to exceed the respective quota level, making it impossible for China to stick to ambitious self-sufficiency targets.[6] Further, the continuous adoption of price-support programs under the MPP and TSP would be challenged by other WTO member countries because such programs infringe on the Uruguay Round Agreement on Agriculture (AoA). Yu et al. (2019) insist that China should better align its agricultural support programs with the AoA.[7] Further, they argue for the Chinese government to urgently reform protectionist policies[8] because they are costly and distort the market transactions. Figure 2.4 shows the producer support estimate (PSE) percentage for some countries and regions, estimated by the OECD-FAO. Given the lack of PSE data for China between 1986 and 1994, they are supplemented by the nominal rate of assistance (NRA) estimates in agriculture. The figure demonstrates that China broke with agricultural exploitation toward a policy of subsidizing farmers and rural people.

[6] The appreciation of the Chinese yuan against the US dollar since 2005 has led to the widening of producer prices between China and other exporting countries. However, we can assert that an increasing comparative disadvantage in Chinse agriculture is a predominant factor behind the widening price gap, as explained in the next section.
[7] The AoA stipulates that, principally, WTO member countries are not principally allowed to adopt market-distorting agricultural policies, such as domestic support and export subsidies. Moreover, they are strongly committed to the promotion of market access.
[8] From 2006, China's central government abolished agricultural taxes and fees levied on farmers completely, and the government introduced various protectionist agricultural programs, which in response to the political slogan of "giving more, taking less and deregulating" (duoyu shaoqu fanghuo).

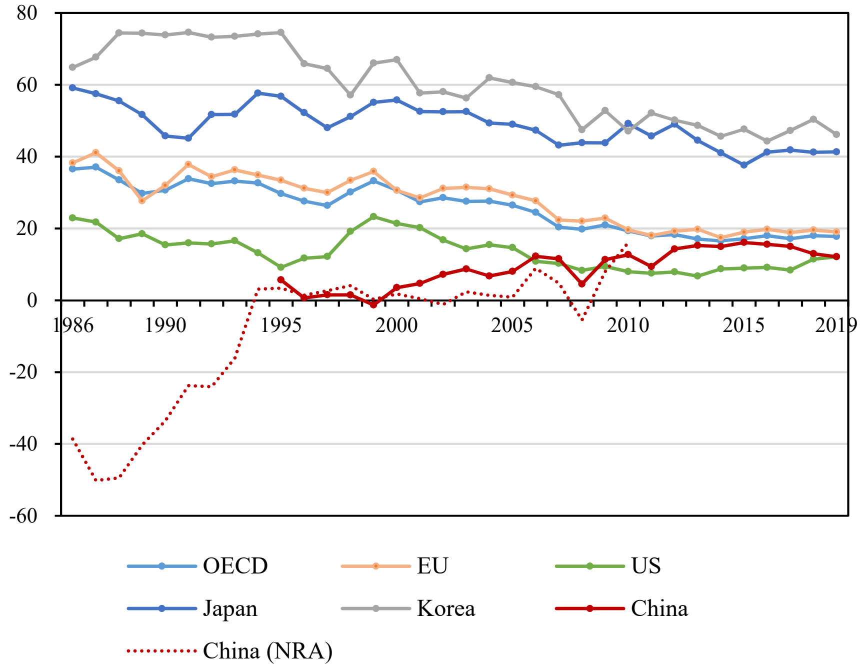

Figure 2.4. PSE (%) for major countries and regions

Source: OECD-FAO Agricultural Outlook. Anderson and Nelgen (2013).

Therefore, the central government of China launched a series of policy reforms in the mid-2010s; they introduced a target price policy for soybean and cotton in 2014 for some specific regions on a trial basis to decouple income support from the determination of farm product prices.[9] The pilot project was followed by reducing the procurement prices for rice and wheat in 2015 and implementing the target price program for maize in 2016, enabling domestic farm product prices to be determined at the market equilibrium level. See Table 2.1 regarding the change in farm product prices after the implementation of these programs. The table shows that the minimum procurement prices remain unchanged until 2007. In 2007, the market price of wheat is higher than minimum procurement price, as a consequence, government unable to procure sufficient wheat for stock, thus, the increase in minimum procurement prices for wheat

[9] A target price policy introduced by China's central government is interchangeable with a deficiency payment scheme.

is inevitable (Hu, 2008). However, around 2016 and 2017, minimum procurement prices for rice began to decline due to oversupply and high stocks in rice market (Wang, 2018).

At least two conceivable drivers lie behind the drastic policy shift: a decline in the government's fiscal revenue growth due to the slowdown of the national economy (Huang and Yang, 2017) and adherence to the international treaty of the AoA. Since China has no aggregate measurement of support (AMS) commitment, subsidy payments for trade-distorting domestic support to farmers cannot exceed the predetermined *de minimis* limit, or 8.5% of the agricultural production value. The fact that China's domestic support came close to the limit agreed in the AoA compelled the government to abolish the protectionist farm policy (Ito, 2015).

Another policy option adopted by the government to commit to the international treaty and alleviate the problems of comparative disadvantage in agriculture and rural hollowing that emerged recently in some remote areas was the farmland consolidation program under the rural revitalization strategy (RRS) banner. The Chinese government initiated the "building a socialist new countryside" campaign in 2006, renamed the RRS. Further, the RRS policy goals align with the major strategy of solving the well-known "three rural problems" advocated officially since 2001 as a necessary way for accelerating rural development.[10] Rural revitalization is a process of comprehensive rejuvenation of the rural population, economy, society, culture, and ecology via economic, political, cultural, and engineering measures to cope with the loss of factors and functional decline within the rural regional system (Zhou et al., 2020a).

[10] Solving "three rural problems" means developing agriculture to simultaneously improve the living conditions of the peasantry and to augment the strength and quality of the countryside (Ye, 2015).

Table 2.1. Minimum procurement and temporary stockpiling prices

	Minimum procurement prices (yuan/kg) Targeted provinces				Temporary stockpiling prices (yuan/kg) Targeted provinces	
	Early Indica rice	Medium and late Indica rice	Japonica rice	Wheat	Maize	Soybeans
	Anhui, Jiangxi, Hubei, Hunan, Guangxi	Anhui, Jiangxi, Hubei, Hunan, Sichuan, Jiangsu, Henan, Guangxi	Jilin, Heilongjiang, Liaoning	Hebei, Jiangsu, Anhui, Shandong, Henan, Hubei	Jilin, Heilongjiang, Liaoning, Inner Mongolia	Jilin, Heilongjiang, Liaoning, Inner Mongolia
2004	1.40	1.44	1.50			
2005	1.40	1.44	1.50			
2006	1.40	1.44	1.50	1.38		
2007	1.40	1.44	1.50	1.38		
2008	1.54	1.58	1.64	1.44	1.50	3.70
2009	1.80	1.84	1.90	1.66	1.50	3.74
2010	1.86	1.94	2.10	1.72	1.80	3.80
2011	2.04	2.14	2.56	1.86	1.98	4.00
2012	2.40	2.50	2.80	2.04	2.12	4.60
2013	2.64	2.70	3.00	2.24	2.24	4.60
2014	2.70	2.76	3.10	2.36	2.24	4.80
2015	2.70	2.76	3.10	2.36	2.00	4.80
2016	2.66	2.76	3.10	2.36		4.80
2017	2.60	2.72	3.00	2.36		
2018	2.40	2.52	2.60	2.30		
2019	2.40	2.52	2.60	2.24		
2020	2.42	2.54	2.60	2.24		

Note: Price for soybean since 2014 are the target prices.
Source: Ministry of Agriculture of PRC.

Wu and Liu (2020) claim that the RRS is closely associated with the land transfer process from individual households to new economic entities, such as large-scale family farms, agricultural cooperatives, or dragon head enterprises.[11] Zhou et al. (2020a) also argue that land consolidation is an important platform and leverage to promote rural revitalization, which can inject new vitality into the sustainable development of rural areas. Since 2013, land consolidation in China aims to increase cultivated land and improve production and living conditions and the ecological environment in rural areas. Thus, recent policy adjustments in reducing grain market support prices and efforts to decouple price support from domestic agricultural support are important steps in the right direction (Yu et al., 2019). Likewise, Huang and Yang (2017) describe this policy shift as "back to the right track" in that the market-distorting government intervention has been dismantled.

2.3. Farmland use policy

Ma et al. (2015) argue that two aspects can be broadly characterize the land-use policy in Chinese agriculture. First is the establishment of individual farmland use rights based on egalitarian principles under the household responsibility system (HRS). Second is the market-oriented land reforms to increase tenure security and land transferability. These two aspects correspond to a lapse of time.

2.3.1. Collectively-owned land system and land reallocation

With the collapse of the people's commune system and implementation of the HRS in the early 1980s, China's farm management system changed dramatically. Farmers were allowed to grow crops at their discretion and retain their farm income as long as they met tax and grain

[11] Dragon head enterprises are agribusiness firms that have played a leading role in the vertical integration of agricultural commodity chains in China (Yan and Chen, 2015).

quota delivery obligations. The right to farm management and the claim on residual farm income raised the incentive to work hard, boosting agricultural productivity. However, land property rights were vested in the hands of rural collectives, which remains unchanged today (Ito et al., 2016a), and the Chinese Communist Party (CCP) shows no inclination toward outright privatization of rural land (Carter and Yao, 2002; Lohmar, 2006).

In 1984, the Chinese government separated collective ownership from individual land use rights and allowed the voluntary exchange of individual land use rights between farmers with the permission from village leaders (Wang et al., 2015). The Land Administration Law enacted in 1986 further encouraged market-oriented land tenure reforms because it aimed to stimulate land rental markets and raise the efficiency of agricultural production (Ma et al., 2015). However, the legitimacy of agricultural land exchange on a voluntary basis was not officially acknowledged until the constitutional amendment in 1988 (Li and Ito 2021).

Although the central government has been actively committed to land tenure security for farm households, rural collectives at the local level confiscated contract rights routinely from some households and redistributed the rights to others (Brandt et al., 2004). This administrative measure, referred to as land reallocation, was designed to equalize per capita land access in response to household demographic change, thereby, preventing inter-household income imbalances from arising (Ito et al., 2016a).[12] According to Zhang (2008), the village-wide reallocation in the 1980s and 1990s occurred once every 8–10 years, supplemented by partial small-scale reallocation. A serious problem from administrative land reallocation was that rural people who temporarily ceased farming for some reason placed themselves at higher risk of having their land contract rights revoked (Ito et al., 2016a). The uncertainty and insecurity were

[12] Rental markets and administrative reallocations are, in principle, substitute mechanisms, as long as efficient resource allocation is realized in the process of equalizing the land-labor ratio across households (Benjamin and Brandt, 2002; Brandt et al., 2004). However, Brandt et al. (2004) express the view that, in practice, administrative reallocation often leaves significant gains from land exchange unexploited.

to the detriment of the sound development of the land rental market (Deininger and Jin, 2005; Feng et al., 2010; Krusekopf, 2002; Tao and Xu, 2007). Accordingly, LML amendments in 2003 prohibited rural collectives from conducting reallocation when land contract rights remain valid.

2.3.2. Land rental markets

It was not until the mid-1980s that China's policymakers legitimized transactions of land-use rights (Article 2 of the LML).[13] The land rental model originally envisaged by the central government involved arm's length transactions within the same community. LML amendments in 1998 stipulate that a two-thirds majority of villagers is required for any non-members of the collective to acquire land-use rights (Ito et al., 2016a). Legalization of land rental has negligible impact on the development of land rental market, but only 3% of land rental ratio in 1995 across the country (Turner et al., 1998). Numerous studies in the literature have investigated the reason behind this slowly development of land rental market in this period. A scarcity in off-farm work opportunity (Kung, 2002) and legal insecurity concerning land use (Lohmar et al., 2001) are considered as the major obstacles to land rental market development. However, in the late 1990s, urban migrants in China outnumbered rural workers employed by township and village enterprises in local areas, which spurred the development of land rental markets (Ito et al., 2016a).

As described earlier in this section, the confiscation of land contract rights by rural collectives in the process of administrative reallocation would undermine farmers' incentive to rent out their land. Thus, for land rental markets to develop, in 2003, the government introduced the Rural Land Contract Law to secure the contract rights of farmers and reduce arbitrarily administrative land reallocation by village cadres. As a result, land tenure insecurity was no

[13] The central government promulgated the Rural Land Contract Law in 2002, giving official approval to market-based land exchanges.

longer the major concern for farm households in China. Land rentals in rural China are expected to increase with more secure tenure rights and a deregulated land rental market (Xu and Du, 2021). It can be concluded that, to enhance property rights-related security for both lessors and lessees, farmland rental policies have experienced a shift from strictly forbidding open-market rentals to allowing unfettered rental of farmland (Kong et al., 2018). In 2014, “the separation of three rights” further enhanced farmland tenure security by improving property rights stability (Xu et al., 2018). In addition, the incentives to guarantee the land contract rights and land use rights were also formally endorsed in the “No. 1 Document,” issued in 2014 (see Appendix Table 2.1 regarding the No.1 documents), which advocated for strengthening farmers’ land contract rights as a policy for promoting land rental development (Ito et al., 2016a).

2.3.3. Structural transformation of Chinese agriculture

Land exchange among farm producers is a prerequisite for modernizing Chinese agriculture because it normally requires enlarging individual producers’ farm size. Moreover, given the massive migration of rural young people, Chinese agriculture is currently undertaken by women and elderly people left behind in the countryside, resulting in the “feminization” and “graying” of agriculture (Ye, 2015). This kind of rural decline has been widely observed in remote areas, followed by a decrease in land-use intensity, potentially increasing farmland abandonment and threating the country’s food security (Ito et al., 2016b). Thus, to avoid worsening the situation, China’s central government embraced the RRS under the current Party General-Secretary, Xi Jinping.

A significant institutional innovation to facilitate land exchange in agriculture was “the separation of three rights” policy initiated in 2014. This program conceptually divides rural land rights into three components: non-tradable property, contract, and tradable land-use rights (Cheng et al., 2019; Wang et al., 2018; Ye, 2015; Zhou et al., 2020b). Property rights are held by rural collectives, contract rights are individual households' right to use collectively-owned lands, and use rights are their right to use land and obtain income from their contracted land. Under the three-right separation system, farmers engaged in off-farm work are willing to part with land-use rights because they do not have to worry about losing their contract rights. Thus, the development of the land rental market in rural areas accelerated during the 2010s. These institutional reforms have been instrumental in securing land rights by lowering transaction costs, encouraging farmers to rent out their land-use rights.

Ye (2015) argues that a second wave of semi-proletarianization occurred in rural China in the wake of the recent land transfers and agricultural modernization. The left-behind rural people, who are used to be family farmers, are now engaged in agriculture as employed workers of non-farm household producers, such as dragonhead enterprises or agricultural cooperatives. Against this backdrop, Luo and Andreas (2020) insist that a drastic transformation of agriculture may be detrimental to farmers' economic well-being if local authorities resort to coercive measures to compel reluctant smallholders to part with their land-use rights. Such an issue is outside the scope of this study. However, it is a critical policy mechanism for further research to consider. Issues related to the development of land rental market will be discussed in the following chapters.

2.4. Agricultural cooperatives

Rural producer organizations (RPOs) have received considerable attention in food policy debates recently because smallholders in developing countries have become increasingly vulnerable to traders' strong bargaining powers under circumstances where vertical coordination of supply chains and globalization rules have dictated the transaction of agricultural products. Given this disadvantage, farmers protect their economic interests by organizing themselves. In this respect, China is far from being an exception. Following the voluntary embryonic development of RPOs in the early 1990s, the central government tried to accelerate this movement by promulgating the farmers' professional cooperatives law in 2007 (Ito et al., 2012).

Table 2.2. Agricultural cooperatives and membership

	Number of cooperatives (10,000)	Total membership size (10,000)	Average membership size (household)	Total employees of the primary industry (10,000)	Cooperative participation rate (%)
2007	2.60	35	13	30,731	0.1
2008	11.09	142	13	29,923	0.5
2009	24.64	392	16	28,890	1.4
2010	37.91	716	19	27,931	2.6
2011	52.17	1,196	23	26,594	4.5
2012	68.89	2,373	34	25,773	9.2
2013	98.24	2,951	30	24,171	12.2
2014	128.88	9,227	72	22,790	40.5
2015	153.11	10,090	66	21,919	46.0
2016	179.40	10,667	59	21,496	49.6
2017	196.90	11,243	57	20,944	53.7
2018	217.30	n.a.	-	20,258	-
2019	220.10	12,200	55	19,445	62.7

Source: Huang and Liang (2018); China Statistical Yearbook; Farmers' Daily; Central government's website.

Table 2.2 presents basic statistics of agricultural cooperatives in China: the number of cooperatives, total number of members, average membership size, and the participation rate (total member ship size / total employees of the primary industry) between 2007 and 2019. The number of agricultural cooperatives increased from 26,000 in 2007 to around 2.2 million in 2019. In 2019, more than 120 million farmers participated in agricultural cooperatives, meaning that 62.7% of employees engaging in the primary industry belong to cooperatives. Although the proliferation of agricultural cooperatives in China is impressive, anecdotal evidence suggests that some cooperatives were established to attract financial supports from the central or local governments and become dormant when the supports finish.

Chinese agricultural cooperatives are characterized by collective ownership, a democratic selection of leaders ("one member one vote" rule), the involvement of common members in management decision-making, free exit, and fair profit distribution. These features are also advocated in the farmers' professional cooperatives law. However, reality differs from the design. A survey of agricultural cooperatives by Liang et al. (2015) elucidates that the distribution of ownership and decision rights is skewed toward a small proportion of core members, and the distribution of profits to farmers is based on patronage, capital share, or both.

According to Huang et al. (2016), cooperatives can be considered as a governance structure that internalizes farmers' external transactions to escape from the opportunistic behaviors of processing enterprises and other agricultural produce buyers. Indeed, three types of farmer-specialized cooperatives in terms of governance structure are recognized in China, that is, farm household-led cooperatives, enterprise-led cooperatives, and related organization-led cooperatives (Xu, 2005). Farm household-led cooperatives can be further divided into common farm household-led and rural elite-led cooperatives. In Gansu province, as shown in Table 2.3, in 2017, over 90% of cooperatives in rural Gansu are Farm household -led cooperatives. Under this structure, all marketing contract arrangements are dominated by common farmers, who are the cooperative members (Huang et al., 2016).

Generally, agricultural cooperatives can improve farmers' production and marketing capabilities by disseminating agricultural technologies and connecting them with lucrative product markets (Ma and Zhu, 2020). Further, cooperatives are vital in overcoming market imperfection in rural areas by providing farmers with credit, insurance, information, production factors, and raw products at favorable conditions. The agricultural cooperative system serves as an effective pathway through which farmers can escape from persistent rural poverty. The Chinese government has put significant efforts into developing agricultural cooperatives to increase market competitiveness and rural household incomes (Liu, et al., 2019).

In China, agricultural cooperatives in rural area provide variety of services and are engaged in different industry. Table 2.3 shows the multidimensional classification of agricultural cooperatives in Gansu province in 2017. According to the data, most of the cooperatives in Gansu are engaged in crop plantation. Meanwhile, service industry mainly includes machinery service, plant protection service, financial service, and others. Based on the scope of operation, about 64% of cooperatives in Gansu province provided production-marketing integration services.

Table 2.3. Multidimensional category of agricultural cooperatives in Gansu in 2017

Industry engaged	crop plantation	35065
	forestry	5833
	animal husbandry	31696
	fishery	428
	service industry	5273
	others	5613
Scope of operation	production-marketing integration	53763
	production service	14674
	purchase service	2497
	warehousing service	927
	marketing service	3081
	processing service	1496
	others	7470
Initiator	farm households	78925
	enterprises	1472
	agricultural technology service organization	666
	others	2845
Rural shareholding cooperatives	yes	2265
	no	81643
Internal credit provision	yes	4993
	no	78915

Distinct from RPOs in other developed and developing countries, some agricultural cooperatives in China are responsible for facilitating land transfer among farm households or launching farm businesses on their own by consolidating scattered plots of farmland into sufficiently large ones (Cheng et al., 2019; Liu et al., 2019). When agricultural cooperatives and other non-farm household producers initiate a farm business, they tend to establish a production base by consolidating small plots. This movement can be identified as the rise of agribusiness to modernize agriculture (Ito et al., 2016a). Table 2.3 reveals that there are 2,265 cooperatives in Gansu province are specialized for land consolidation directly. Indeed, from my field work in rural Gansu, some agricultural cooperatives other than rural shareholding cooperatives are also involved into land rental market by gathering the land use rights from farmers directly. Meanwhile, the limitation of this study is that there are some cooperatives that are not related to land rental market, but we cannot distinguish such cooperatives from those who involved into land exchange. Afterall, little is known about whether the involvement in land rental markets by agricultural cooperatives help facilitate land exchange, thereby enhancing farm production efficiency. The highlighted topics will be addressed in the subsequent studies.

2.5. Gansu and its rural economy

2.5.1. General information of Gansu

Gansu Province is in northwestern China, where the Loess Plateau, Inner Mongolia Plateau, and Qinghai-Tibet Plateau meet. It is a vital strategic pivot linking the center of the country with the vast territory in the extreme west, the narrow corridor of Gansu. For several centuries, this area has served as a passageway between the upper Yellow River area and East Turkistan. The province covers an area of 425,800 square kilometers, with a population of 26.47 million in 2019. While most Gansu residents belong to the Han ethnic group, there is a significant Hui Muslim population across the province.

Administratively, Gansu Province is divided into 12 prefecture level municipalities and two autonomous prefectures (Figure 2.5), which govern 86 counties. The climate in Gansu undergoes sharp temperature fluctuations in summer and winter, with uneven and unpredictable precipitation throughout the year. Precipitation is low across most of Gansu. Gansu's average precipitation in 2019 was 491.1 mm. However, it becomes increasingly less frequent in some inland areas. Gansu's per capita water resources is 1,231 cubic meter, with 59% of the national average. Recently, the total land area for agricultural use in the province decreased gradually, reaching 18.55 million hectares in 2019, among which wood, cultivated, and garden lands increased while grasslands declined significantly from 14.11 million hectares in 2005 to 5.92 million hectares in 2019.

Figure 2.5. Gansu province

Source: Google map

Gansu's diverse landscapes include parts of the Gobi Desert, the Yellow River, numerous mountain formations, and remnants of the Silk Road and the Great Wall of China. The province partially located on Loess Plateau is mountainous in the south and flat in the north. Even so, the highest peak of the province is in the north with an altitude of 5,808 meters above sea level. Its lowest point is in the east with an altitude of only 550 meters above sea level. Hilly areas and the plateau comprise 70% of the land; the desert and Gobi desert comprises 15%.

Traditionally, Gansu is a poor area. The frequency of earthquakes, droughts, and famines has contributed to its economic instability and low agricultural productivity. However, the metallogenic condition in Gansu Province is superior, with uneven distribution. The reserve of mineral resources in Gansu fuels a relatively complete industry based on mining, smelting, and processing in the province. Recently, the exhaustion of natural resources has threatened Gansu's manufacturing and mining industries. The growing public awareness of environmental protection and stricter regulations on pollutions has also constituted a major challenge for Gansu's high-energy-consumption and high-environmental-impact industries. Apart from mineral resources, Gansu is also at the forefront of China's efforts to increase energy production from renewable sources. It hosts hydroelectricity along the Yellow River, solar panels across the Hexi Corridor, and wind turbine farms in the far north. Although much of China's energy is still coal-powered, the development of renewable energy sources is on the rise.

In the past few years, Gansu has undergone a major economic transformation toward a service-based economy, showing great potential for sustainable future economic development. In 2014, the tertiary sector in Gansu overtook the secondary sector in GDP contribution for the first time, leading the economic sector ever since. In 2019, the primary industry accounted for 12.0% of the gross regional product; the secondary and tertiary industries accounted for 32.8% and 55.1%, respectively. However, the employment composition differs; the primary industry accounts for 53.0%, followed by the tertiary and secondary industries at 31.9% and 15.1%.

2.5.2. Gansu economy and agriculture

Table 2.4 shows the per capita disposal income in Gansu and China between 2000 and 2019. The average income disparity between Gansu and China falls within the range of 1.61

and 1.68 during the period, which seems to be in the tolerance level. Table 2.4 shows that the urban-rural income ratio is higher for Gansu than for the national average by 0.6 to 0.8 points. Christiansen et al. (2013) empirically examined rural development in Inner Mongolia and Gansu, noting that the poor experienced challenges accessing remunerative rural off-farm employment. The fact that the share of income from wages and salaries is relatively small in Gansu (Table 2.4) lends strong support to the argument that rural diversification is limited in rural Gansu relative to the national average. Therefore, increasing agricultural productivity holds enormous promise for poverty alleviation in less developed areas in Gansu.

Figures 2.6–2.8 provide geographical information on the per capita disposal income, urban-rural income gap, and the rural population ratio for 14 cities in 2019. The disposal income of Jiayuguan, located in northwestern Gansu, is among the highest, followed by Lanzhou, a capital city of Gansu Province. However, the disposal income of cities such as Dingxi, Longnan, Linxia, and Gannan, located in the southeast, is relatively low. Notably, Linxia and Gannan are ethnic minority autonomous regions. Intriguingly, the income gap forms an increasing gradient from the northwest to the southwest part of the province, leading to a negative correlation between the per capita income and the urban-rural income gap. Meanwhile, the income gap is positively correlated with the rural population ratio. Ultimately, to alleviate rural poverty, especially in least-developed regions, encouraging employment diversification in rural areas and increasing agricultural labor productivity are desperate requirements.

Table 2.4. Per capita disposal income of rural/urban households and income disparity

			2000	2005	2010	2015	2019
National	Per capita disposal income (n)	Yuan/person	3,738.9	6398.9	12,495.6	21,966.2	30,732.8
	Disposal income of rural households (a)	Yuan/person	2,253.4	3,254.9	5,919.0	11,421.7	16,020.7
	Income from wage and salaries	%	31.2	36.1	41.1	40.3	41.1
	Net business income	%	63.3	56.7	47.9	39.4	36.0
	Net income from properties	%	2.0	2.7	3.4	2.2	2.4
	Net income from transfers	%	3.5	4.5	7.7	18.1	20.6
	Disposal income of urban households (b)	Yuan/person	6,280.0	10,493.0	19,109.4	31,194.8	42,358.8
Gansu	Per capita disposal income (g)	Yuan/person	2,265.9	3,812.9	6,830.7	13,466.6	19,139.0
	Disposal income rural households (c)	Yuan/person	1,428.7	1,979.9	3,424.7	6,936.2	9,628.9
	Income from wage and salaries	%	24.9	29.6	35.0	28.5	28.8
	Net business income	%	70.8	63.8	54.2	43.6	44.9
	Net income from properties	%	1.1	1.0	1.2	1.8	1.3
	Net income from transfers	%	3.2	5.5	9.6	26.1	25.0
	Disposal income of urban households (d)	Yuan/person	4,916.3	8,086.8	13,188.6	23,767.1	32,323.4
Disparity	National-Gansu (n)/(g)		1.65	1.68	1.83	1.63	1.61
	National urban-rural (b)/(a)		2.79	3.22	3.23	2.73	2.64
	Gansu urban-rural (d)/(c)		3.44	4.08	3.85	3.43	3.36

Source: China Statistical Yearbook (National Bureau of Statistics of China).

Note: Per capita disposal incomes for National and Gansu between 2000 and 2010 are the author’s estimates.

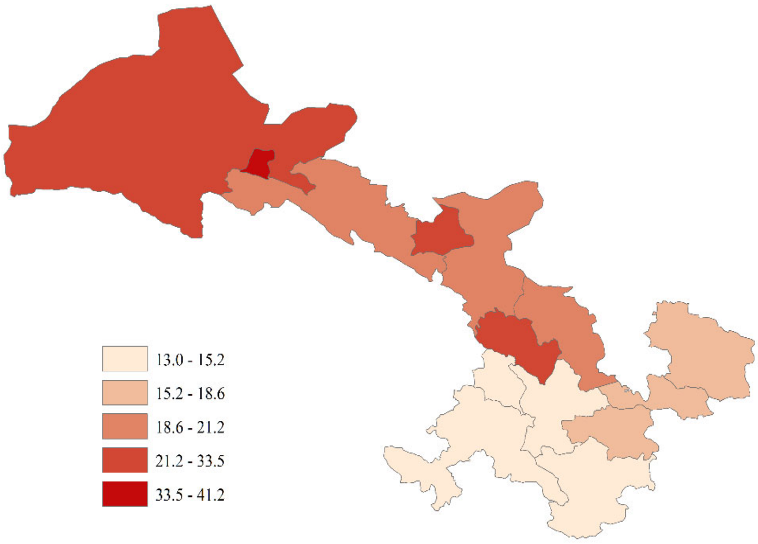

Figure 2.6. Per capita disposal income (1,000 yuan)

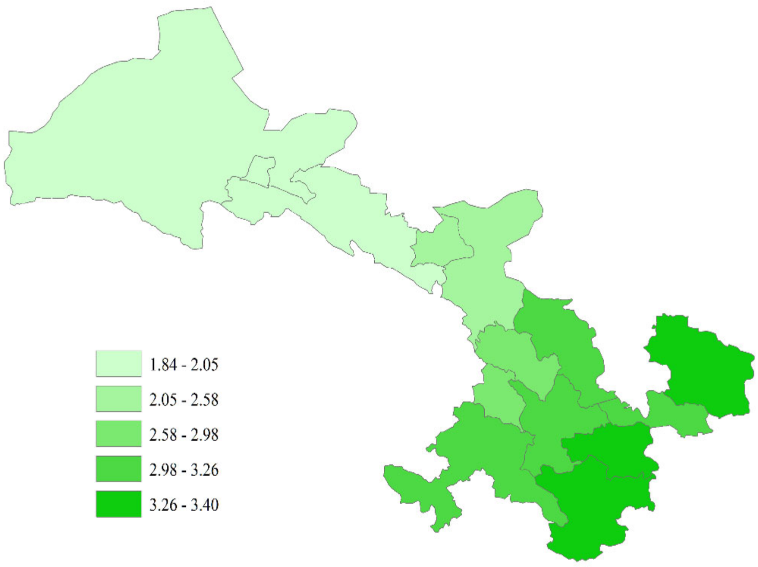

Figure 2.7. Urban-rural income gap

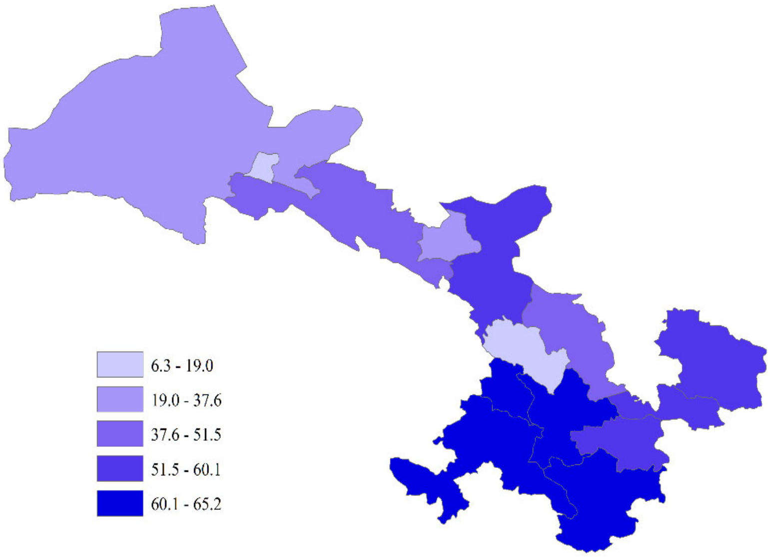

Figure 2.8. Ratio of rural population (%)

2.5.3. Crop production in Gansu

Table 2.5 shows the production volume of grain, cash crops, vegetables and fruits, irrigation rate, soil-quality index, and per capita rural household income at the city level in 2019. Due to great variability among regions regarding topographical, geological, and climatic conditions, agriculture in Gansu is characterized by a wide range of crop diversity. It is worthwhile to note, however, that Gansu's crop composition regarding production volume is considerably similar to the national average. An essential crop in Gansu is maize, harvested across the province. In the early 2000s, many maize seed companies launched businesses in Zhangye city, in mid-western Gansu. Consequently, maize production in this area grew rapidly. Maize production in other areas merely meets food and feed consumption needs. Fresh fruits and vegetables (FFV) are also major crops in Gansu, grown throughout the province. Recently, the terms of trade in grain production have worsened because of the disestablishment of the MPP and TSP programs, inducing many Chinese farmers to grow FFV. Further, the central government of China has set a farm policy to encourage farmers in the Western region (Gansu included) to grow FFV, thus narrowing the urban-rural income disparity.

Table 2.5. Agricultural production in Gansu in 2019

	Grain production (10,000 tons)	Cash crop production (10,000 tons)	Vegetable and fruit production (10,000 tons)	Irrigation rate (%)	Soil quality	Per capita rural household income (yuan)
Lanzhou	30	5	193	40.8	3.45	13,605
Jiayuguan	2	1	14	43.7	4.70	21,027
Jinchang	41	2	75	89.5	4.67	15,719
Baiyin	96	13	200	31.3	2.85	9,927
Tianshui	123	16	207	8.7	2.94	8,439
Wuwei	103	14	291	79.0	4.21	12,566
Zhangye	139	15	119	74.3	4.74	14,944
Pingliang	105	7	62	10.1	3.13	9,083
Jiuquan	46	12	188	102.4	4.85	18,609
Qingyang	145	13	99	9.8	2.58	9,686
Dingxi	152	38	55	13.4	2.44	8,226
Longnan	85	21	76	18.3	1.85	7,734
Linxia	68	9	35	34.0	2.65	7,512
Gannan	11	8	2	5.7	1.69	8,437

Source: Gansu Development Yearbook; Zhang et al. (2018).

Zhang et al. (2018) employ a five-point Likert scale to measure land quality level for 14 cities in Gansu.[14] This study employs their data to compute the soil-quality index. Table 2.5 shows that the index ranges from 1.69 to 4.74, with Zhangye among the highest, and Gannan (located in hilly and mountainous areas of southern Gansu) the lowest. Since the irrigation rate is an ingredient of the Likert scale, the estimated soil-quality index has a strong positive correlation with the irrigation rate. Notably, in Table 2.5, cities with low per capita rural household income have low soil-quality scores, reminding us of the importance of public agricultural investment for eliminating rural poverty.

[14] Eleven indicators determine the scale: available potassium, organic compounds, available phosphorus, soil texture and structure, effective of soil layer thickness, annual accumulated temperature, an annual precipitation, probability of irrigation, slope, altitude, and geomorphic type.

Appendix Table 2.1. Evolution of No.1 central documents

Time	Theme	Keywords
2004	Policies to Increase Farmers' Income	Agricultural structure, rural employment, urban-rural income gap, secondary and tertiary industries in rural
2005	Strengthening rural work and improving the overall production capacity of agriculture	Comprehensive agricultural production capacity, agricultural and rural economic structure, increase food production, increase farmers' income
2006	Constructing a new socialist countryside	Comprehensive Rural Reform, Rural Social Security, Rural Democratic Political Construction
2007	Developing modern agriculture and steadily promoting the construction of a new socialist countryside	New type of skilled farmer, agricultural water conservation, mechanization, and informatization, resource utilization rate, agricultural labor productivity
2008	Fortifying the foundation of agriculture	Urban-rural integration, farmland water conservation, agricultural efficiency improvement
2009	Promoting Stable Development of Agriculture and Sustained Income Growth of Farmers	Rural social stability, declining food production, effective supply of agricultural products
2010	Strengthening the Efforts of Coordinative Urban-Rural Development and Further Consolidating the Basis of Agricultural and Rural Development	Basic financial services, green food, organic agricultural products, rural organization construction of basic unit
2011	Accelerating Water Conservancy Reform and Development	Conservation of soil and water, hydropower resources, flood control and drainage
2012	Accelerating the scientific and technological innovation to strengthen supply of agricultural products.	Agricultural technology promotion, rural business information
2013	Developing Modern Agriculture to Strengthen the Vitality of Rural Areas	Family farms, Land exchange, rural collectives
2014	Comprehensively Deepening Rural Reform and Speeding up Agricultural Modernization.	"Grain for Green”, transfer of land use rights, micro-credit
2015	Stepping up Reform and Accelerating Agricultural Modernization	Household registration system reform, rural collective property rights system reform, poverty reduction through rural tourism

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Chapter 3

Region differences and dynamic evolution of agricultural technology in China

Abstract

Along with industry upgrading and urbanization, the agricultural industry in China has been experiencing a stage of rapid development. However, the unbalanced regional development is still a key issue that needs to be discussed even today. This chapter compares technical efficiencies (TE) and technological gap ratios (TGR) for farm sectors of three regions between two study periods in China. A stochastic meta frontier approach is applied to account for the regional heterogeneity. The estimation results suggest that the provinces differ in productivity performance and farm production technology, with the eastern region being the most advanced area, and the western region having being struggling to catch up with other regions. The research target of the following chapters, Gansu province, shows an obvious effort to minimize the technology gap between individual frontier and meta frontier during past few decades.

Keywords: regional disparity; meta frontier; technical efficiency; technology gap.

3.1. Introduction

China's agricultural output has grown rapidly in the past several decades, particularly since the rural reforms that began in 1979. The National Bureau of Statistics (NBS) report that from 1979 to 2020, the agricultural output value at constant price grew at a rate of 5.5% per annum. Coinciding with the rapid growth of agricultural is a marked increase in the spatial gap of China's farm sector, and the issue of China's regional disparity in agricultural productivity has been the subject of intense research by many economists (Cao and Birchenall, 2013; Chen and Song, 2008; Chen et al., 2008; Gong, 2020; Li and Zhang, 2013; Wang et al., 2019).

Xin and Qin (2011)'s study on regional disparity of agricultural productivity suggests that the growth rate of agricultural labor productivity in eastern China is significantly greater than that in the central and western regions from 1987 to 2005. However, by using data from 2000 to 2013, Bin and Vassallo (2016) demonstrated that some eastern provinces developed at a relatively slow rate on agricultural labor productivity, whereas many inland provinces are included in the fast-growing group of agricultural labor productivity. Meanwhile, many scholars have conducted profound research on agricultural TFP growth and its components from the perspective of regional disparity (Gong, 2020; Li and Zhang, 2013; Wang et al., 2019). Li and Zhang (2013) suggests that during 1985-2010, the annual rates of agricultural TFP growth are 4.5%, 3.4%, 3.0% in the eastern, central, and western, respectively. Gong (2020) confirms that the average TFP in eastern China is increasing faster and is the most promising region to catch up with the production frontier when compared with central and western. Many other studies also reached a consistent conclusion that the agricultural TFP growth in the eastern region performed better than the western and central regions before 2000s (Cao and Birchenall, 2013; Chen and Song, 2008; Chen et al., 2008; Wu, 2001). It is believed that poor natural resource endowments, weak infrastructure, low literacy rates and insufficient investment and personnel in science and technology research all constrain the development and adoption of new technologies and associated improvements of agricultural productivity in western China (Fan and Chan-Kang, 2005). However, it is worthwhile to note that the TFP growth rates in the western region improved rapidly after 2000, while those of the east region slightly decreased (Tong et al., 2012). In agricultural TFP decomposition, the agricultural technical efficiency of China was found to be extremely high in the eastern plains of China, whereas the area with extremely low efficiency are mainly distributed in the southwest and the western regions of China (Chen and Song, 2008; Ma et al., 2021). Moreover, some studies on the regional disparity of agricultural TFP indicated a trend of convergence (Hong et al., 2010; Li and Zhang, 2013; Ma and Feng, 2013), while some literature showed significant divergence effects in regional disparity (Wang et al., 2013). Therefore, there still remains some debate about the temporal and spatial evolution of China's agricultural productivity and technical efficiency.

Given this backdrop, the specific objective of this study is to provide new evidence on production efficiency and technology gap of farm sector across regions in China using the stochastic meta frontier model developed by Huang et al (2014). This study uses panel data of 31 provinces in China and divides the study period into two parts, the first period is from 1984 to 2000, while the second period is from 2001 to 2020.

The contribution of this study to the literature is to provide empirical insights into the question of whether/how marginalized regions catch up with advanced regions in terms of agricultural technology. In China, the economy of the eastern coastal region is the most developed area. By contrast, the vast inland regions of China, especially the western area, are much lagging behind, although the situation of spatial unbalance has got effectively improved after the Chinese government adopted the intensive strategic measures to promote the development of western regions in 2000. Given China a big country with a vast territory and a large variation in economic development, it is of particular importance to distinguish between intra-and inter- regional productivity disparities in order to accurately diagnose the cause of imbalanced development. The meta frontier model is most suitable for this purpose.

The rest of the chapter is organized as described in what follows. In Section 2, the overview of spatial and temporal characteristics of agricultural production in China is discussed. In section 3, the methodology, including the theoretical model, the empirical model, and the data used, are described. In Section 4, estimation results are presented, and the last section concludes.

3.2. Spatial and temporal characteristics of farm production in China

China consists of 31 provinces, autonomous regions, and municipalities. There is a huge inter-regional difference in the natural, socio-economic, and policy factors, such as resource endowments and geographic conditions. The 7th Five Year Plan for the National Economic and Social Development of the People's Republic of China in 1985 has divided the mainland China into three regions, namely, the eastern, central and western regions, according to their economic development levels and geographical positions. Such classification has been adopted by many scholars for analyzing the spatial disparity of a particular phenomenon in China. In this study, 31 provinces in mainland China are grouped into three regions based on aforementioned government's document. Figure 3.1 shows the classification of the groups, where the eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan; The central region includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan; The western region includes Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang.

Figure 3.1. The administrative divisions and three regions in China

In 2020, the agricultural sector (including crop, livestock, forestry, and fishery) produced commodities and services with the value added of 7.36 trillion yuan, by utilizing 127.86 million hectares of arable land and 177.15 million labor force. Although the share of agriculture in the GDP declined significantly from 28.2% in 1985 to 8.0% in 2020, real output of the sector has expanded substantially over time. Along with the expansion of agricultural output, the average farm size and the number of professional farmers has increased. Since the 1990s, millions of farmers have rented out their land and worked full-time off the farm (Wang et al. 2011; Huang and Ding 2016). Figure 3.2 illustrate the land labor ratio in the national average and three regions since 1985. It shows that, between 1985-2000, the average farm size remained stable in whole country, with central area being larger than the national average. However, the regional disparities became more visible than ever since 2000. The average farm size of the central region is rising faster than any other regions and national average after 2000. This may partly due to the specialization of this region into grain production, consistent with Lu et al. (2020)'s argument. Based on the changes of average farm size, we divided past few decades into two period in our study to better analyze the agricultural development in China; the first period is 1985-2000, and the second period is 2001-2020. Because Hainan was part of Guangdong province until 1988, and Chongqing was separated from Sichuan province in 1997, in the first study period, there are 29 observations in total while in the second period, there are 31 observations.

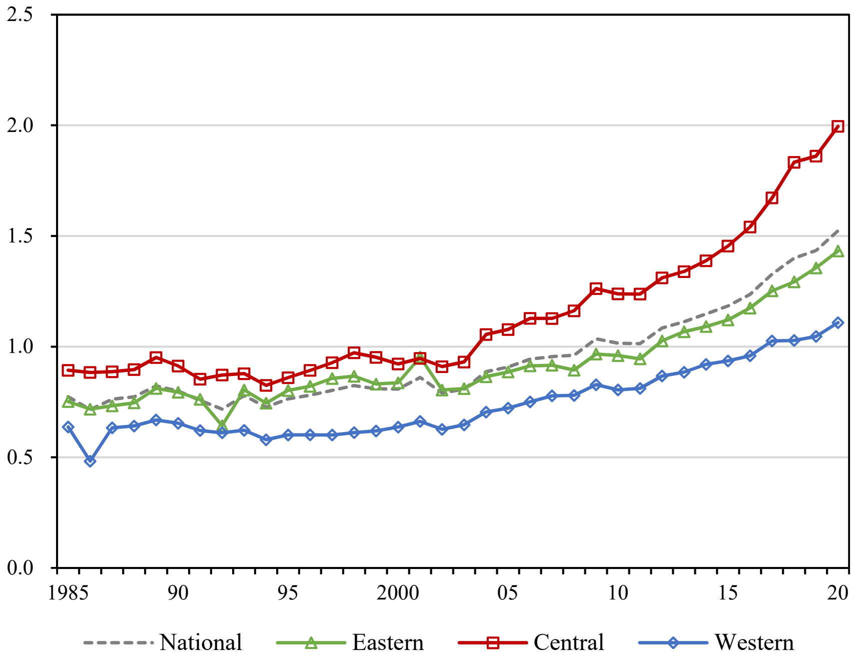

Figure 3.2. The land-labor ratio among regions since 1985 in China

Figure 3.3 presents the annual growth rate of agricultural output and input among regions in two periods. From the figure, in the first period, the annual growth rate of real output value in all regions is steady around 5-6%, but in the second period, this rate in western remain unchanged, while that in the eastern and central regions decreased significantly. Similar trend can be seen in the annual growth rate of farm machinery input in agricultural production in two periods. For the fertilizer input, in the first period, all regions maintained a relatively high annual growth rate around 8-9%, however, in the second period, with increasing necessity to abate agricultural-related pollutions, the Chinese central government launched the ‘action plan for the zero growth of fertilizer use' in 2015. The annual growth rate of fertilizer input in all regions decreased considerably, especially in eastern regions. For the labor input, the annual growth rate is positive in the central and western regions, while negative in the eastern region, which is consistent with the reality that the development of non-farm labor market is more active in coastal areas in 1984-2000. In the second period, negative annual growth rate appears in all regions, and the rate in the western region decreased slowest among all regions. For the sown area, in the first period, all the regions increased gradually, and the western record the highest annual growth rate, followed by the central region. In the second period, the annual growth rate of sown area in the eastern turns to negative, and the central record the highest annual growth rate, followed by western.

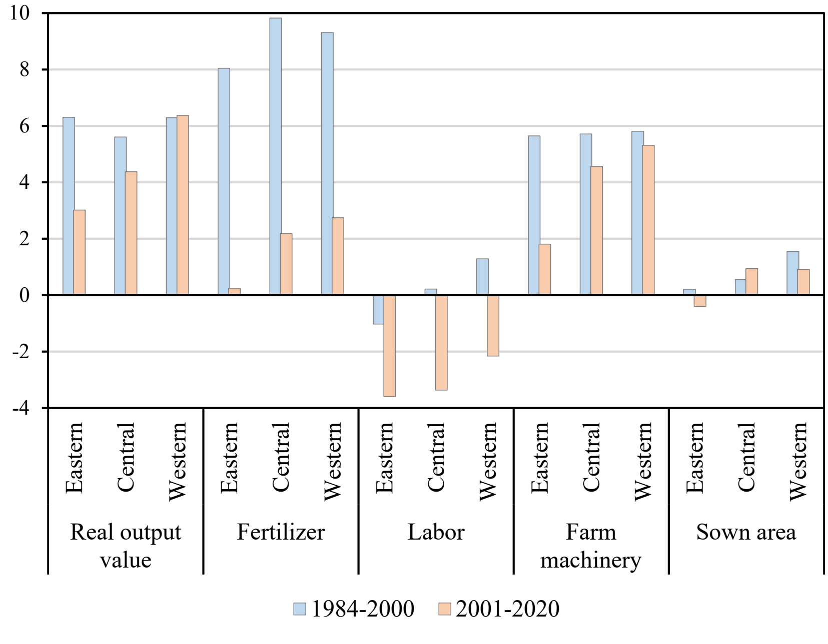

Figure 3.3. The annual growth rate of agricultural output and input among regions

From the perspective of agricultural productivity growth, regional differences and dynamic evolution are also worth noting. It is well known that agricultural labor productivity can be decomposed into two parts, land productivity and land-labor ratio. Figure 3.4 shows the annual growth rate of productivity and farm size among regions in two periods in China. In the first period, the annual growth rate of labor productivity in the eastern regions is among the highest, followed by the central, and then the western region. Meanwhile, the annual growth rate of land productivity and land-labor share the same order in this period. However, the situation changed dramatically in the second period. After 2000, the agricultural labor productivity in the western region increased most rapidly, with the annual growth rate of 8.5%, followed by 7.8% in the central, and 6.6% in the eastern region. In the same period, the land productivity in the western region show the highest annual growth rate, 5.5%, while the eastern and the central regions share the similar annual growth rate of 3.4%. Moreover, compared with first period, the annual growth rate of land-labor ratio in all regions increased significantly, especially in the central region, consistent with Figure 3.2.

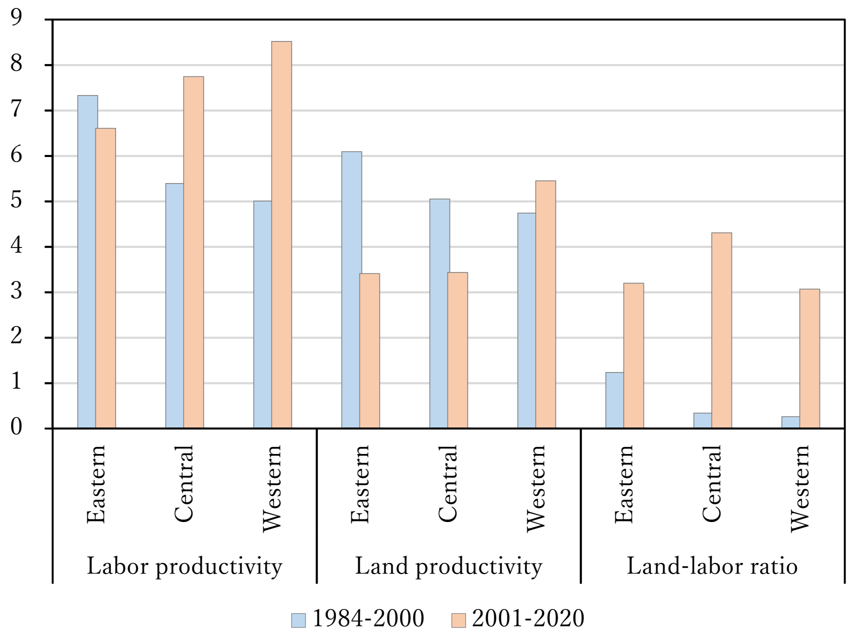

Figure 3.4. The annual growth rate of productivity and farm size among regions

3.3. Methodology

3.3.1 Theoretical model

In the economics literature, the use of frontier models to assess the level of efficiency of farm production is a popular practice in the literature. Different frontier models have been applied, ranging from non-parametric to parametric and stochastic methods. The non-parametric approach such as data envelopment analysis is sensitive to outliers since the measurement error is ignored (Coelli et al., 2005; Barnes et al., 2009). Meanwhile, the stochastic frontier analysis (SFA) can accommodate noise, such as measurement errors due to the weather and pest infestation that are likely to be significant in farming. In agricultural sector, the SFA is commonly used and assumes that the underlying technology is same for all sample observations, regardless of differences in the working environment (Kumbhakar et al., 2012). However, farm sector in different regions are expected to face dissimilar technology sets and input use because of resource endowments (O'Donnell et al., 2008). Thus, in this study, a stochastic meta frontier approach is applied.

Hayami (1969) and Hayami and Ruttan (1970) introduced the concept of the meta production function, defined as an envelope of traditional production functions, assuming that all producers of different groups potentially have access to the same technology. Following this approach, Battese et al (2004) and O'Donnell et al (2008) consider the fact that technology could differ across regions and introduced the meta frontier production function model that control the heterogeneity by establishing homogeneous groups within the sample. This model is estimated in two steps: first, by using a stochastic frontier analysis to determine each regional frontier, and second, by using linear programming approaches to determine the meta frontiers with simulated or bootstrapped standard errors. However, it is not possible to include the determinants (the production environment) of regional differences since a linear programming approach is used. Furthermore, no statistical properties can be ascertained due to programming techniques (Huang et al, 2014). To overcome these drawbacks, Huang et al (2014) introduced a new two-step approach using stochastic frontier analysis (SFA) to estimate both the group frontiers in step one and the meta frontier in step two. With this framework, it is possible to include production environment variables in both steps.

A general conventional stochastic production frontier model is given by:

$$Y_{it} = f(\boldsymbol{X}_{it})\exp(v_{it}^k - u_{it}^k) \quad (3.1)$$

where Y_{it} is the output produced by province i at time t, X_{it} is a vector of factor inputs, the terms v_{it} is the stochastic error term, and the terms u_{it} is a one -sided error representing the technical inefficiency of province i at time t. Both v_{it} and u_{it} are assumed to be independently and identically distributed with variances σ_v^2 and σ_u^2, respectively. Equation (3.1) is estimated with the assumption that all provinces use a similar production technology or operate in the same environment. However, it is inappropriate to estimate an identical frontier function encompassing every province when they use different technologies. To accommodate the potential regional variation of agricultural production frontiers and obtain comparable technical efficiencies for the provinces, the regional stochastic frontier model is defined by:

$$Y_{it}^k = f^k(\boldsymbol{X}_{it}^k)\exp(v_{it}^k - u_{it}^k) \quad (3.2)$$

where Y_{it}^k denotes the output level for province i in the k^{th} region at the year of t, X_{it}^k is the input vector, the terms v_{it}^k represents the error term and is assumed to be independently and identically distributed as $v_{it}^k \sim N\,(0,\ \sigma_{vk}^2)$. The terms u_{it}^k is a one-sided error representing technical inefficiency and is distributed as $u_{it}^k \sim N^+\,(0,\ \sigma_{uk}^2\,(z_{it}^k))$, where z_{it}^k denotes the exogenous vector of variables determining inefficiency specific to each province within each region. The technical efficiency of the i^{th} province relative to the region k frontier can be computed as:

$$\mathrm{TE}_{it}^k = \frac{Y_{it}^k}{f^k(\boldsymbol{X}_{it}^k)\exp(v_{it}^k)} = \exp(-u_{it}^k) \quad (3.3)$$

The predicted value of on the region-specific frontier is given by

$$\hat{Y}_{it}^{k} = f_t^k(\boldsymbol{X}_{it}^{k})$$

Unlike the deterministic meta-frontier, the meta-frontier in this study enjoys stochastic properties and accommodates idiosyncratic shock (Huang et al., 2014). Namely, the common underlying meta-frontier production function, $f_t^M(\boldsymbol{X}_{it}^{k})$, for all provinces at the year of t is defined as

$$f_t^k(\boldsymbol{X}_{it}^{k}) = f_t^M(\boldsymbol{X}_{it}^{k}) \exp(-w_{it}^{k}) \quad (3.4)$$

Where $w_{it}^{k} \geq 0$ and the subscript M represents "meta frontier". Equation (3.4) implies that the meta-frontier envelops all individual regions' frontiers. Thus, we have $f_t^k(\boldsymbol{X}_{it}^{k}) \leq f_t^M(\boldsymbol{X}_{it}^{k})$.

Figure 3.5 illustrates the meta frontier production model. The ratio of the region k's frontier production function to the meta-frontier is defined as the technology gap ratio (TGR),

$$\mathrm{TGR}_{it}^{k} = \frac{f_t^k(\boldsymbol{X}_{it}^{k})}{f_t^M(\boldsymbol{X}_{it}^{k})} = \exp(-w_{it}^{k}) \quad (3.5)$$

From equation (3.3) – (3.5), we have

$$\frac{Y_{it}^{k}}{f_t^M(\boldsymbol{X}_{it}^{k})} = \frac{f_t^k(\boldsymbol{X}_{it}^{k})}{f_t^M(\boldsymbol{X}_{it}^{k})} \cdot \frac{Y_{it}^{k}}{f_t^k(\boldsymbol{X}_{it}^{k}) \exp(v_{it}^{k})} \cdot \exp(v_{it}^{k}) = \mathrm{TGR}_{it}^{k} \times \mathrm{TE}_{it}^{k} \times \exp(v_{it}^{k}) \quad (3.6)$$

By accounting for the random noise component, the decomposition of this equation can be expressed alternatively as (Huang et al., 2014)

$$\mathrm{MTE}_{it}^{k} \equiv \frac{Y_{it}^{k}}{f_t^M(\boldsymbol{X}_{it}^{k}) \exp(v_{it}^{k})} = \mathrm{TGR}_{it}^{k} \times \mathrm{TE}_{it}^{k} \quad (3.7)$$

where MTE_{it}^{k} measures the province's technical efficiency with respect to the meta frontier production function.

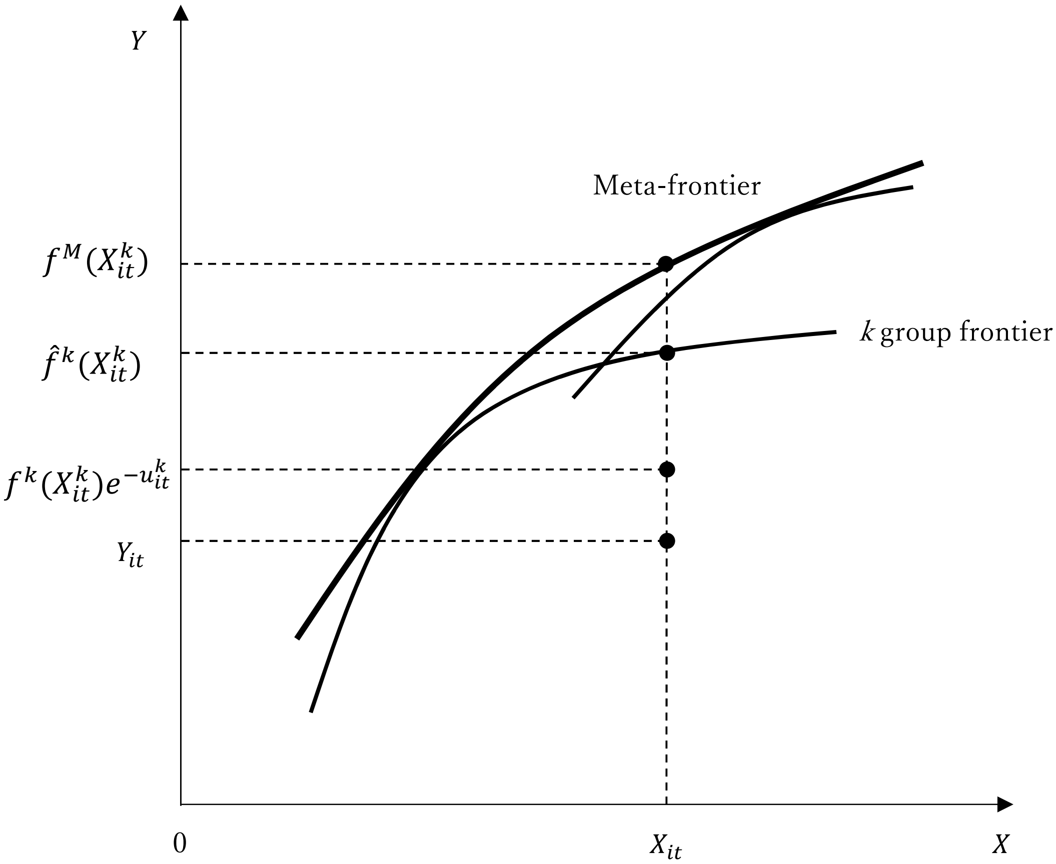

Figure 3.5. The meta-frontier function for different groups

The meta frontier proposed by Huang et al (2014) is estimated by two steps: first, a region-specific frontier (equation (3.8)) is estimated, and second, estimates from the k^{th} region is pooled to estimate the meta frontier (equation (3.9)).

$$\ln Y_{it}^k = f^k\left(X_{it}^k\right) + v_{it}^k - u_{it}^k \tag{3.8}$$

$$\ln \hat{f}^k\left(X_{it}^k\right) = f^M\left(X_{it}^k\right) + v_{it}^M - u_{it}^M \tag{3.9}$$

3.3.2 Empirical model

In this study, a translog stochastic production function was used to estimate provinces' agricultural technology:

$$\ln Y_{it}^{k} = \beta_0^k + \sum_{j=1}^{4}\beta_j^k \ln X_{jit} + \frac{1}{2}\sum_{j=1}^{4}\beta_{jj}^k\left(\ln X_{jit}\right)^2 + \sum_{j=1}^{4}\sum_{l=2}^{4}\beta_{jl}^k \ln X_{jit}\ln X_{lit}$$

$$+\beta_t^k t + \frac{1}{2}\beta_{tt}^k + \sum_{j=1}^{4}\beta_{jt}^k \ln X_{jit}\, t + \sum_i \gamma_i(\text{year dummy}) + v_{it}^k - u_{it}^k \quad (3.10)$$

where Y_{it} is agricultural outputs, X_{jit} is a vector of inputs by provinces over time t. Meanwhile, neutral technological change is captured by the year dummy variables. The two components u and v are assumed to be distributed independently of one another: $\sigma_{uv} = 0$. The inefficiency term can be expressed by:

$$-\text{TE}_{it} = \delta_0 + \sum_{j=1}^{4}\delta_j\, z_{jit}^k \quad (3.11)$$

where z represents the vector of province-level, socioeconomic and institutional factors supposed to influence inefficiency.

Given the estimators, the elasticity of scale is given by:

$$\eta = -\sum_j \frac{\partial \ln Y_{jt}}{\partial \ln X_{jt}} \quad (3.12)$$

The production technology exhibits constant returns to scale when $\eta = 1$. If $\eta > (<)\ 1$, the technology exhibits increasing (decreasing) returns to scale.

This study analyzes the growth rate of total factor productivity (TFP), which can be decomposed into three components: technical change (TC), technical efficiency change (ΔTE), and the scale economies (SE). (See Feng and Serletis (2010) for rigorous proof and Aguiar et al. (2017) for its empirical applications.) That is:

$$\frac{d\ln\text{TFP}}{dt} = \text{TC} + \Delta\text{TE} + \text{SE}, \quad (3.13)$$

where

$$TC = \frac{\partial \ln Y}{\partial t}$$

$$\Delta\text{TE} = \frac{\partial \ln \text{TE}_{it}}{\partial t}$$

$$\text{SE} = \left(\frac{\eta - 1}{\eta}\right)\sum_k \left(-\frac{\eta_k}{\eta}\right)\frac{d\ln X_{kt}}{dt}$$

While estimating equations (3.10) and (3.11), we must control for potential bias stemming from time-invariant unobservables and the endogeneity problem in the equations. The Stata command of “xtsfkk” developed by Karakaplan (2017) is used in this study to control for the endogeneity problem in the frontier and/or inefficiency equations in longitudinal settings.

3.3.3 Data

Data used for this empirical analysis is provincial level panel data for 1984-2020, with 31 provinces. The data sources are the China statistical yearbook and China agriculture statistical report. The data used in this study contain one output variable and four input variables. The output variable is measured by the total value of agricultural production at constant prices. To obtain data on real output value, we employed the distinct agricultural product priced index as deflators for each province. The four input variables are land, labor, farm machinery, and fertilizer. Land is defined as the total sown area of farm production (1,000 ha). Labor is measured as total employment engaged in agricultural production (10,000 person), which is not available directly from China statistical yearbook. We first compute the ratio of gross output value of agriculture to that of the primary industry, and then estimate farm labor by multiplying the ratio by the total employment in the primary industry. Farm machinery is measured by the total power of agricultural machines (10,000 kilowatt hours) used for agricultural production, and fertilizer is measured by the total chemical fertilizer consumption that is converted to net ingredients (10,000 tons).

In the analysis, province-specific environmental variables were included in the inefficiency equation, given by equation (3.11). These variables are irrigation ratio, measured by the irrigated area divided by the total sown area; affected area ratio, which is the agricultural land area damaged by natural disasters divided by the total sown area; grain production ratio, measured by the sown area of grain production divided by total sown area.

3.4. Estimation results

3.4.1 Technical efficiency and technology gap

Before estimating the stochastic frontier production function, the stationary of the variables of interest, including the regressand should be verified. A Fisher-type unit root test is applied, and the results are shown in Appendix Table 3.1. The results strongly reject the null hypothesis that all panels contain unit roots in favor of the alternative that at least one panel is a stationary process. Besides, we test a null hypothesis that SFPF estimators do not differ among regions, which is verified by a likelihood-ratio test. The statistical value of λ in the first study period equals 258.31 (Prob>chi2=0.0000), and in the second period equals 666.76 (Prob>chi2=0.0000), suggesting that the null hypothesis can be rejected.

Table 3.1 shows the estimates of the translog stochastic frontier model for the pooled data. In both two periods, the models exhibit positive and highly significant first-order parameters, fulfilling the monotonicity condition for a well-behaved production function, except the capital input in the second period, which is positive but not significant. The coefficient of the “Eastern dummy” variable for the first period is 0.152 and significant at 1% level, suggesting that the agricultural productivity of eastern is 1.16 times higher than that in the western region. The coefficient of the “Central dummy” variable in this period is 0.138, but not significant. There is also a significant difference in the productivity between the eastern and central regions (*p*-value: 0.003). In the second period, the positive and significant coefficient of “Eastern dummy” (0.203) implies that the agricultural productivity of eastern is 1.23 times higher than that in the western region. Meanwhile, the coefficient of “Central dummy” in this period became negative and significant, suggesting that the agricultural productivity in central is lower than that in western region. Comparing these two periods, the improvement of agricultural productivity in western is remarkable, and the issue of the driving force behind this improvement in western region will be discussed below.

Table3.1. Estimates of the translog stochastic frontier model for the pooled data

	1984-2000		2001-2020	
Production frontier	Estimates	SE	Estimates	SE
ln (*fer*)	0.160***	0.036	0.328***	-0.047
ln (*lab*)	0.257***	0.051	0.095***	-0.036
ln (*cap*)	0.156***	0.053	0.019	-0.032
ln (*lad*)	0.386***	0.067	0.394***	-0.074
ln (*fer*)*ln (*lab*)	-0.087**	0.036	0.025	-0.075
ln (*fer*)*ln (*cap*)	0.001	0.043	0.065	-0.075
ln (*fer*)*ln (*lad*)	0.199***	0.056	-0.916***	-0.088
ln (*lab*)*ln (*cap*)	0.326***	0.068	0.087	-0.054
ln (*lab*)*ln (*lad*)	-0.700***	0.104	-0.192*	-0.111
ln (c*ap*)*ln (*lad*)	-0.347***	0.122	-0.019	-0.09
0.5*ln (*fer*)*ln (*fer*)	-0.043	0.036	0.701***	-0.117
0.5*ln (*lab*)*ln (*lab*)	0.459***	0.084	0.079	-0.101
0.5*ln (*cap*)*ln (*cap*)	0.034	0.098	0.002	-0.082
0.5*ln (*lad*)*ln (*lad*)	0.822***	0.240	1.009***	-0.166
ln (*fer*)*ln(*time*)	0.011**	0.005	-0.022***	-0.004
ln (*lab*)*ln(*time*)	-0.014***	0.005	0.016***	-0.004
ln (*cap*)*ln(*time*)	0.003	0.007	-0.006*	-0.004
ln (*lad*)*ln(*time*)	-0.009	0.009	0.014***	-0.005
Eastern dummy	0.152**	0.073	0.203**	-0.092
Central dummy	0.138	0.126	-0.164*	-0.098
Environmental variables				
Irrigation ratio	0.090	0.151	-3.015***	0.652
Affected area ratio	0.932***	0.164	0.922***	0.180
Grain production ratio			-0.739**	0.322
Number of observations	492		620	
Log likelihood	428.81		500.96	
Mean technical efficiency	0.67		0.74	

Note: *, ** and *** indicate statistical significance at the 1%, 5% and 1% levels, respectively.

The lower part of Table 3.1 shows the estimation result of the inefficiency term of equation (3.11). The coefficient of irrigation rate in the first period is positive but not significant, while in the second period it became negative and significant. This suggests that before 2000, the irrigation rate does not affect technical efficiency of farm production, while after 2001, an increase in the irrigation rate helps improve the technical efficiency. The coefficient of the land area damaged by natural disasters divided by the sown area is positive and significant in both study periods, suggesting that the natural disasters adversely affect the technical efficiency, which is consistent with our expectation. Moreover, the coefficients of grain production ratio in the second study period is negative and significant, suggesting that the enlargement of grain production improves technical efficiency of farm production during past twenty years. Indeed, Grain crops are generally considered to be relatively land-intensive crops. Farmers that specialize more in grain crops are therefore more likely to rent additional land than farmers specializing in less land-intensive crops (Liu et al., 2018).

Table 3.2 shows the estimation results for the meta frontier function by using the estimates obtained from the region-specific frontiers. In both two periods, the models exhibit positive and highly significant first-order parameters. For the environmental variables, the coefficient of "Eastern dummy" changes from positive in the first period to negative in the second period, but not significant. The coefficient of "Central dummy" is positive but not significant in both two periods.

Table 3.3 and 3.4 show the estimated TE, TGR and MTE by provinces in two periods. Evidently, the eastern provinces achieved relatively high MTE, with Beijing's score among the highest. Meanwhile, the MTE scores in western provinces are averagely lower than the others, with no exception for Gansu province. Comparing the changes of TGR scores between two study period, we can see that in most provinces, the TGR scores improved to some extent. As discussed in the theoretical part, a lower (higher) TGR value implies a larger (smaller) technology gap between the regional frontier and the meta frontier. Thus, it can be concluded that the individual regional frontier has approached to the meta frontier during past few decades for almost all provinces.

Table 3.2. Estimation results for the meta frontier

	1984-2000		2001-2020	
Production frontier	Estimates	SE	Estimates	SE
ln (*fer*)	0.210***	-0.022	0.268***	-0.035
ln (*lab*)	0.340***	-0.025	0.142***	-0.024
ln (*cap*)	0.190***	-0.033	0.105***	-0.02
ln (*lad*)	0.446***	-0.04	0.341***	-0.042
ln (*fer*)*ln (*lab*)	-0.080***	-0.022	-0.345***	-0.049
ln (*fer*)*ln (*cap*)	-0.122***	-0.025	0.209***	-0.051
ln (*fer*)*ln (*lad*)	0.265***	-0.032	-0.483***	-0.066
ln (*lab*)*ln (*cap*)	-0.033	-0.03	0.115***	-0.032
ln (*lab*)*ln (*lad*)	-0.603***	-0.036	0.071	-0.075
ln (c*ap*)*ln (*lad*)	0.300***	-0.04	-0.338***	-0.059
0.5*ln (*fer*)*ln (*fer*)	0.002	-0.022	0.543***	-0.08
0.5*ln (*lab*)*ln (*lab*)	0.634***	-0.041	0.228***	-0.063
0.5*ln (*cap*)*ln (*cap*)	-0.031	-0.058	0.173***	-0.051
0.5*ln (*lad*)*ln (*lad*)	0.267***	-0.047	0.566***	-0.098
ln (*fer*)*ln(*time*)	0.010***	-0.003	-0.026***	-0.003
ln (*lab*)*ln(*time*)	0.014***	-0.003	0.010***	-0.003
ln (*cap*)*ln(*time*)	0.019***	-0.004	-0.004	-0.003
ln (*lad*)*ln(*time*)	-0.050***	-0.005	0.021***	-0.004
Environmental variables				
Eastern dummy	0.330	-0.690	-0.840	-0.653
Central dummy	1.152	-0.707	1.033	-0.675
Time trend	0.072***	-0.006	0.081***	-0.007
Number of observations	493		620	
Log likelihood	665.29		761.81	
Mean technical efficiency	0.7701		0.7909	

Note: *, ** and *** indicate statistical significance at the 1%, 5% and 1% levels, respectively.

Table 3.3. The estimated TE, TGR and MTE by provinces (1984-2000)

	Group	MTE	TGR	TE
Beijing	Eastern	0.876	0.901	0.973
Tianjin	Eastern	0.725	0.877	0.827
Hebei	Eastern	0.409	0.846	0.484
Liaoning	Eastern	0.683	0.984	0.695
Shanghai	Eastern	0.771	0.794	0.970
Jiangsu	Eastern	0.677	0.753	0.899
Zhejiang	Eastern	0.605	0.990	0.611
Fujian	Eastern	0.680	0.950	0.715
Shandong	Eastern	0.509	0.709	0.718
Guangdong	Eastern	0.807	0.823	0.980
Guangxi	Eastern	0.499	0.833	0.598
Shanxi	Central	0.358	0.549	0.650
Inner Mongolia	Central	0.527	0.700	0.752
Jilin	Central	0.628	0.802	0.783
Heilongjiang	Central	0.544	0.659	0.826
Anhui	Central	0.536	0.594	0.901
Jiangxi	Central	0.538	0.723	0.744
Henan	Central	0.455	0.603	0.755
Hubei	Central	0.589	0.606	0.972
Hunan	Central	0.511	0.613	0.835
Sichuan	Western	0.538	0.624	0.863
Guizhou	Western	0.453	0.464	0.976
Yunnan	Western	0.446	0.505	0.883
Tibet	Western	0.306	0.330	0.923
Shaanxi	Western	0.426	0.542	0.785
Gansu	Western	0.427	0.494	0.862
Qinghai	Western	0.326	0.376	0.861
Ningxia	Western	0.341	0.451	0.755
Xinjiang	Western	0.780	0.792	0.985

Table 3.4. The estimated TE, TGR and MTE by provinces (2001-2020)

	Group	MTE	TGR	TE
Beijing	Eastern	0.843	0.990	0.852
Tianjin	Eastern	0.543	0.971	0.559
Hebei	Eastern	0.545	0.835	0.653
Liaoning	Eastern	0.704	0.806	0.873
Shanghai	Eastern	0.578	0.684	0.844
Jiangsu	Eastern	0.778	0.791	0.984
Zhejiang	Eastern	0.834	0.917	0.910
Fujian	Eastern	0.826	0.879	0.939
Shandong	Eastern	0.618	0.833	0.742
Guangdong	Eastern	0.888	0.938	0.946
Guangxi	Eastern	0.604	0.866	0.699
Hainan	Eastern	0.742	0.900	0.825
Shanxi	Central	0.363	0.822	0.443
Inner Mongolia	Central	0.431	0.615	0.698
Jilin	Central	0.435	0.514	0.845
Heilongjiang	Central	0.556	0.916	0.608
Anhui	Central	0.450	0.624	0.723
Jiangxi	Central	0.484	0.672	0.720
Henan	Central	0.573	0.587	0.975
Hubei	Central	0.638	0.651	0.980
Hunan	Central	0.602	0.622	0.968
Chongqing	Western	0.480	0.849	0.568
Sichuan	Western	0.659	0.972	0.678
Guizhou	Western	0.345	0.986	0.350
Yunnan	Western	0.472	0.842	0.562
Tibet	Western	0.527	0.626	0.844
Shaanxi	Western	0.563	0.778	0.725
Gansu	Western	0.394	0.867	0.455
Qinghai	Western	0.390	0.818	0.478
Ningxia	Western	0.319	0.647	0.498
Xinjiang	Western	0.680	0.701	0.970

The estimated TEs, TGRs, and MTEs by regions are illustrated in Figure 3.6 and 3.7, and the detailed information of these indicators can be seen in Appendix Table 3.2. In 1984-2000, the average TE score for the regional frontier in western is the highest among all regions (0.88). However, a high score of the TE does not necessarily mean that the region is performing well in agriculture. From the table, the eastern region achieved the highest TGR (0.86) with minimum variation (SD = 0.09). Conversely, the lowest average TGR score was estimated for western China in this study period. Thus, it can be concluded that the technology is more advanced in eastern region than that in other regions since the former is closer to meta frontier technology. Meanwhile, the provinces in western region are to some extent far away from the meta frontier than other provinces in 1984-2000, and the average TGR score is 0.51, which is still 49% behind the optimal production technology level, indicating that western provinces have great potential for farm production technology improvement. Appendix Table 3.2 also shows that there are significant differences in the average MTE scores among the three regions in the first study period, with highest MTE score in eastern and lowest MTE score in western.

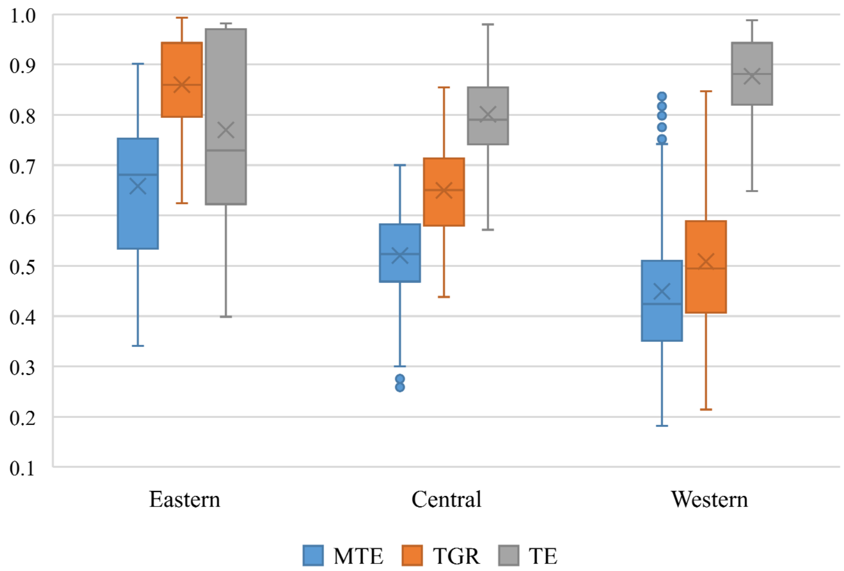

Figure 3.6. Distribution of estimated TE, TGR, and MTE by regions (1984-2000)

In the second study period, the estimated TE in eastern region saw an improvement, whereas that in central and western regions declined. The TGR scores in all regions showed an upward trend, indicating that the distance between the regional frontier and the meta-frontier in all regions is narrowing, and that the gap between the individual regional production technology and the meta production technology is shrinking. Nevertheless, it is worth noting that there is a remarkable increase of TGR score in western region during this period; it rose from 0.51 to 0.81.

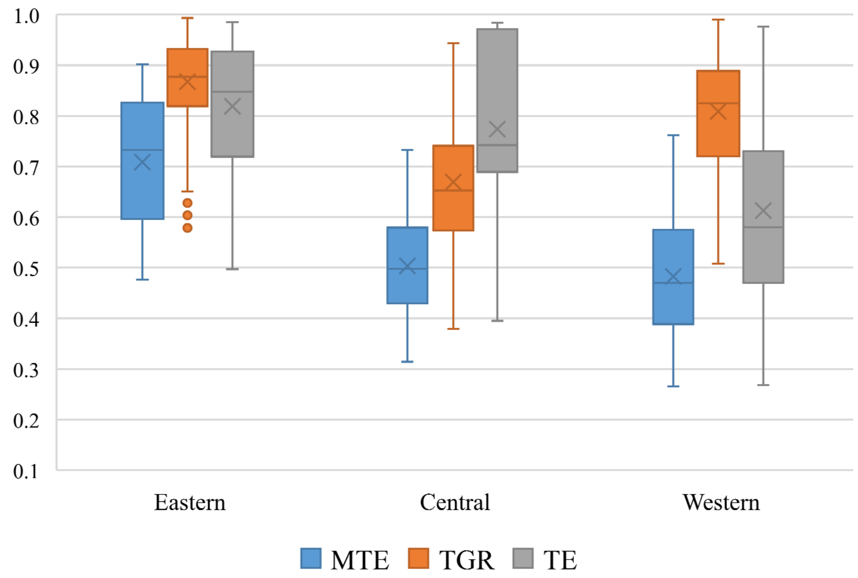

Figure 3.7. Distribution of estimated TE, TGR, and MTE by regions (2001-2020)

Comparing two study periods, the drastic changes of TE, TGR, and MTE in the western region during past two study periods imply that although the western provinces fell far behind other areas from the perspective of agricultural technical efficiency, the dynamic increase of TGR in the region reveals the efforts of western provinces to reduce the technology gap in farm sector and to catch up with other better-performing areas during past few decades.

Last but not the least, I pay special attention to the performance of Gansu province. In the first study period, the estimated MTE, TGR, and TE in the province is 0.43, 0.50, and 0.86, respectively, which is similar to the performance of western average. In the second study period, the estimated MTE, TGR, and TE in the province changed to 0.40, 0.87, and 0.46, respectively, while the MTE, TGR, and TE in western region is 0.48, 0.61, and 0.61. During 2000-2020, the TE in Gansu province is extremely lower than the regional average, suggesting that Gansu province failed to run agricultural production efficiently relative to their regional frontier, although the province has succeeded in narrowing the technology gap between provincial frontier and meta frontier. Therefore, the technical efficiency improvement in Gansu province is a topic worth to be analyzed in the following chapters.

3.4.2 Decomposition of TFP growth

In general, the TFP growth rate is decomposed into three elements: technical change (TC), a change in technical efficiency (∆ TE), and the scale effects (SE). This study calculated these elements from the regional stochastic frontier model for two study periods, and the results are presented in Table 3.5. The table show that, in the first study period, the annual growth rate of national agricultural output value is 4.91%, with the rate being almost the same among regions. During this period, the contribution of TFP was quite small, which denotes that agricultural productivity growth is mainly from the input augmentation. The TFP growth in eastern region is among the highest, followed by western and central. Besides, the TC in western region is negative during this period, reflecting a slowdown of technical progress in the agricultural sectors of western region. The negative SE in all regions except western suggest that agricultural TFP in general has not benefited from economies of scale except western provinces. The scale effect in farm production can be realized by accelerating intensive farmland use through land consolidation.

During the period 2001-2020, the agricultural output grew differently among regions, with the highest in the western region (6.18%) and the lowest in the eastern region (2.97%). During this period, TFP growth accounted for about 70% of the output expansion in farm sector, and the western region achieved the highest growth rate of TFP, followed by the central and eastern regions. The result is in line with the studies of Diao et al. (2018) and Shen et al. (2019). In this period, technical change is the major source driving the improvement of agricultural TFP, which is consistent with the observation that China has developed strong public agricultural R&D program and extension system to innovate and to disseminate agricultural technology. According to Fuglie (2018) and Sheng et al. (2020), the increasing R&D in China is responsible for the improvement of agricultural productivity. Chai et al. (2019) suggest that in China, a series of policy initiatives bolstered public and private investments in agricultural R&D, especially after 2000. By 2015, China was spending more than $10 billion annually on agricultural R&D, nearly quintuple the country's R&D spending in 2000[15]. Notably, during 2001-2020, the western region has made a remarkable progress in TC, which is in line with aforementioned improvement of TGR in this region.

Table 3.5. Decomposition of TFP growth (%)

		output growth	TFP	TC	ΔTE	SE
1984-2000	National	4.91	0.05	2.08	-0.10	-1.93
	Eastern	4.96	1.68	1.82	-0.01	-0.13
	Central	4.52	-0.57	1.43	-0.06	-1.93
	Western	5.51	0.00	-0.20	-0.21	0.42
2001-2020	National	4.19	2.26	2.37	0.04	-0.15
	Eastern	2.97	2.60	2.57	0.00	0.03
	Central	4.34	3.46	3.22	0.19	0.06
	Western	6.18	4.44	3.48	0.91	0.05

[15] https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=104237

3.5 Conclusion

Despite the rapid growth of agricultural production in China, the nation has faced challenges of unbalanced growths among regions. Recognized the challenges, China central government has initiated several development programs to narrow regional gaps since the early 2000s, and one of the major efforts is to boost agricultural productivity (Wang et al., 2019). This study has provided some interesting results on the regional variation of agricultural productivity in China. The main purpose of this chapter is to compare the interregional and the intertemporal agricultural technology in China since 1984, using a stochastic meta-frontier approach. The results of the empirical analysis indicated the following findings in terms of the MTEs and TGRs. First, during the study period, the MTE value in the eastern and the western regions increased, while the western region records the lowest MTE score. The results highlight the existence of a technical inefficiency in the western region. The farm production in western could improve its performance through a better management using the available technologies and resources in the future.

Second, the empirical analysis provide evidence that the average value of TGR in the eastern region is among the highest in both study periods, implying that the region adopts technology superior to that in the central and western regions. Nevertheless, the mean TGR of the western region grows more rapidly than other two regions, indicating that the technology gap between the regional frontier and the meta frontier in the western region was narrowed significantly during past few decades. The result demonstrated that the producers in less developed area, such as the western region, is struggling to catch up with others in terms of agricultural technology during past two decades. The analysis of TFP growth supported this argument, and suggested that the technical progress is the main contributor to the productivity improvement in western region since 2000.

Third, during past few decades, Gansu province improved its technical efficiency via advancing the production frontier, and the gap between the meta frontier and the provincial frontier shrink considerably. Nonetheless, the score of TE and MTE in the province decreased to some extent during 2000-2020, and cannot reach the western average performance in terms of technical efficiency. The result implies that the agricultural performance in the province is inferior to the western average level. In this context, besides inter-regional disparity, the differences of agricultural productivity and technology within the region is also crucial to the rural development in China.

Appendix Table 3.1. Fisher-type unit root test

Variables	Inverse chi-squared		Inverse normal		Inverse logit		Modified inv.chi-squared	
	Statistics	p-value	Statistics	p-value	Statistics	p-value	Statistics	p-value
Output	188.133	0.000	-7.311	0.000	-8.271	0.000	11.327	0.000
Fertilizer	168.809	0.000	-6.797	0.000	-7.319	0.000	9.592	0.000
Labor	144.605	0.000	-6.101	0.000	-6.106	0.000	7.418	0.000
Capital	129.422	0.000	-5.126	0.000	-5.255	0.000	6.055	0.000
Land	122.043	0.000	-5.288	0.000	-5.182	0.000	5.392	0.000

Appendix Table 3.2. Estimates of technical efficiency and technology gap ratio by regions

	1984-2000			2001-2020		
	Eastern	Central	Western	Eastern	Central	Western
TE to the regional frontier (TE)						
Mean	0.77	0.80	0.88	0.82	0.77	0.61
Std. Dev	0.17	0.09	0.08	0.13	0.18	0.19
Minimum	0.40	0.57	0.65	0.50	0.39	0.27
Maximum	0.98	0.98	0.99	0.99	0.98	0.98
Technology gap ratio (TGR)						
Mean	0.86	0.65	0.51	0.87	0.67	0.81
Std. Dev	0.09	0.09	0.15	0.09	0.13	0.12
Minimum	0.62	0.44	0.21	0.58	0.38	0.51
Maximum	0.99	0.86	0.85	0.99	0.94	0.99
TE to the meta frontier (MTE)						
Mean	0.66	0.52	0.45	0.71	0.50	0.48
Std. Dev	0.14	0.09	0.15	0.13	0.10	0.12
Minimum	0.34	0.26	0.18	0.48	0.31	0.26
Maximum	0.90	0.70	0.84	0.90	0.73	0.76

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Chapter 4

An empirical study of land rental development in rural Gansu, China: The role of agricultural cooperatives and transaction costs

Abstract

The land rental ratio in China has increased significantly over recent years, with the national average reaching 37% in 2017. A significant body of literature has analyzed the driving force behind this movement; however, there still remains much to be learned about the land rental markets in rural China. This paper analyzes the factors that influence the land exchange in Gansu province whose land rental ratio was among the lowest in China at the start of the 2010s. This study contributes to the literature by discussing the role agricultural cooperatives and transaction costs that are measured by land exchange disputes. We estimate the land rental ratio equation using a panel dataset of 86 counties in Gansu province from 2013 to 2017. The identification strategy is an application of the instrumental variable estimation method based on a fixed effects model. The conclusions can be summarized as follows. First, the agricultural cooperatives have a positive impact on the land rental development, suggesting that non-farm household producers are the major contributors to the demand side of farmland exchange. Second, transaction costs have a detrimental effect on land exchange, suggesting that the land rental markets are plagued by pervasive market failure. Accordingly, the public organizations such as the arbitration committees established in rural Gansu play a vital role in reducing the transaction costs arising from land use disputes among lessors and lessees.

Keywords: land rental; agricultural cooperatives; transaction costs; IV estimation.

4.1. Introduction

As agriculture is more land-intensive than other industries such as the manufacturing and service sectors, exploring the way to use farmland efficiently is a major challenge for its sustainable development. This is especially true for land-poor but economically high-performing countries, in which economic development drains scarce resources from agriculture, thereby reducing the labor force, which is followed by a decrease in land use intensity and potentially an increase in the area of farmland abandoned (Ito et al., 2016b; Lichtenberg and Ding, 2008; Zhou et al., 2020). In this context, the issue of land rental has received considerable attention as a policy tool to circumvent these problems and secure agricultural land use.

Efficient land use is of particular importance for Chinese agriculture, partly because it is characterized by small individual farms with excessively fragmented farmland (Tan et al., 2006) and partly because the reduction in arable land has raised demographic pressure on China’s limited land resources and triggered concern about food security (Liu et al., 2014). Further, the ageing of farm operators, acute shortage of successors, and mass exodus of rural people driven by the increase in the opportunity cost of farm labor are exacerbating the problem by hollowing out the farming industry in some areas (Li et al., 2014). Given this situation, the international competitiveness of Chinese agriculture is being eroded, jeopardizing the long-held policy goal of maintaining food self-sufficiency. Against this background, China’s central government is stimulating agricultural modernization and industrialization by promoting land usufruct accumulation in favor of large-scale farms (Ye, 2015). In this process, the government has shifted the land reallocation mechanism among farmers away from a dependence on administrative initiatives toward the adoption of a decentralized and market-oriented means to transfer land use rights. Well-functioning land markets could allow competent farmers to gain access to additional land, which not only raises the wealth of lessors and lessees of land but also enhances the overall efficiency of land use and agricultural productivity. In other words, the difference in agricultural productivity among farm producers provides them with an incentive to agree land lease contracts (Deininger and Jin, 2005).

Indeed, the area of rented land in China has increased significantly over recent years, reaching 34 million ha in 2017, equivalent to 37% of all contracted land. The explosive growth in off-farm labor market activities and resulting heterogeneous productivity levels among farm households (FHs) have served as the main catalyst of rising land rental activity (Kung, 2002; Yao, 2000). Further, the progressive land system reform that has ensured the security and transferability of land rights has facilitated the development of land rental markets in the country (e.g., Benjamin and Brandt, 2002; Brandt et al., 2004; Cheng et al., 2019; Ito et al., 2016a; Jin and Deininger, 2009; Zhou et al., 2020). Concretely, strengthened land contract rights have helped eliminate farmers' fear of losing their land and encouraged them to rent out their land to others (Min et al., 2017; Wang et al., 2015; Zhang et al., 2019). Huang and Ding (2016) and Ito et al. (2016a) claim that intermediaries such as land transfer service centers and rural shareholding cooperatives have played an important role in reducing the transaction costs associated with the exchange of land use rights, thereby promoting land rental activities. However, there remains much to be learned about land rental markets in rural China, and therefore further empirical research is needed.

Our study analyzes the driving forces behind the rapid development of the land rental market in Gansu province, which is located in the northwest of Mainland China. More precisely, we contribute to the discussion by providing empirical evidence of the role of agricultural cooperatives and transaction costs in the land rental market in rural Gansu. Although Gansu previously fell far behind other provinces in the development of its land rental markets, a significant improvement has been witnessed in recent years (Liu et al., 2018). Specifically, the land rental ratio was among the lowest in China (below 10%) at the start of the 2010s, as described by Liu et al. (2019) and Wang et al. (2018b). However, it rose sharply thereafter, reaching 26% in 2017. Thus, addressing the issue of Gansu as a case study is not merely academically intriguing but also particularly useful for better understanding national land use dynamics. Methodologically, we estimate the land rental ratio equation using a panel dataset of 86 counties in Gansu province for the presented analysis. To correct the potential bias stemming from time-variant and -invariant unobservables, we employ an instrumental variable estimation method based on a fixed effects model.

Our field work over the past several years in rural Gansu reveals that agricultural cooperatives serve as central facilitators of land transactions. However, land exchange disputes among farmers have recently escalated across the province, which has had a detrimental effect on land rental activities. Indeed, our econometric analysis shows that agricultural cooperatives contribute significantly toward the development of land rental markets, which is consistent with the findings of Cheng et al. (2019) and Huang and Ding (2016). The fact that non-farm household producers (NFHPs) have played an important role as lessees in facilitating land exchange in rural China is worth emphasizing, as many agricultural economists believe that family farms are considered to be the predominant mode of crop production globally with efficient advantages over other producers (Allen and Lueck, 1998; Eswaran and Kotwal, 1985; Pollak, 1985; Schmitt, 1991). In addition, our theoretical model suggests that high transaction costs, proxied by land exchange disputes, prevent both lessors and lessees from participating in land rental markets, with the result that land use inefficiency is likely to persist (Deininger and Binswanger, 2001; Deininger and Feder, 2009; Ito et al., 2016a; Key et al., 2000; Macours et al., 2010). The quantitative analysis in this study shows that public organizations established at the county level in Gansu province play a vital role in reducing the transaction costs that arise from the conflicts in land exchange between lessors and lessees.

Our contribution to the literature is to provide empirical insights into the factors that promote and impede the development of land rental markets in China. The rural structural transformation represented by the major departure from the principle of owner-cultivators toward the promotion of large-scale farming through land rental market development is the most important agricultural reform in China since the introduction of the Household Responsibility System in the late 1970s. Given the promise of this approach for addressing the food security challenges facing China (Deininger et al., 2014; Liu et al., 2018; Rada et al., 2015), a growing number of empirical studies have examined recent farmland transactions in the country. However, while those based on household micro data explore the land exchange decisions of lessors and lessees and identify the household characteristics that determine their participation in rental markets (Kimura et al., 2011; Min et al., 2017; Shi et al., 2018; Tang et al., 2019), they fail to highlight the market outcome of land transactions. FHs' willingness to participate in rental markets does not necessarily lead to an increase in the rented area when transaction costs are high and/or potential lessors and lessees are mismatched in the rental market. Our study thus bridges this important gap in the literature by focusing on the land rental ratio as the market outcome.

The remainder of this paper is structured as follows. Section 2 reviews the evolution of China's rural land rental markets with an emphasis on institutional aspects and highlights the characteristics of land exchange in Gansu province. Section 3 presents the theoretical model of land exchange as well as discusses the advantages and disadvantages of land rental markets and administrative land reallocation. Section 4 explains the econometric technique used for the regression analysis and data processing required to estimate the model. Section 5 presents the results of the estimation and sensitivity tests. Finally, Section 6 summarizes our results and draws policy implications.

4.2. Research background and the land market in rural Gansu

4.2.1. Institutional reforms of land use in rural China

The central government of China has long attached great importance to the exchange of farmland use rights. Current land rental markets in rural areas did not emerge suddenly or all at once, but rather evolved gradually through the process of trial and error. The founding principle of today's land institutions in rural China dates back to the Household Responsibility System introduced in the late 1970s. Under this system, rural collective organizations granted land contract rights to rural citizens at birth, initially for a five-year lease period.[16] Farmers were also allowed to make their own decisions on the crops they grew and retain their farm income as long as they met tax and grain quota delivery obligations (Ito et al., 2016a). However, land property rights were vested in the hands of rural collectives, which remains unchanged today.

In 1984, the Chinese government separated collective ownership from individual land use rights and allowed the voluntary exchange of individual land use rights between farmers with the permission from village leaders (Wang et al., 2015). The Land Administration Law enacted in 1986 further encouraged market-oriented land tenure reforms because it aimed to stimulate land rental markets and raise the efficiency of agricultural production (Ma et al., 2015). However, the legitimacy of agricultural land exchange on a voluntary basis was not officially acknowledged until the constitutional amendment in 1988.

Later, the Chinese government provided more detailed directives on rural land rights by promulgating the Rural Land Contract Law in 2003, which prohibited the land reallocations within villages in response to demographic changes. This policy program, referred to as the administrative reallocation, aimed to equalize per capita land access in response to household demographic changes and thus prevent inter-household income imbalances from arising (Ito et

[16] This was extended to 15 years in 1984, and extended again in 1993 for an additional 30 years after the initial term expired.

al., 2016a). According to Zhang (2008), village-wide reallocation occurred once every 8–10 years during the 1980s and 1990s, supplemented by partial small-scale reallocation. A serious problem arising from administrative land reallocation was that rural people who temporarily ceased farming for some reason placed themselves at higher risk of having their land contract rights revoked, which undermined farmers' incentive to rent out their land (Ito et al., 2016a).

The Rural Land Contract Law specified that land contract and use rights, which are held by FHs, may be exchanged with other village households through subcontracting, leasing, transferring, swapping, and using shareholding cooperatives. Hence, this law increased the transferability and security of land rights noticeably (Deininger and Jin, 2009). Another important institutional innovation was aforementioned "the separation of three rights" policy that started in 2014. This program conceptually divides rural land rights into three components: non-tradable property rights, contract rights, and tradable land use rights (Cheng et al., 2019; Wang et al., 2018a; Zhou et al., 2020). Property rights are held by rural collectives, whereas contract rights are individual households' entitlement to use the collectively owned land and use rights are their right to use land and obtain income from their contracted land. Under this system, FHs have become willing to transfer land use rights because they do not have to worry about losing their contract rights. As a consequence, the development of the land rental market in rural areas accelerated during the 2010s. These institutional reforms have been instrumental in securing land rights by lowering transaction costs, which has encouraged farmers to rent out their land use rights.

Figure 4.1 illustrates the average land rental ratio nationally since 2000 and inter-regional differences in the ratio between 2000 and 2009.[17] In the early 2000s, the central region advanced ahead of other regions, while the west (including Gansu) lagged behind. During this period, the national average increased from 8% in 2000 to 15% in 2009; furthermore, it

[17] Owing to data limitations, inter-regional differences are not known for 2010 and beyond.

continued to rise during the 2010s. Compared with 2010, the land rental ratio in China increased by 2.5 times in 2017, reaching 37%, and the proportion of farmers participating in land transfers increased by 16.7% (Zhou et al., 2020). The land rental ratio of the leading five provinces in China reached more than 50% in 2017: Shanghai 75.4%, Beijing 63.2%, Jiangsu 61.5%, Zhejiang 56.8%, and Heilongjiang 52.1%.[18] In general, the ratio is relatively high in the suburbs of metropolitan cities, some coastal provinces, and grain production regions.

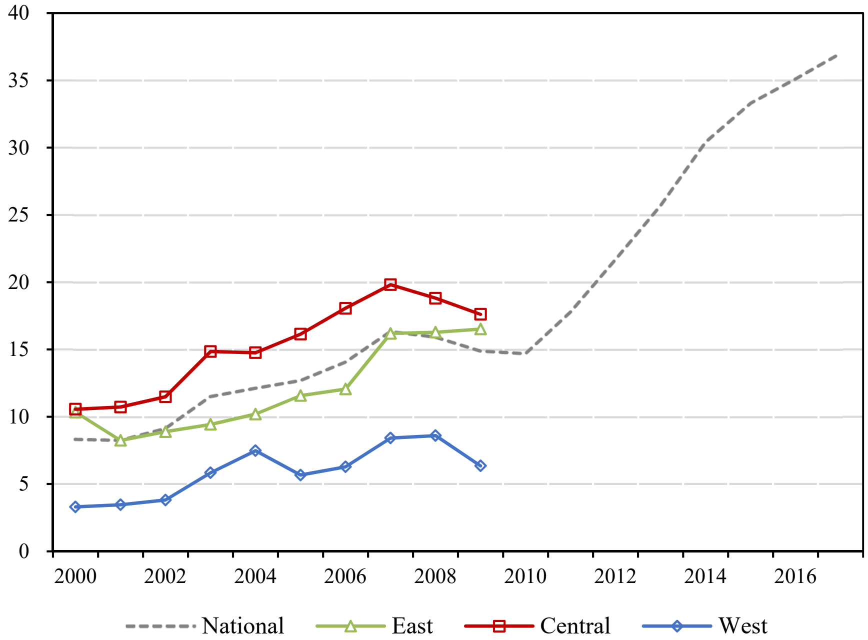

Figure 4.1. Regional differences in the land rental ratio (%)

Source: The Survey Data of National Fixed Observation Points in Rural Areas of the Ministry of Agriculture, and the summary based on the statistical data published by the Ministry of Agriculture.

4.2.2. Land rental market in rural Gansu

Figure 2.5 in Chapter 2 illustrates the location of Gansu and administrative boundaries of its 14 city-level governments.[19] Rural Gansu is the least developed area in China; the annual per capita disposable income of rural households was 8,076 yuan (USD 1,164) in 2017, which

[18] Statistics from the Ministry of Agriculture, China.
[19] Jiayuguan city in the western part of the province has no county-level government. Since data on this city are unavailable, it is excluded from the analysis.

was among the lowest in the country and only 60% of the national average. The primary industry accounted for 11.5% of the total value added of the Gansu economy in 2017, higher than the national average by 3.6 percentage points. Although the share of cultivated area in the province is no more than 2.3% of the national total, Gansu is known as the major production region of maize for seeds.[20]

The landforms in the province are complex and diverse, comprising mountainous regions, plateaus and river valleys, as well as plains and deserts. Mountainous and hilly areas account for the largest proportion, while the area of flatland is relatively small (only 22% of the land area). With such diversified landforms, agricultural patterns can be divided into the Longnan mountainous farming regions, loess plateau dryland farming regions in the east, Gannan plateau farming regions, and irrigation agricultural regions of the Hexi Corridor. Gansu is semi-arid due to geographical constraints and atmospheric circulation effects, with access to surface water resources limited and unevenly distributed.

Table 4.1. Land rental by economic entity in Gansu

year	Area (share) rented by farm households	Area (share) rented by NFHPs	Area (share) rented by other entities
2013	4.34 (58.3%)	2.43 (32.7%)	0.67 (9.1%)
2014	5.14 (52.5%)	3.47 (35.4%)	1.18 (12.1%)
2015	5.48 (48.8%)	4.40 (39.2%)	1.35 (12.0%)
2016	5.93 (48.1%)	4.94 (40.1%)	1.46 (11.8%)
2017	6.01 (45.8%)	5.56 (42.3%)	1.56 (11.9%)

Source: The Rural Operation and Management Statistics from the Department of Agriculture and Rural Affairs of Gansu province

Note: Area unit: million mu (1mu=1/15 ha).

In Gansu, following the national trend, NFHPs such as agricultural cooperatives and dragon head enterprises have increasingly entered into farm businesses by renting land. Table 4.1 reports the area and share of rented land by economic entity in 2013–2017, showing that the

[20] Statistics from the China Statistical Yearbook.

rented land share of NFHPs increased from 32.7% in 2013 to 42.3% in 2017, with the share of FHs naturally decreasing. Figure 4.2 illustrates the land rental ratio and number of NFHPs in China and Gansu in 2010–2017,[21] showing that the land rental ratio moved in parallel with the number of NFHPs both in China and in Gansu. Liu et al. (2019) report that the farmland rental market in Gansu province has developed rapidly, with the rental ratio reaching 24.6% in 2016. According to the General Office of the State Council and the annual report on working of the Gansu government, the average farmland rental ratio in 2014, 2015, and 2016 was 20.4%, 23.5%, and 24.6%, respectively. Thus, the land rental ratios are consistent among data sources.

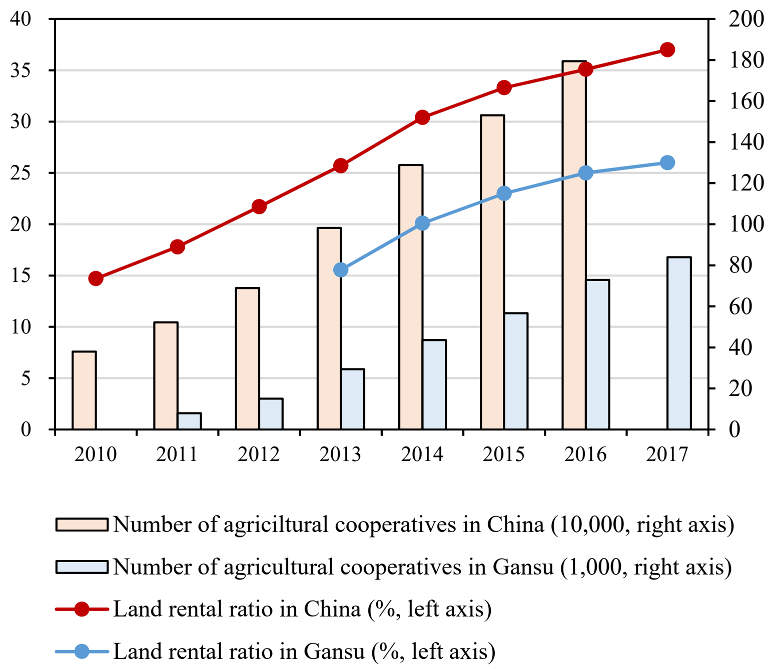

Figure 4.2. Agricultural cooperatives and the land rental ratio in China and Gansu

Source：The Rural Operation and Management Statistics from the Department of Agriculture and Rural Affairs of Gansu province, and Huang et al. (2018).

[21] For the land rental ratio in China and Gansu to be comparable, the contracted land area is used as the denominator. Owing to data limitations, the two indicators do not cover the whole period.

Figure 4.3 plots the land rental ratio and density of agricultural cooperatives (DAC hereafter), which measures the number of crop agricultural cooperatives divided by the total number of FHs, at the city level in Gansu for 2013–2017. There is a strong positive correlation between the two variables. However, the causality between these two variables are not clear from the figure. Exploring the impact of these proliferated NFHPs on the development of the land rental market is thus one of the major aims of this study.

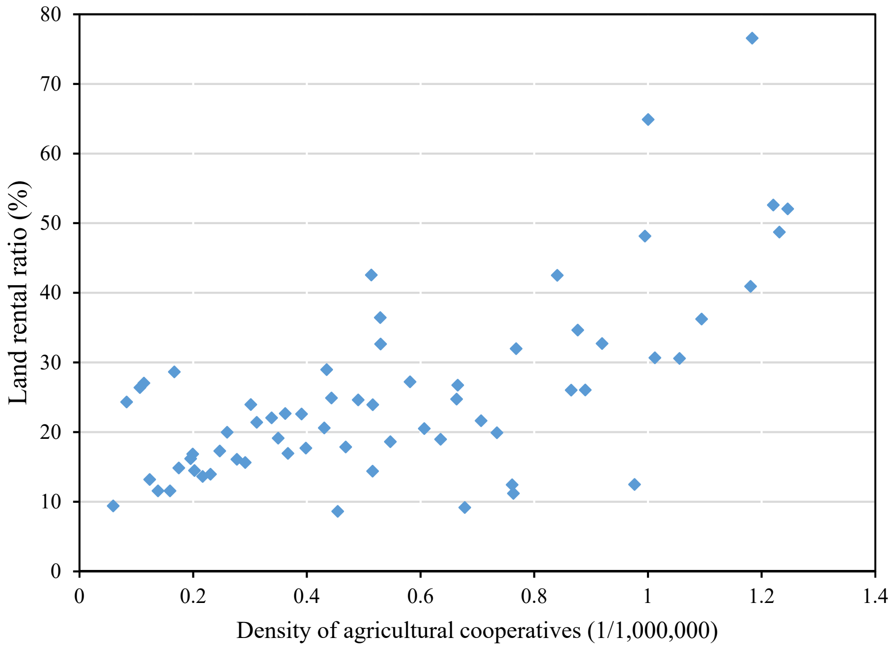

Figure 4.3. The density of agricultural cooperatives and the land rental ratio

Source: The Rural Operation and Management Statistics from the Department of Agriculture and Rural Affairs of Gansu province.

More than 80% of FHs in Gansu province have already obtained land contract right certificates, which may be a result of the land titling reform initiated by the Ministry of Agriculture, Gansu. The land reform of formalizing land contracts and land use rights (the separation of three rights) has fostered the development of land rental markets. By contrast, the confiscation of land contract rights during the administrative reallocation has undermined contract rights holders' incentive to rent out their land use rights to others. As described above, this negative effect has been alleviated considerably by the policy to separate land contract and land use rights. According to Ma et al. (2005), who surveyed rural Gansu, only 6% of households have experienced an administrative reallocation since 1998, with all experiencing only one land reallocation since that year. Hence, land rights are highly secured in our study site.

4.3. Theoretical model

4.3.1. Land rental markets

We develop a model of land exchange following Deininger and Jin (2005). A demand function of land, which is in principle derived from producers' profit-maximizing behavior, is given by $S = S(p,\ r,\ \boldsymbol{Z})$, where p and r denote the real agricultural product price and rental price, respectively. The vector $\boldsymbol{Z}$ represents fixed factor inputs. Taking account of the regularity conditions of the factor demand function, $\frac{\partial S}{\partial p} > 0$ and $\frac{\partial S}{\partial r} < 0$, we specify the land demand function of FH i as $S_i = a_i(p,\ \boldsymbol{Z}_i) - r$ with $\frac{\partial a_i(\cdot)}{\partial p} > 0$ to simplify the following discussion.

Based on this specification, we consider a situation in which there are m potential lessors ($i = 1$) and n potential lessees ($i = 2$) in land rental markets. It is natural to assume that $a_1(\cdot) < a_2(\cdot)$, indicating that demand for land is larger for potential lessees than for potential lessors for the given p. To the extent that all FHs own the same area of farmland (contracted land in the Chinese context) of $\bar{S}$, excess demand for land (ED) is represented by $ED_i = S_i - \bar{S}$. Thus, the land rental market is in equilibrium when $mED_1 + nED_2 = 0$, which yields the equilibrium rent (r^*) and land rental ratio (Y^*), defined as the land area transacted between lessors and lessees (ΔS^*) divided by the total area of farmland in this market (H),

$$r^* = \frac{ma_1(\cdot)+na_2(\cdot)}{m+n} - \bar{S}, \tag{4.1}$$

$$Y^* = \frac{\Delta S^*}{H} = \frac{mn[a_2(\cdot)-a_1(\cdot)]}{(m+n)H}. \tag{4.2}$$

As long as all FHs participate in the rental market, we have $H = (m + n)\bar{S}$.

Although we have $\frac{\partial r^*}{\partial p} > 0$, the sign of $\partial \frac{\Delta Y^*}{\partial p}$ is not determined theoretically because both $\frac{\partial a_1}{\partial p}$ and $\frac{\partial a_2}{\partial p}$ are positive. As noted earlier, a growing number of FHs in China are participating in land rental markets as either lessors or lessees, which is raising the land rental ratio. This movement in the real world is consistent with the prediction of our model in that $\frac{\partial Y^*}{\partial m} > 0$ and $\frac{\partial Y^*}{\partial n} > 0$. In line with this thinking, the entry of NFHPs such as agricultural cooperatives and dragon head enterprises into the farm sector also facilitates the development of land rental markets. Further, equation (4.2) shows that the larger the difference between $a_2(\cdot)$and $a_1(\cdot)$, the higher is the land rental ratio.

Since the inverse factor demand function of land is written as $r = a_i(p) - S_i$, the quantity of output at constant prices for FH i is represented by $Q_i = a_i(\cdot)S_i - \frac{S_i^2}{2}$. Thus, when there is no rental market, the quantity of output is expressed as $Q_i^b = a_i(\cdot)\bar{S}_i - \frac{\bar{S}_i^2}{2}$. When FHs participate in rental markets, the lessor gains rental revenues, while the lessee incurs rental costs. Thus, the quantity of output (or revenue at constant prices) for a representative lessor and lessee is expressed as $Q_1^a = a_1(\cdot)S_1 - \frac{S_1^2}{2} + r^*(\bar{S} - S_1)$ and $Q_2^a = a_1(\cdot)S_2 - \frac{S_2^2}{2} - r^*(S_2 - \bar{S})$, respectively. Substituting equation (4.1) into these equations, we have

$$\Delta Q_1 = Q_1^a - Q_1^b = \frac{(\Delta S_1)^2}{2} > 0, \text{ where } \Delta S_1 = \frac{\Delta S^*}{m},$$
$$\Delta Q_2 = Q_2^a - Q_2^b = \frac{(\Delta S_2)^2}{2} > 0, \text{ where } \Delta S_2 = \frac{\Delta S^*}{n}.$$

As expected, land exchange through rental markets increases the quantity of output for both potential lessors and potential lessees. In other words, the difference in demand for land provides them with an incentive to exchange their land use rights, which not only makes them better off but also enhances the overall efficiency of land use.

However, the pervasive market failure associated with high transaction costs inhibits the efficiency-enhancing reallocation of land (e.g., Deininger and Jin, 2005; Ito et al., 2016a, b; Ravallion and Van de Walle, 2006; Skoufias, 1995; Tang et al., 2019). Transaction costs in land rental include the costs of finding and negotiating with land exchange counterparts as well as monitoring and enforcing rental agreements (Ricker-Gilbert and Chamberlin, 2018; Tang et al., 2019). When transaction costs per rented land area for the i -th lessor and j -th lessee are denoted by t_{1i} and t_{2j}, their demand for land can be represented by $S_{1i} = a_1 + t_{1i} - r$ and $S_{2j} = a_2 - t_{2j} - r$, respectively.[22] Further, to the extent that $S_{1i} \geq \bar{S}$ (or $t_{1i} \geq \bar{S} - a_1 + r$) and $S_{2j} \leq \bar{S}$ (or $t_{2j} \geq a_2 - \bar{S} - r$), the lessor and lessee do not participate in rental markets because of the high transaction costs. As a result, the numbers of lessors and lessees who exchange their land use rights in the market fall to m' $(< m)$ and n' $(< n)$, respectively. In this situation, the rental market equilibriums are given by

$$r_T^* = \frac{m'a_1(\cdot) + n'a_2(\cdot) + T_1 - T_2}{m' + n'} - \bar{S}, \tag{4.3}$$

$$Y_T^* = \frac{m'n'[a_2(\cdot) - a_1(\cdot)] - (n'T_1 + m'T_2)}{(m' + n')H}. \tag{4.4}$$

where $\sum_{i=1}^{m'} t_{1i} = T_1$ and $\sum_{j=1}^{n'} t_{2j} = T_2$.

Equation (4.3) shows that $\frac{\partial r_T^*}{\partial T_1} > 0$ and $\frac{\partial r_T^*}{\partial T_2} < 0$ and equation (4.4) suggests that transaction costs have a detrimental effect on the land rental ratio ($\frac{\partial Y_T^*}{\partial T_1} < 0$ and $\frac{\partial Y_T^*}{\partial T_2} < 0$). Further, $Y_T^* < Y^*$ from equations (4.2) and (4.4). In other words, the presence of transaction costs drives a wedge between potential lessors and lessees and creates a price band within which some FHs find it unprofitable to participate in rental markets, thereby reducing the amount of land transacted through rental markets (Deininger and Jin, 2005; Key et al., 2000). From our field work in rural Gansu, agricultural cooperatives may reduce transaction cost in land exchange by serving as an intermediate agency among lessors and lessees.

[22] Output inclusive of rental revenues for lessors equals $Q_{1i}^a = a_1(\cdot)S_{1i} - \frac{S_{1i}^2}{2} + (r - t_{1i})(\bar{S} - S_{1i})$, whereas that exclusive of rental costs for lessees equals $Q_{2j}^a = a_2(\cdot)S_{2j} - \frac{S_{2j}^2}{2} - (r + t_{2j})(S_{2j} - \bar{S})$. From $\partial Q_{1i}^a / \partial S_{1i} = \partial Q_{2j}^a / \partial S_{2j} = 0$, we can derive lessors' and lessees' demand for land.

4.3.2. Rental markets vs. administrative reallocation

Instead of land rental markets, we consider another mechanism that reallocates land among farmers previously adopted formally in rural China, namely, the administrative reallocation. Suppose rural collectives, as social planners, maximize total agricultural output in a rural community, denoted by $G = mQ_1^a + nQ_2^a$, with respect to S_1 and S_2, subject to $mS_1 + nS_2 = (m + n)\bar{S}$. This optimization problem provides the same solutions for $\Delta S_1 = \bar{S} - S_1$ and $\Delta S_2 = S_2 - \bar{S}$ as the case in which rental markets determine the land reallocation. Not only does this strongly suggest that rental markets and the administrative reallocation have a substitutional role, but also that market forces based on individual behavior in the pursuit of self-interest maximize total output led by the "invisible hand." However, the presence of transaction costs reduces rented land, which results in lower output overall.[23]

On the contrary, to implement the administrative reallocation effectively, rural collectives have to be informed of individual producers' demand for land. When labor force endowments were the driving force behind the inter-household difference in agricultural productivity in the 1980s, rural collectives only needed to reallocate land in accordance with the demographic change in each household.[24] However, with the development of agricultural technology, rural collectives must now consider other factors when reallocating land. Further, given the challenges of knowing in advance the potential abilities of NFHPs and new entrants in land rental markets to manage the farm and cultivate the land, the problem of hidden information (or information asymmetry), in lieu of transaction costs, becomes all the more severe when land is reallocated on the basis of administrative initiatives. Indeed, the pitfalls of central planning are fundamentally problems of information, meaning that planners cannot mobilize the knowledge

[23] Kung and Shimokawa (2012) point out a substitutional role between land rental and the administrative reallocation in the context of the partial reallocation based on demographic changes.

[24] Local cadres of rural collectives in charge of the one-child family program were in a position to know each household demographic change, which enabled them to reallocate land contract rights in accordance with labor endowments.

they need for their decision-making (McMillan, 2002).

4.4. Methodology

4.4.1. Regression equation and estimation strategy

We estimate the following equation:

$$Y_{it} = \alpha_i + \alpha_A A_{it} + \alpha_T T_{it} + \boldsymbol{X}_{it}'\boldsymbol{\beta} + \varepsilon_{it}, \tag{4.5}$$

where Y_{it} measures the land rental ratio in county i at time t. The key explanatory variables of A_{it} and T_{it} denote the DAC and transaction costs of land exchange, respectively. The vector $\boldsymbol{X}_{it}$ and scalar ε_{it} represent other variables related to land exchange, including control variables, and an error term, respectively. To explore the impact of agricultural cooperatives in rural Gansu, we add the variable A_{it} into equation (4.5). Our recent field work in Gansu revealed that agricultural cooperatives also serve as intermediaries for promoting land exchange among FHs.[25] Hence, we expect $\alpha_A > 0$. Although, to the best of our knowledge, few attempts have been made to examine empirically the effect of transaction costs on land transactions, probably because they are difficult to measure, it can be hypothesized from the model in Section 3 that transaction costs are an important factor that adversely affects the development of land rental markets. It follows that $\alpha_T < 0$ is expected.

To test the hypothesis regarding transaction costs, we use a variable of land exchange disputes as a proxy for transaction costs. With the development of land rental markets in rural China, many lessors and lessees now sign a rental contract with their counterparts, which can inevitably lead to land exchange disputes. Indeed, disputes skyrocketed from 1,760 to 4,844 between 2013 and 2017 across the province.[26] Our interviews with local governors in Gansu

[25] Ito et al. (2016a) claim that rural shareholding cooperatives play a significant role in mediating land exchange among FHs in rural Jiangsu. Although this system has been experimentally introduced in Gansu, the number of cooperatives established in the province remained no more than 2,200 in 2017, with a geographical skew.
[26] Annual report of the Statistical Bureau of Gansu.

revealed that many factors are behind this phenomenon. First, incomplete contracts are considered to be responsible for the steep increase in disputes. As Feng (2008), Jin and Deininger (2009), and Wang et al. (2015) claim, land rental in China is characterized by informal oral agreements, which are likely to render a contract unenforceable. Second, the incomplete execution and/or breach of contract play a role; some lessees pay rent less and later squat the rented land, while in certain circumstances lessors convert the rented-out farmland to other uses without lessees' consent. Third, the capitalization of government subsidies in land rental prices gives rise to land rental disputes. For example, as argued by Zhang et al. (2020), China's grain subsidy programs have raised land rental prices considerably over recent years, which is likely to provoke an argument about the redistribution of benefits. However, irrespective of which cause is the main driving factor, a conflict of interests between lessors and lessees causes the transaction costs of land exchange to rise, which ultimately hinders the development of land rental markets. Viewed in this light, we adopt land exchange disputes as a proxy for transaction costs.

When estimating equation (4.5), we must control for the potential bias stemming from time-variant and -invariant unobservables. Since panel data are available in this study, we can employ fixed effects, random effects, and correlated random effects (CRE) models. The fixed effects model provides unbiased estimators as long as the error term of ε_{it} is uncorrelated with the regressors, namely, A_{it}, T_{it}, and $\boldsymbol{X}_{it}$ in equation (4.5). When applying the random effects model, it has to meet certain conditions, namely, that the unobserved individual effect of α_i is distributed independently of the regressors, in addition to there being no correlation between the regressors and error term. The CRE approach is instrumental in overcoming these restrictions, as it allows us to control for time-invariant unobserved heterogeneity by including the means of all the time-varying covariates (Wooldridge, 2010). Further discussion on this issue is provided in Section 5.

Besides the biases arising from time-invariant unobservables, we must pay special attention to the potential endogeneity of the DAC (A_{it}) and transaction costs (T_{it}), which is caused by the correlation between the error term (ε_{it}) and these two key variables. To overcome this problem, we use the instrumental variable (IV) estimation method in this study. The instruments must be correlated with A_{it} and T_{it}, as well as orthogonal to ε_{it}, but must not directly affect Y_{it} in equation (4.5).

For the instrument of A_{it}, we use the DAC at the city level (except county i itself) following Kung (2002), Liu et al. (2017), and others. After embryonic development in the early 1990s when their inception was only voluntary, agricultural cooperatives gained momentum nationally from the 2000s. The Chinese central government tried to accelerate this movement by promulgating the Farmers' Professional Cooperatives Law in 2007, suggesting that the establishment of agricultural cooperatives has been motivated by policy initiatives in a top-down fashion. To the extent that rural people in neighboring counties interact and consult with each other on this issue, the density of agricultural cooperatives at the county level is considered to be closely associated with the DAC at the city level. More importantly, land rental markets in China rarely extend beyond the administrative boundaries of counties. Thus, the DAC at the city level is positively correlated with such density at the county level without affecting the land rental ratio in counties directly, which ensures the validity of the instrument.

As the instrument for land exchange disputes (a proxy variable for transaction costs), we use the number of arbitration committee members divided by the total number of FHs at the county level (i.e., the density of arbitration committees). In 2009, the central government issued directives on arbitration committees to resolve the soaring numbers of land disputes over contract and use rights in rural areas. Although the establishment of local arbitration committees is not compulsory, they had already been established in all 86 counties in Gansu by 2017. As such, 1,458 committee members were working across the province in 2017; however, the density distribution is skewed geographically. According to the Law of the People's Republic of China on the Mediation and Arbitration of Rural Land Contract Disputes, an arbitration committee shall be concurrently formed by the representatives from the local people's government and from its relevant departments, representatives from the relevant people's groups, representatives from rural collective economic organizations, farmer representatives, and professionals of law, economics and other relevant specialties. In particular, the number of farmer representatives and professionals of law and economics and other relevant specialties shall account for at least one half of the members of the arbitration commission. Since arbitration committee members play an important role in resolving land exchange disputes but are not directly involved in land exchange, the density of arbitration committees is considered to be a valid instrument.

4.4.2. Data

We use two sources for data collection. The first is the Rural Operation and Management Statistics provided by the Department of Agriculture and Rural Affairs, Gansu, which contain socioeconomic and sociodemographic information by county. These statistics are considered to be the most appropriate and useful data source for the present study because they record farmland exchange, farm labor endowments, public organizations and institutions related to farmland use, the business activities of farms and NFHPs, and so on. We principally draw on the Rural Operation and Management Statistics for the processing data unless otherwise noted. The second data source is the Gansu Rural Yearbook published by the Statistics Bureau, which provides a broad range of information on the quantity of farm inputs and outputs, farm product and factor input price indexes, and so on. To perform the econometric analysis, we compile a panel dataset from 2013 to 2017. To check whether the data between the two sources are consistent, we select overlapping entries and then calculate the aggregated value of all the county-level data of the rural population, number of households, labor force in the primary sector, arable land area, and so on, before comparing them with the published provincial rural yearbook. This comparison demonstrates that the data of the overlapping items from different sources match closely, which verifies their credibility and reliability. Table 4.2 presents the definitions and descriptive statistics of the data used for the econometric analysis. The between SD (standard deviation) and within SD in the table evaluate the variation in the variables between different counties and periods, respectively.

Table 4.2. Variable descriptions and summary statistics

Variables	Descriptions		Mean	SD
Land rental ratio	land rental area divided by contracted land area	overall		0.136
		between	0.235	0.121
		within		0.062
DAC	number of crop farming cooperatives divided by 1000 FHs	overall		0.041
		between	0.049	0.035
		within		0.021
Land exchange disputes	number of land exchange disputes divided by number of FHs	overall		0.009
		between	0.002	0.006
		within		0.006
Ratio of migration	number of migrant labors divided by number of FHs	overall		0.287
		between	0.736	0.277
		within		0.088
Ratio of part-time FHs	number of part time households divided by number of FHs	overall		0.068
		between	0.043	0.068
		within		0.016
Ratio of family farms	number of family farms divided by 1000 FHs	overall		0.037
		between	0.014	0.035
		within		0.013
Effective irrigation rate	effective irrigated area divided by total contracted land area	overall		0.604
		between	0.495	0.555
		within		0.246
Farm product price relative to factor input price	agricultural product price index divided by the agricultural factor input price index	overall		0.083
		between	1.076	0.051
		within		0.066
Land contract right certificates	number of land contract rights certificates divided by 10000 FHs	overall		0.199
		between	0.824	0.180
		within		0.085
Farm machinery/land ratio	ratio of agricultural machinery power to contracted land area	overall		1.886
		between	0.852	1.690
		within		0.848
Fertilizer/land ratio	ratio of chemical fertilizer consumption to contracted land area	overall		0.021
		between	0.022	0.018
		within		0.010
Output/land ratio	ratio of agricultural products to contracted land area	overall		1.777
		between	0.950	1.785
		within		0.631

The "ratio of migration" variable measures the number of migrants working continuously outside their home village for more than six months a year divided by the total number of FHs. The out-migration of rural people associated with economic growth is an important prerequisite for promoting land rental, especially in rural regions whose farm sectors are characterized by small landholdings and overemployment (Brandt et al., 2001; Ito et al., 2016a; Kung, 2002; Lohmar et al., 2001; Yao, 2000). It follows that the higher the ratio of migration, the more actively farmland is exchanged in rental markets. The "ratio of part-time FHs" variable measures the number of part-time FHs divided by the total number of FHs. To create this variable, we focus exclusively on FHs that earn more income from the non-farm sector than the farm sector. Because such FHs are likely to stop working on land in the future, they are expected to become potential lessors in land rental markets.

The "ratio of family farms" variable is defined as the number of family farms divided by the total number of FHs. Different from the general concept in other countries, family farms in China are relatively large farms with family members as the main labor force being engaged in farm production and sustaining their livelihood mainly by agriculture.[27] Although fostering as many family farms as possible is a major policy goal in China, their presence in rural Gansu is still negligible (0.16% in 2017). Despite this, they are expected to help develop land rental markets as potential lessees.

Using the Gansu Rural Yearbook, we create the "farm product price relative to factor input price" variable. The farm price index is computed as the weighted average of individual product prices, while the agricultural production material price index is regarded as the factor input price. As described in Section 3, an increase in the relative price has a positive effect on the land rental price, whereas the impact on the land rental ratio cannot be determined theoretically. In other words, the latter effect is an empirical issue. The "land contract right certificates" variable is equal to the number of FHs that hold certificates divided by the total number of FHs. As explained in Section 2, the enhancement of security and transferability of land rights is crucial for encouraging land rental in agriculture. As part of the land rights realignment program

[27] More precisely, family farms in China are defined as commercial FHs whose operation area is beyond 50 mu or 3.3 ha (two crops a year) or 100 mu or 6.7 ha (one crop a year) and those renting land under longer than a five-year contract.

over the past few decades, the Chinese central government ordered local governments to issue land contract right certificates to FHs to separate land contract rights from land use rights. This program has spread throughout the province of Gansu, with more than 80% of FHs becoming certificate holders, as shown in Table 4.2.[28] Finally, we use the Gansu Rural Yearbook to create the control variables of the "farm machinery/land ratio," "fertilizer/land ratio," and "output/land ratio." The absence of these control variables could result in the estimated parameters of interest suffering omitted variable bias.

4.5. Estimation results and discussion

4.5.1. Estimation results

In this study, we employ a control function approach (CFA), which is an IV estimation method, to remove the potential biases stemming from the correlation between A_{it} and T_{it} in equation (4.5) and unobserved time-variant factors.[29] Concretely, we compute the predicted values of the residuals obtained from the first-stage regression and include them as covariates in the second-stage regression. The null hypothesis is that the coefficients of these residuals in the land rental equation are zero in the regression-based Hausman test for the exogeneity of the "DAC" and "land exchange disputes" (Wooldridge, 2010). To put it another way, the significant coefficients of the predicted residuals in the second-stage regression indicate the presence of endogeneity and possible reduced bias compared with using an ordinary least squares approach.

Table 4.3 reports the estimation results of equation (4.5). We estimate the parameters using the CFA with the fixed effects model. Since panel data are used, we compute the *t*-values based on clustered standard errors. The first and second columns show the estimation results of the

[28] The survey results of Xu et al. (2019), who collect data from more than 8,000 rural households across 27 provinces in China, show that 41% had contract right certificates in 2014.
[29] The CFA and IV estimation methods provide the same estimated parameters but slightly different standard errors.

first-stage regression in which the two potential endogenous variables are regressed on the covariates including the excluded instruments. For the regression of "DAC," the coefficient of "city-level DAC" is positive and significant at the 1% level (*t*-value: 10.24). On the contrary, for the regression of "land exchange disputes," the coefficient of "arbitration committee density" is negative and significant at the 1% level (*t*-value: -4.94). The findings that the DAC at the county and city levels are positively correlated and that the density of the arbitration committee and land exchange disputes are negatively correlated meet our expectations. The results of the first-stage regression thus suggest that there is no weak instrument problem in our analysis.[30]

Columns (a) and (b) show the estimation results of the second-stage regression using ordinary least squares (OLS) and the CFA, respectively. The coefficient of predicted residuals 1, based on the DAC equation in the first stage, is significant at the 5% level. Likewise, the coefficient of predicted residuals 2, based on the land exchange disputes equation in the first stage, is also significant at the 5% level. These results suggest that the "DAC" and "land exchange disputes" variables should be treated as endogenous in equation (4.5). The coefficient of the "DAC" is positive (1.808 for the CFA) and significant at the 1% level. On the contrary, the coefficient of "land exchange disputes" is negative both for the OLS model (-0.131) and for the CFA (-1.897), while it is statistically significant when the CFA is used. These results lend strong support to our three hypotheses: first, the two key regressors are endogenous; second, the entry of NFHPs into farming helps increase the land rental ratio; and third, transaction costs impede the development of the land rental market.

The positive and significant coefficient of the "ratio of migration" variable suggests that the out-migration of rural people helps promote land exchange, consistent with the argument in this study as well as in previous research (Ito et al., 2016a; Kung, 2002; Yao, 2000). Table 4.3

[30] We reject the hypothesis of weak instruments based on the Cragg–Donald Wald *F* statistic (36.52), which is used as a rule of thumb to test the hypothesis in the case of multiple endogenous variables.

shows that a rise in "farm product price relative to factor input price" contributes to an increase in the land rental ratio, which suggests that the extent to which demand for land is expanded by an improvement in the terms of trade of agricultural production is larger for lessees than for lessors (see Section 3).[31] Although we expect the variables related to potential lessors and lessees to have an explanatory power for the land rental ratio equation, the coefficient of neither the "ratio of part-time FHs" nor the "ratio of family farms" is statistically significant. In addition, the coefficient of "land contract right certificates" is not significantly associated with the land rental ratio, perhaps because most FHs have become certificate holders in rural Gansu. Moreover, the effective irrigation rate is unrelated to the land rental ratio.

By differentiating equation (4.5) with time, we have

$$1 = \alpha_A \frac{\Delta A_{it}}{\Delta Y_{it}} + \alpha_T \frac{\Delta T_{it}}{\Delta Y_{it}} + \sum_k \beta_k \frac{\Delta X_{kit}}{\Delta Y_{it}} + \frac{\Delta \varepsilon_{it}}{\Delta Y_{it}}. \qquad (4.6)$$

Based on equation (4.6), we perform a decomposition analysis to understand the extent to which each variable contributes to the change in the land rental ratio. In this analysis, we use the CFA estimators in column (b) in Table 4.3 and all the county averages for the explanatory and explained variables. The average land rental ratio increased from 17.1% to 27.9% during 2013–2017. Among the various driving forces, the "DAC" variable makes the largest contribution (approximately 65%). With the exception of the error term, this is followed by "farm product price relative to factor input price" (10%). Although the "land exchange disputes" variable affects the increase in the land rental ratio adversely, the magnitude of the absolute value is small (-4.2%). Hence, agricultural cooperatives are the main factor in developing land rental markets in Gansu. However, whether their contribution is ascribed to their direct involvement in land rental markets as lessees or their role as intermediaries facilitating land transactions among FHs is uncertain. On this issue, further research is needed.

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[31] Table 4.2 shows that "farm product price relative to factor input price" rose by 7.6% during 2013–2017.

Table 4.3. Estimation results of the first and second stages

	1st stage				2nd stage			
					(a)		(b)	
	Agricultural cooperative density		Land exchange disputes		OLS		CFA	
	coefficient	*t*-value	coefficient	*t*-value	coefficient	*t*-value	coefficient	*t*-value
City-level DAC	0.837***	(10.24)	0.037***	(2.95)	—		—	
Arbitration committee density	0.029	(0.97)	-0.049***	(-4.94)				
DAC	—		—		1.206***	(5.60)	1.808***	(5.77)
Land exchange disputes	—		—		-0.131	(-0.33)	-1.897**	(-2.45)
Ratio of migration	0.004	(0.25)	-0.003*	(-1.75)	0.102**	(2.58)	0.076*	(1.93)
Ratio of part-time FHs	0.018	(0.59)	0.015	(1.35)	-0.012	(-0.11)	-0.055	(-0.54)
Ratio of family farms	0.094	(0.82)	-0.025	(-0.94)	0.714	(1.41)	0.422	(0.89)
Effective irrigation rate	-0.001	(-0.12)	-0.007	(-0.88)	0.045	(1.04)	0.034	(0.84)
Farm product price relative to factor input price	0.008	(0.44)	0.007	(1.22)	0.190***	(4.55)	0.146***	(3.52)
Land contract right certificates	0.006	(0.39)	0.000	(0.10)	0.094	(1.15)	0.092	(1.19)
Farm machinery/land ratio	-0.004***	(-2.67)	0.005***	(3.31)	0.011	(1.48)	0.022**	(2.61)
Fertilizer/land ratio	0.255*	(1.85)	0.078	(0.73)	0.825	(0.95)	1.051	(1.27)
Output/land ratio	0.001	(0.98)	-0.000	(-1.21)	-0.009***	(-2.69)	-0.010***	(-3.12)
Predicted residuals 1	—		—				-1.041**	(-2.47)
Predicted residuals 2	—		—				1.944**	(2.29)
Overall R^2	0.893		0.784		0.351		0.313	
Number of OBS	416		416		416		416	

Note: The *t*-values are based on clustered standard errors with *, **, and *** indicating statistical significance at the 10%, 5%, and 1% levels, respectively.

4.5.2. Robustness check

The theoretical framework in Section 3 suggests that part-time farms and family farms play a role as potential lessors and lessees in land rental markets, respectively. In this context, the endogeneity problem associated with reverse causality is likely, not only because the land rental ratio is influenced by both the “ratio of part-time FHs” and the “ratio of family farms” variables, but also since land exchange affects the presence of part-time and family farms in land rental markets. To alleviate the bias stemming from this two-sided causality, we take the one-year lag of these variables to estimate equation (4.5) as a robustness check. We also add the lagged dependent variable into the second-stage regression to examine the planned adjustment to the long-run equilibrium of the land rental ratio. Here, we aim to investigate the extent to which the estimated parameters of interest are robust when the aforementioned variations are considered. We also check the robustness of the estimators using the CRE model.

Table 4.4 presents the estimation results based on the CFA.[32] Column (c) shows the result when the two lagged variables are used as regressors instead of “ratio of part-time FHs” and “ratio of family farms” in the current year. The two predicted residuals are significant, suggesting that the two key explanatory variables of A_{it} and T_{it} should be treated as endogenous. Compared with column (b) in Table 4.3, the coefficient of “arbitration committee density” becomes large in absolute value, whereas that of “DAC” remains almost unchanged. In addition, there is little change in the coefficients of the other variables.

Column (d) shows the estimation results when the lagged dependent variable is added into the equation of column (b) in Table 4.3. The estimated coefficient of Y_{it-1} is 0.140 with a *t*-value of 1.46. The fact that the coefficient is not significantly different from zero suggests that the adjustment speed is so swift that any gaps between the equilibrium and real land rental ratios

[32] The first-stage estimation results are not shown here because they are similar to those reported in columns (1) and (2) in Table 4.3. These are available on request.

narrow quickly. The two predicted residual coefficients indicate that the key variables of A_{it} and T_{it} are still endogenous; however, the coefficient of the "land exchange disputes" variable becomes insignificant, as does the coefficient of "farm product price relative to factor input price." The coefficient of "land contract right certificates" becomes significant, although only at the 10% level. Column (e) shows the estimation result when the lagged dependent and independent variables are employed simultaneously. The results show no significant changes.

Finally, we apply the CRE model to the data. The CRE model has an advantage over the random effects model in that it is better able to relax the restriction of no correlation between the unobserved individual effect of α_i and the other regressors in equation (4.5). For this purpose, we add the means of all the time-varying covariates, denoted by $\bar{A}_i$, $\bar{T}_i$, and $\bar{\boldsymbol{X}}_i$ for the counties, into equation (4.5) to control for time-invariant heterogeneity. Table 4.5 presents the estimation results. As shown in column (f), the variables of $\bar{A}_i$ and mean of the "effective irrigation rate" are significant at the 5% and 10% levels, respectively. However, this does not significantly affect the estimated parameters of interest. Column (g) shows the estimation result when the "lagged ratio of part-time FHs" and "lagged ratio of family farms" variables are used. Similar to in column (d) in Table 4.4, the coefficient of "land exchange disputes" becomes insignificant. However, this does not affect the other estimated parameters to any large extent.

Overall, our robustness test results offer unambiguous evidence that agricultural cooperatives help increase the land rental ratio, while transaction costs, proxied by land exchange disputes, are negatively correlated with the rental ratio.

Table 4.4. Estimation results (robustness check)

	(c)		(d)		(e)	
	CFA coefficient	*t*-value	CFA coefficient	*t*-value	CFA coefficient	*t*-value
Lagged land rental ratio	—		0.140	(1.46)	0.122	(1.17)
DAC	1.891***	(4.75)	1.389***	(3.58)	1.649***	(3.42)
Land exchange disputes	-5.011**	(-2.30)	-2.813	(-1.42)	-4.178*	(-1.76)
Ratio of migration	0.023	(0.78)	0.017	(0.69)	0.011	(0.43)
Ratio of part-time FHs	–		0.030	(0.04)	–	
Lagged ratio of part-time FHs	0.259	(1.05)	—		0.200	(0.76)
Ratio of family farms	–		0.463	(1.06)	–	
Lagged ratio of family farms	0.081	(0.17)	—		0.076	(0.16)
Effective irrigation rate	0.013	(0.24)	0.053	(1.03)	0.020	(0.32)
Farm product price relative to factor input price	0.148***	(2.93)	0.062	(1.45)	0.123**	(2.19)
Land contract right certificates	0.122	(1.47)	0.165*	(1.78)	0.141*	(1.71)
Farm machinery/land ratio	0.038*	(1.94)	0.016	(0.96)	0.031	(1.47)
Fertilizer/land ratio	1.677	(1.46)	1.393	(1.30)	1.640	(1.35)
Output/land ratio	-0.015***	(-3.04)	-0.008**	(-2.01)	-0.011***	(-2.66)
Predicted residuals 1	-1.277**	(-2.46)	-0.922*	(-1.88)	-1.155**	(-2.01)
Predicted residuals 2	5.786***	(2.81)	4.220**	(2.26)	5.469***	(2.57)
Overall R^2	0.218		0.410		0.327	
Number of OBS	332		331		331	

Note: The *t*-values are based on clustered standard errors with *, **, and *** indicating statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 4.5. Estimation results by CRE model (robustness check)

	(f)		(g)	
	CRE Coefficient	*z*-value	CRE Coefficient	*z*-value
DAC	1.807***	(5.44)	1.768***	(4.36)
Land exchange disputes	-1.906***	(-2.80)	-3.319	(-1.39)
Ratio of migration	0.076*	(1.91)	0.015	(0.48)
Ratio of part-time FHs	-0.055	(-0.51)	–	
Lagged ratio of part-time FHs	–		-0.147	(-0.73)
Ratio of family farms	0.418	(0.93)	–	
Lagged ratio of family farms	–		0.093	(0.21)
Effective irrigation rate	0.034	(0.81)	0.055	(1.15)
Farm product price relative to factor input price	0.147***	(3.20)	0.076*	(1.99)
Land contract right certificates	0.090	(1.27)	0.111	(1.46)
Farm machinery/land ratio	0.022***	(2.75)	0.022	(1.23)
Fertilizer/land ratio	1.053	(1.30)	1.278	(1.16)
Output/land ratio	-0.010***	(-2.83)	-0.013***	(-2.70)
Mean				
DAC	-1.132**	(-2.15)	-1.077*	(-1.98)
Land exchange disputes	-0.059	(-0.01)	0.252	(0.05)
Ratio of migration	0.022	(0.37)	0.085	(1.21)
Ratio of part-time FHs	0.030	(0.18)	–	
Lagged ratio of part-time FHs	–		0.159	(0.64)
Ratio of family farms	0.003	(0.00)	–	
Lagged ratio of family farms	–		0.225	(0.26)
Effective irrigation rate	0.108*	(1.65)	0.102	(1.41)
Farm product price relative to factor input price	-0.091	(-0.45)	-0.016	(-0.07)
Land contract right certificates	-0.204	(-1.09)	-0.233	(-1.20)
Farm machinery/land ratio	-0.024	(-1.03)	-0.025	(-0.85)
Fertilizer/land ratio	-1.970	(-1.43)	-2.234	(-1.46)
Output/land ratio	0.009	(1.33)	0.009	(1.37)
Overall R^2	0.443		0.313	
Number of OBS	416		416	

Note: The *t*-values are based on clustered standard errors with *, **, and *** indicating statistical significance at the 10%, 5%, and 1% levels, respectively.

4.6. Conclusion and policy implications

Over recent decades, China's central government has adopted a series of policy programs to promote the comprehensive development of land rental markets in rural areas, with the land rental ratio rising sharply from 14.7% in 2010 to 37% in 2017. Complementing previous empirical research, we investigate the driving forces behind this radical rise by estimating the land rental ratio equation at the local level, with a panel dataset of 86 counties in Gansu province. To correct the potential bias arising from the endogeneity problem, we use the CFA estimation method with a fixed effects model. Although a large amount of the literature has found insightful results on this issue, the discussion in this study provides a view from market perspectives rather than individual behaviors in land transactions. The present study thus addresses this important gap in the literature. Our estimation results lend strong support to the view that agricultural cooperatives raise the land rental ratio markedly, while transaction costs, proxied by land exchange disputes, have a detrimental effect on the development of land rental markets. Our sensitivity tests using alternative regressors and estimation methods corroborate the robustness of the estimators.

Based on the theoretical considerations and empirical results presented in this paper, we can draw important policy implications. First, our results demonstrate that NFHPs facilitate the development of land rental markets. This finding occurs with the policy orientation of the government's "No. 1 central document" issued in 2013 that encouraged and supported farmers to rent out their land to new agricultural management entities, including agricultural cooperatives. However, the advent of non-family farms as major land lessees seems to be a puzzle for agricultural economists and practitioners, partly because family farms account for the major share of food production globally (Lowder et al., 2016) and partly because they are traditionally viewed as the most efficient units of crop farming (Allen and Lueck, 1998;

Eswaran and Kotwal, 1985; Pollak, 1985; Schmitt, 1991).[33]

Second, as explained in this study, rental markets and the administrative reallocation serve as substitutional measures to reallocate farmland and thus maximize farm productivity. While the administrative reallocation was an effective tool to this end when labor endowments were the most influential factor that explained inter-household differences in demand for farmland, the growing number of NFHPs entering into farming and rapid progress in production methods make it difficult for rural collectives to reallocate land efficiently. Indeed, given the diversified units of producers and farm technologies, they cannot return to a time when rural collectives took the initiative in every aspect of rural economies. In this sense, a policy shift of the central government away from a dependence on administrative initiatives toward the adoption of a market-oriented means to transfer land rights can be seen as a step in the right direction. However, as supported empirically by the findings of this study as well as those in the literature, land rental markets are plagued by pervasive market failure owing to high transaction costs. Accordingly, public organizations such as the arbitration committees established in rural Gansu play a critical role in reducing the transaction costs arising from land use disputes among lessors and lessees. Alternatively, rural collectives, instead of committing to land reallocation directly, could help develop the land rental market by fulfilling the role of land exchange intermediaries.

The limitations of this study include the narrow focus on a specific region, namely, Gansu province in China. In addition, a caveat is needed before generalizing our conclusions to other settings because the majority of farmland rental transactions occur in administrative regions such as townships and villages. Further, the extent to which the entry of NFHPs helps attain the ultimate policy goal of enhancing agricultural productivity through land exchange remains to

[33] As in China, NFHPs play a significant role as lessees in facilitating land market development in Japanese agriculture. In this stage, it is too hasty to conclude that the loss of international competitiveness in agriculture automatically erodes the power of family farms and invariably encourages NFHPs to become significant players in agricultural development (Ito et al., 2016b).

be answered. Nevertheless, the insights gained from this study are likely to be relevant to other parts of rural China as well as countries facing the challenge of efficient land use.

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Chapter 5

Determinants of technical efficiency and farmers' crop choice rationality: A case study of rural Gansu, China

Abstract

Land exchange based on market transactions in which lessors and lessees participate voluntarily not only makes them better off but also enhances the overall efficiency of land use and agricultural production. However, it is worthwhile to empirically explore the effect of land rental on overall technical efficiency in the context of Chinese agriculture because non-farm household producers have increasingly entered the farming business as cultivators. If such producers underperform farm households in terms of efficiency, land consolidation does not necessarily deliver the desired outcome. This study demonstrates that the development of land rental markets improves agricultural technical efficiency at the aggregate level. It also suggests that there is room for further increase in farm's allocative efficiency by shifting resources away from cereal toward horticultural production.

Keywords: stochastic frontier output distance function; technical and allocative efficiency; land rental; agricultural cooperatives.

5.1. Introduction

There is solid evidence that better functioning of land rental markets in agriculture could help the economy to realize considerable gains in land-use efficiency and aggregate production (Benjamin and Brandt, 2002; Deininger and Jin, 2005). Given that most farms in the world are family-oriented smallholders (Graeub et al., 2016; Lowder et al., 2016), one driver behind farmland exchange is a widening inter-household difference in the land–labor ratio due to uneven decreases in agricultural labor among farms, which provides them with an impetus for inter-farm resource reallocation (Ito et al., 2016). This suggests that land exchange based on market transactions in which lessors and lessees participate voluntarily not only makes them better off but also enhances the overall efficiency of land use and agricultural production (Li and Ito, 2021). If, however, they do not exchange the resources on a voluntary basis and/or on level ground, the land exchange may not necessarily deliver the desired "market outcome".[34]

This perspective is particularly important in the Chinese context as non-farm household producers (NFHPs), such as agricultural cooperatives (ACs) and dragon head enterprises,[35] have increasingly entered the farming business as cultivators (Cheng et al., 2019; Huang and Ding, 2016; Li and Ito, 2021). Against this, there is an established view among agricultural economists that family farming has efficiency advantages over NFHPs because family members, as residual claimants on farm income, have a strong motivation to work diligently (Allen and Lueck, 1998; Eastwood et al., 2010; Pollak, 1985; Schmitt, 1991). Further, unlike family farms, large-scale NFHPs incur additional costs due to the need to supervise hired labor working in widely dispersed agricultural environments where

[34] Luo and Andreas (2020) argue that farmland consolidation by NFHPs may be detrimental to agricultural production efficiency if local authorities resort to coercive measures to compel smallholders to part with their land-use rights.
[35] Dragon head enterprises are agribusiness firms that have played a leading role in the vertical integration of agricultural commodity chains in China (Yan and Chen, 2015).

quality of work is hard to monitor; a lack of such monitoring would undoubtedly lead to poor performance and inefficiency (Otsuka et al., 2016). As such, we assert that exploring the causal effect of land rental on farm production efficiency constitutes an important issue for empirical studies to investigate.

The central government of China has been stimulating agricultural modernization and industrialization since the early 2000s by promoting land usufruct accumulation in favor of large-scale farms and NFHPs (Li and Ito, 2021; Ye, 2015). The farmland consolidation program has accelerated under the rural revitalization strategy (RRS), the goals of which align with the government's strategy of solving the well-known "three rural problems," advocated officially since 2001 as essential for accelerating rural development. Wu and Liu (2020), and Zhou et al. (2020a) argue that land consolidation is an important platform and provides leverage for the promotion of rural revitalization. It is considered, however, that the government's ultimate goals of promoting land exchange are to reinforce food production capacities to achieve the long-held policy objective of maintaining a grain self-sufficiency rate that is as high as possible. Thus, this study carefully examines whether the development of land rental markets leads to overall improvement in agricultural production efficiency. At the same time, considering the central government's strong involvement in food markets, we believe that farmers' crop choice rationality is another important issue to be empirically explored.[36]

Methodologically, we estimate a stochastic frontier output distance function (SFODF) using panel data from 86 counties in Gansu Province. Gansu is a relatively underdeveloped area located in the northwest of mainland China. The land–rental ratio (LRR), which is

[36] Many Asian countries have followed a similar trajectory in eating habits, shifting away from the traditional dominance of rice towards Western food types. As a result, diversification and selective expansion of farm products are policy challenges relevant to both China and other Asian countries (Ito, 2015).

defined as the land area transacted divided by the total contracted land area, in the province was among the lowest in China (below 10%) at the beginning of the 2010s (Liu et al., 2019a; Wang et al., 2018b). However, it rose sharply thereafter, reaching 26% in 2017 (Li and Ito, 2021). Since many farmers and NFHPs in Gansu Province grow multiple crops, including vegetables and fruits, we estimate the SFODF with multiple inputs and outputs, in lieu of a standard stochastic frontier model with multiple inputs and a single output. Further, to correct the potential bias in the estimators stemming from the endogeneity problem, we employ an instrumental variable estimation method.

Our first contribution to the literature is to provide empirical insights into the question of whether the development of land rental markets exerts a positive effect on technical efficiency at the aggregate level. Previous empirical studies, such as Feng (2008), Liu et al. (2019b), and Zhang et al. (2011), examine the relationship between land transactions or administrative reallocation and technical efficiency in Chinese agriculture, employing a standard stochastic frontier model. The main objective of these studies is to examine whether farmers' individual behavior in land transactions improves technical efficiency. However, they cannot highlight the "market outcome" of land rental development because their empirical studies use household micro data. If farmland transfers from producers with lower productivity to those with higher productivity, overall efficiency in the market never fails to improve. However, this desired outcome may not happen, due to the reasons mentioned above. By using aggregated level data, it is possible to evaluate the impact of land rental market development on the overall efficiency improvement of farm production. To the best of our knowledge, few attempts have been made to explore this causality at the aggregate level.[37] Our study thus bridges this important gap in the literature.[38]

[37] Chen and Huffman (2006) estimate a stochastic frontier production function using China's county-level data. However, they do not address the causal effect of land reallocation on technical efficiency.
[38] Lawin and Tamini (2019) analyze the land tenure security on the technical efficiency of smallholders

The second contribution of this study is to quantitatively examine the extent to which famers make a rational decision on their product mix. It is reasonable to assume that farm managers intend not merely to maintain high technical efficiency but also to maximize their income or profit by achieving high allocative efficiency. This requires them to diversify or selectively expand farm production in response to changes in product prices. China offers an interesting case in this respect. As described above, the central government has long placed a high premium on national self-sufficiency in staple foods, but the relative price of farm products is moving in favor of non-grain products recently. Thus, the issue of crop choice rationality of farm producers is worth analyzing in economic terms.

The remainder of this study is structured as follows. Section 2 reviews agricultural production and the burgeoning development of land rental markets and ACs in Gansu. Section 3 presents a theoretical model of the SFODF as well as the data processing required for the econometric analysis. Section 4 then presents the estimation results. Finally, Section 5 concludes the study with a brief summary of the findings and draws policy implications.

5.2. Outline of agriculture in Gansu

5.2.1. Farm production and land use

Gansu is predominantly an agricultural area, and the farm sector in the province plays an important role in developing the rural economy. The landforms in the province are complex and diverse, comprising mountainous regions, plateaus, and river valleys as well as plains and deserts. Mountainous and hilly areas account for the largest proportion, while the area of flatland is relatively small (only 22% of the land area). Due to geographical constraints and atmospheric circulation effects, access to surface water resources is limited

in Benin. Michler and Shively (2015) also examine the relationship between land tenure and farm efficiency, using household panel data in the Philippines.

and unevenly distributed. Despite such multifarious topography and critical environmental conditions, the agricultural sector in Gansu has maintained a stable growth rate over the years, with agricultural products being highly diversified within the province. Figure 5.1 illustrates the location of Gansu and the administrative boundaries of its 14 city-level governments. It also provides geographical information on the irrigation rate for those 14 cities in 2017, which forms an increasing gradient from the southwest to the northwest part of the province. It is considered that the availability of water resources for crop farming constitutes one of the most important factors that regulate a production frontier.

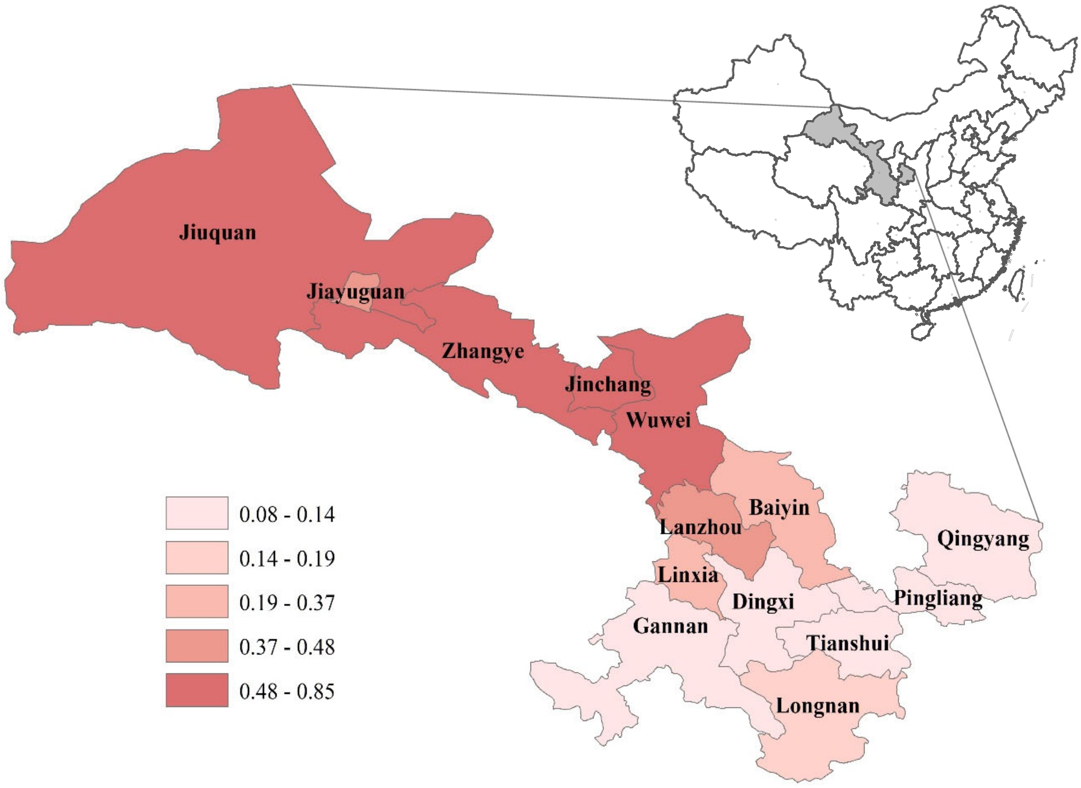

Figure 5.1. Administrative boundaries and irrigation rate in Gansu

Source: Google maps.

Note: The agricultural patterns can be divided into the Longnan mountainous farming regions (Longnan), Loess plateau dryland farming regions in the east (Lanzhou, Baiyin, Tianshui, Pingliang, Qingyang, Dingxi, and Linxia,), Gannan plateau farming regions (Gannan), and irrigation agricultural regions of the Hexi Corridor (Jiayuguan, Jinchang, Wuwei, Zhangye, and Jiuquan).

In this study, we divide farm products or production activities into three categories: Sector 1 is grain, including wheat, maize, and tubers; Sector 2 is cash crops, such as cotton and oil crops; and Sector 3 is vegetables and fruits. Table 5.1 presents farm production (10,000 tons) and the share of sown area by sector between 2000 and 2018. The production of all three sectors showed an increasing trend over the years, with the annual growth rate of Sector 3 being among the highest (5.6%). In the early 2000s, many maize seed companies launched their businesses in western Gansu, with the result that maize production grew more rapidly than Sector 3 production during this period, by 5.9% per annum, although this is not shown in Table 5.1.

Table 5.1. Farm production and the share of sown area by sector

	Farm production (10,000 ton)			The share of sown area (%) National average in parentheses					
	Sec. 1	Sec. 2	Sec. 3	Sec. 1		Sec. 2		Sec. 3	
2000	581.6	47.4	622.9	76.4	(68.6)	12.8	(14.1)	10.8	(17.3)
2005	703.2	61.4	640.9	71.2	(65.8)	14.0	(14.2)	14.8	(20.0)
2010	826.5	74.1	879.3	72.2	(69.1)	12.0	(12.5)	15.8	(18.5)
2011	902.0	74.2	944.2	71.9	(68.7)	12.0	(12.1)	16.1	(19.2)
2012	1022.1	79.0	1042.0	71.9	(68.9)	11.3	(11.7)	16.8	(19.4)
2013	1052.0	81.4	1127.6	71.8	(69.2)	11.0	(11.4)	17.2	(19.3)
2014	1074.0	84.2	1219.1	71.8	(69.2)	10.6	(11.2)	17.6	(19.6)
2015	1083.4	81.5	1306.7	72.1	(69.7)	10.0	(10.8)	18.0	(19.4)
2016	1049.8	84.4	1422.8	71.3	(70.1)	10.0	(10.5)	18.7	(19.4)
2017	1037.8	80.6	1609.5	70.2	(69.4)	10.8	(10.6)	19.0	(20.0)
2018	1072.8	73.9	1662.6	69.9	(68.7)	10.3	(10.5)	19.8	(20.8)

Source: Rural Operation and Management Statistics (Department of Agriculture and Rural Affairs, Gansu), China Statistical Yearbook.

The right half of Table 5.1 shows the share of sown area, with the figures in parentheses representing the national average.[39] Sector 1 has accounted for the largest share of land use in Gansu consistently for the period concerned, but its share declined

[39] The sown area of Sectors 1 to 3 covers around 90% of the provincial total sown area. Production of traditional Chinese medication, which is grown in some specific areas, accounts for more than half of the remaining 10%.

between 2000 and 2018, from 76.4% to 69.9%. Sector 2 has barely maintained a double-digit percentage, but its share has declined since 2005, accounting for 10.3% in 2018. In contrast, the share of Sector 3 in Gansu increased significantly, from 10.8% to 19.8%. It is worth noting that China's Statistical Yearbook overestimated the output and sown area of the horticulture and livestock industries in some provinces between 2007 and 2016. Therefore, using amended statistical data, we created Table 5.1; we discuss a way to re-estimate the data below in Section 3. Most noteworthy in Table 5.1 is that land-use patterns in Gansu agriculture show a similar trend with the national average.

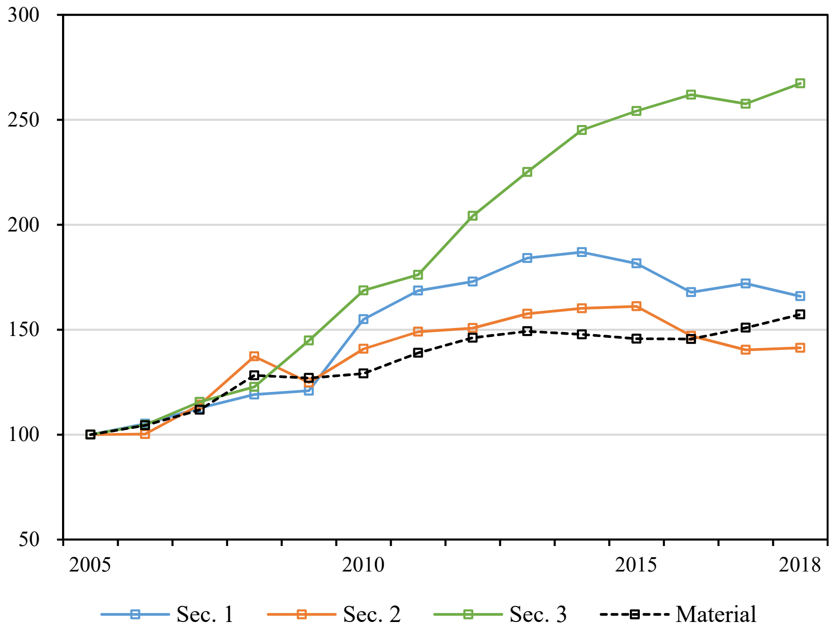

Figure 5.2. Price indexes of agricultural products and material in Gansu

Source: Gansu Development Yearbook (Gansu Statistical Bureau).

Figure 5.2 illustrates the Laspeyres price index of agricultural products (Sectors 1 to 3) and material in Gansu (the year 2005=100). The index of Sector 1 showed an upward trend between 2005 and 2014, but the tendency was reversed thereafter. The index of Sector 2 followed basically the same trend, hitting a peak in the year 2015, and declining thereafter.

Although the central government implemented a set of protectionist policy programs in the early 2000s, including producer subsidy and price support for agricultural products, they launched a series of policy reforms in the mid-2010s; they introduced a target price policy for soybean and cotton in 2014 for specified regions on a trial basis to decouple income support from the determination of farm product prices. The pilot project was followed by a reduction in the procurement prices for rice and wheat in 2015, and the implementation of the target price program for maize in 2016. Compared to Sectors 1 and 2, the terms of trade in Sector 3 improved significantly during the period concerned, with the index reaching 267 in 2018.

A close look at Table 5.1 and Figure 5.2 reveals that the rapid expansion of Sector 3 in terms of the production and share of sown area was caused, in all likelihood, by price movement in favor of horticultural products over the previous several years. Another conceivable reason for the sharp growth of Sector 3 in Gansu lies in the central government's policy initiatives. Due to the recent worsening terms of trade in grain production, most, if not all, Chinese farmers are motivated to switch to more lucrative crops. Although the government has restricted such crop diversification in the eastern and central provinces, which constitute the major production region for grain, they are encouraging farmers in western China (Gansu included) to grow fresh fruits and vegetables, with a view to narrowing the inter-regional rural income disparity.

5.2.2. Land rental markets and agricultural cooperatives

To use farmland efficiently, China's central government has shifted the land transaction mechanism among farm households (FHs) away from a dependence on the administrative reallocation toward the adoption of a decentralized and market-oriented means to transfer land-use rights. With a view to developing land rental markets, the government has implemented the comprehensive land rights realignment program, which lengthens contract times, prohibits administrative reallocation during rental periods, provides contract certificates, and guarantees the warranty of inherited contract rights. Among other things, as mentioned in Chapter 2 and 4, the "three rights separation" policy initiated in 2014 had a significant effect on land rental markets in rural China. This program conceptually divides rural land rights into three components; non-tradable property rights; non-tradable contractual rights; and tradable land-use rights (Cheng et al., 2019; Wang et al., 2018a; Ye, 2015; Zhou et al., 2020b). Property rights are held by rural collectives, contract rights are rights of individual households to use collectively-owned lands, and land-use rights are their right to use land and obtain income from their contracted land. Under the three rights separation system, farmers engaged in off-farm work are willing to part with their land-use rights because they do not have to surrender their contract rights. Thus, the development of the land rental market in rural areas accelerated during the 2010s.

The LRR in China has increased significantly, from 14.7% in 2010 to 37.0% in 2017, with NFHPs' share of rented land areas rising from 20% in 2010 to 31% in 2016 (China Statistical Yearbook of Rural Operation and Management, the Ministry of Agriculture). This remarkable fact holds true for rural Gansu. Figure 5.3 illustrates the LRR in Gansu Province between 2013 and 2017. The rental ratio rose sharply during the period examined in this study, from 15.6% in 2013 to 26.0% in 2017. In this process, NFHPs play an increasing role as lessees, with their market share of rented land area increasing from 33% in 2013 to 42% in 2017. Further, our field work over the past several years in rural Gansu reveals that ACs have made a sizable contribution toward the development of land rental markets, not only through renting land directly as lessees but also by serving as intermediate agents of land exchange among FHs.[40] Namely, ACs facilitate FHs willing to expand their

[40] Ito et al. (2016) show that rural shareholding cooperatives in Jiangsu, China have played an important

farm size to fulfill their desire to improve profitability. However, it remains an empirical question whether this leads to an improvement in agricultural technical efficiency.

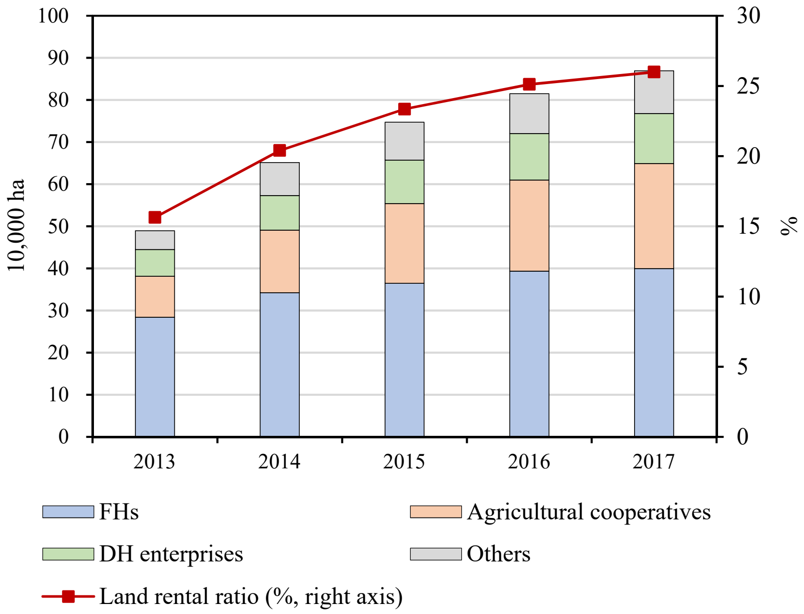

Figure 5.3. The rented land area and land rental ratio

Source: Rural Operation and Management Statistics (Department of Agriculture and Rural Affairs, Gansu).

According to the Farmers' Professional Cooperatives Law (FPCL), ACs are characterized by NFHPs and mutual help economic organizations based on the principle of the Household Responsibility System. Following the embryonic development of rural producer organizations, which were established on a voluntary basis in the early 1990s, the central government tried to accelerate this movement by promulgating the FPCL in 2007 (Ito et al., 2012). The past several years has witnessed the proliferation of ACs in China, with the total number being boosted seventyfold, from 26,000 in 2007 to 2.2 million in 2019. Likewise, the number of such cooperatives in Gansu increased rapidly, from 29,357

role in reducing the transaction costs associated with the exchange of land use rights, thereby promoting land rental activities. However, the establishment of rural shareholding cooperatives in Gansu hovers at an experimental level.

in 2013 to 83,908 in 2017. Apart from the intermediate role, we must consider the potential impact of ACs on agricultural productivity or technical efficiency. Previous studies, such as Gong et al. (2019), Ito et al. (2012), Jia et al. (2012), and Zhang et al. (2020), demonstrate that ACs have been fulfilling a major role in providing AC member households with key input on credit, production, and marketing information, as well as new technology and seedlings. In turn, this has helped them to overcome persistent market failures and to modernize production technologies, thus enhancing the economic welfare of AC participants. Using the selectivity-corrected stochastic frontier production function, Dong et al. (2019) and Ma et al. (2017) show that average technical efficiency is consistently higher for AC participants relative to non-participants.

5.3. Methodology

5.3.1. Stochastic frontier output distance function (SFODF)

In the economics literature, the use of frontier models to assess the level of efficiency of farm production is a popular practice in the literature. Different frontier models have been applied, ranging from non-parametric to parametric and stochastic methods. The non-parametric approach such as data envelopment analysis is sensitive to outliers since the measurement error is ignored (Coelli et al., 2005; Barnes et al., 2009). Meanwhile, the stochastic frontier analysis (SFA) can accommodate noise, such as measurement errors due to the weather and pest infestation that are likely to be significant in farming. In agricultural sector, the SFA is commonly used and assumes that the underlying technology is same for all sample observations.

As farm production has recently become more diversified across regions in Gansu (Table 5.1), we use a SFODF approach to describe farm production technology with multiple inputs and multiple outputs. The main objective of adopting this approach in this study is to identify factors that influence technical efficiency. Technical efficiency measures the actual output relative to the potential maximum or frontier output of a production unit at given technological and input levels (Brümmer et al., 2006; Coelli and Perelman, 2000; O'Donnell and Coelli, 2005).

We assume the following production possibility set:

$$P(\boldsymbol{X}) = \{\boldsymbol{Y} \in R_{+}^{M}: \ \boldsymbol{X} \text{ can produce } \boldsymbol{Y}\},$$

where the vectors $\boldsymbol{X}$ and $\boldsymbol{Y}$ denote vector inputs and outputs, respectively. The output distance function (ODF) is defined as:

$$D_O(\boldsymbol{X},\ \boldsymbol{Y}) = min\ \left\{\theta: \ (\tfrac{\boldsymbol{Y}}{\theta}) \in P(\boldsymbol{X})\right\},$$

where θ is defined as a distance parameter that is less than or equal to 1. The ODF is non-decreasing, linearly homogeneous and convex in $\boldsymbol{Y}$, and non-increasing and quasi-convex in $\boldsymbol{X}$. From homogeneity of degree one in $\boldsymbol{Y}$, we have:

$$\lambda D_O = D_O(\boldsymbol{X},\ \lambda Y_1,\ \lambda Y_2).$$

Thus, the following equation is obtained by assuming $\lambda = \frac{1}{Y_1}$:

$$\frac{D_O}{Y_1} = D_O(\boldsymbol{X},\ 1,\ \frac{Y}{Y_1}) \equiv D(\boldsymbol{X},\ \boldsymbol{Y}^{*}).$$

Taking the natural log of both sides of this equation yields:

$$\ln Y_1 = -\ln D\ (\boldsymbol{X},\ \boldsymbol{Y}^{*}) + \ln D_O. \qquad (5.1)$$

The term D_O denotes the score of technical efficiency. Since we have $0 < D_O \leq 1$, $-u = \ln D_O$ is negative with the maximum value equal to zero. The term of $-u$ represents the inefficiency element with a one-sided disturbance; the closer the value of D_O is to unity, the more technically efficient are the farmers' choices. As such, we have:

$$\ln Y_1 = -\ln D\ (\boldsymbol{X},\ \boldsymbol{Y}^{*}) - u. \qquad (5.2)$$

By specifying $\ln D\ (\boldsymbol{X},\ \boldsymbol{Y}^{*})$ in equation (5.2) as the trans-log form, we express the SFODF as:

$$-\ln Y_{1it} = \alpha_0 + \textstyle\sum_k \alpha_k \ln X_{kit} + \sum_m \beta_m \ln Y_{mit}^{*} + \gamma_t \ln t + \frac{1}{2}\sum_k \sum_l \alpha_{kl} \ln X_{kit} \ln X_{lit}$$

$$+\sum_k \sum_m \chi_{km} \ln X_{kit} \ln Y^*_{mit} + \sum_l \alpha_{lt} \ln X_{lit} \ln t + \frac{1}{2} \sum_m \sum_n \beta_{mn} \ln Y^*_{mit} \ln Y^*_{nit}$$

$$+\sum_n \beta_{nt} \ln Y^*_{nit} \ln t + \gamma_{tt} (\ln t)^2 + \chi \cdot \text{Irrigation rate}_{it} + u_{it} + v_{it} \tag{5.3}$$

where i and t denote country and time, respectively. To take account of the difference in production technologies or heterogeneity in the SFODF among counties, the variable of irrigation rate is included in equation (5.3). The availability of water resource is considered to be one of the most important factors that regulates agricultural production frontiers. Albeit very simple, this is an effective method to reduce the estimation biases arising from the assumption of homogeneous frontier function.

In equation (5.3), v_{it} is i.i.d. $N(0,\ \sigma_v^2)$, that is, independent and identically distributed with zero mean and variance σ_v^2, and u_{it} is i.i.d. $N^+(\mu_{it},\ \sigma_u^2)$ with one-sided distribution. The two components u and v are also assumed to be distributed independently of one another: $\sigma_{uv} = 0$. Technical efficiency can be calculated as $TE_{it} = exp(-u_{it})$. The parameters in equation (5.3) have properties of $\alpha_{kl} = \alpha_{lk}$, $\beta_{mn} = \beta_{nm}$ from the symmetric conditions. A trans-log function is a second-order Taylor-series approximation centered at zero. Therefore, prior to the estimation, all of the respective output and input variables are normalized such that $\bar{\ln} X = \bar{\ln} Y = \bar{\ln} t = 0$.

Given the estimators, the elasticity of scale is given by:

$$\eta = \sum_k \frac{\partial \ln D(\boldsymbol{X}, \boldsymbol{Y}^*)}{\partial \ln X_k} = -\sum_k \frac{\partial \ln Y_1}{\partial \ln X_k}.$$

The production technology exhibits constant returns to scale when $\eta = 1$. If $\eta > (<)\ 1$, the technology exhibits increasing (decreasing) returns to scale. The monotonicity condition of the SFODF requires both $\frac{\partial \ln Y_1}{\partial \ln Y^*_m} > 0$ and $\frac{\partial \ln Y_1}{\partial \ln X_l} < 0$, which are reduced to $\beta_m > 0$ and $\alpha_l < 0$ at the mean values of the variables, respectively. Meanwhile, convexity in outputs will be ensured if and only if all the principal minors of the following Hessian matrix are non-negative:

$$H = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1M} \\ h_{21} & h_{22} & \cdots & h_{2M} \\ \vdots & \vdots & \cdots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MM} \end{bmatrix}$$

where $h_{ij} = \frac{\partial^2 D(\boldsymbol{X}, \boldsymbol{Y}^*)}{\partial Y_i^* \partial Y_j^*}$. From equations (5.1) to (5.3), we have:

$$\frac{\partial \ln D(X, Y^*)}{\partial \ln Y_k} = -\frac{\partial \ln Y_1}{\partial \ln Y_k^*} \equiv \beta_k^{TL} \qquad (k = 2,3).$$

Thus, the second derivatives of $D(\boldsymbol{X},\ \boldsymbol{Y}^*)$ are given by:

$$\frac{\partial^2 D(\boldsymbol{X}, \boldsymbol{Y}^*)}{\partial Y_m^{*2}} = -\frac{D(\boldsymbol{X}, \boldsymbol{Y}^*)}{Y_m^{*2}} [\beta_{mm} - \beta_m^{TL}(\beta_m^{TL} + 1)],$$

$$\frac{\partial^2 D(\boldsymbol{X}, \boldsymbol{Y}^*)}{\partial Y_m^* \partial Y_n^*} = -\frac{D(\boldsymbol{X}, \boldsymbol{Y}^*)}{Y_m^* Y_n^*} [\beta_{mn} - \beta_m^{TL} \beta_n^{TL}].$$

We did not impose the convexity constraints when estimating the SFODF (Henningsen and Henning, 2009).

5.3.2. Technical and allocative efficiency

The inefficiency term can be linearly expressed as:

$$-\mathrm{TE}_{it} = \delta_0 + \boldsymbol{Z}_{it}'\boldsymbol{\delta} + \varepsilon_{it}, \qquad (5.4)$$

where $\boldsymbol{Z}_i$ denotes a vector of explanatory variables expected to influence technical efficiency. These variables include the LRR, the AC participation ratio (ACR), and other control variables. The ACR is defined as the number of employees working for crop-farming cooperatives divided by the total labor force engaged in the primary sector. To obtain the consistent and unbiased estimators, we have to estimate equations (5.3) and (5.4) simultaneously (Battese and Coelli, 1995).

We can argue the maximization of farm revenues only when a SFODF satisfies the convexity condition in outputs. The first-order condition of revenue maximization for technically efficient producers ($D_0 = 1$ in equation (5.1)) is given by:

$$\mathrm{MRTS}_{mn} = \frac{p_m}{p_n},$$

where MRTS_{mn} represents the marginal rate of technical substitution, given by:

$$\mathrm{MRTS}_{mn} = \frac{\frac{\partial D(\boldsymbol{X}, \boldsymbol{Y}^*)}{\partial Y_m}}{\frac{\partial D(\boldsymbol{X}, \boldsymbol{Y}^*)}{\partial Y_n}},$$

and p_k denotes output price of sector k. Thus, the allocative efficiency score is defined as:

$$\mathrm{AE}_{mn} = \frac{\mathrm{MRTS}_{mn}}{\frac{p_m}{p_n}} \tag{5.5}$$

When AE_{mn} is larger (smaller) than unity, sector m is over (under)-produced relative to sector n. To put it another way, when AE_{mn} is unequal to unity, the product mix between sectors m and n is allocatively inefficient.

5.3.3. Estimation strategy

While estimating equations (5.3) and (5.4), we must control for potential bias stemming from time-invariant unobservables and the endogeneity problem in the equations. Since panel data are available in this study, we can remove bias arising from time-invariant unobservables by employing a fixed effects model. To overcome the remaining bias associated with endogeneity, we can employ the instrumental variable (IV) estimation method. The Stata command of "xtsfkk" developed by Karakaplan (2017) is very powerful for the present study. The advantage of this command is that it can control for the endogeneity problem in the frontier and/or inefficiency equations in longitudinal settings.[41] In this study, we eliminate the potential estimation bias stemming from endogeneity with respect to the two key variables of LRR and ACR. The instruments must be correlated with LRR and ACR but must not directly affect the technical efficiency.

We use LRR and ACR at the city level, except county i itself, as excluded

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[41] Unlike the standard control function approach, we can estimate parameters with a one-step procedure (Karakaplan and Kutlu, 2017).

instruments of LRR and ACR, following Kung (2002), Li and Ito (2021), Liu et al. (2017), Rao et al. (2020), and others. It is reasonable to consider that LRR at the city level is correlated with that of the county level as the promotion of land exchange has gained momentum nationally since the 2000s. However, it must be unrelated to technical efficiency at the county level. The city-level ACR is also considered to be a valid instrument. After embryonic development in the early 1990s, ACs have evolved nationally since the 2000s. The Chinese central government tried to accelerate this movement by promulgating the FPCL, suggesting that the establishment of ACs was motivated by policy initiatives in a top-down fashion. Considering the extent to which rural people in neighboring counties interact and consult with each other on this policy issue, the participation in ACs at the county level is likely to be associated with ACR at the city level (Li and Ito, 2021). More importantly, AC activities at the city level do not directly affect technical efficiency at the county level.

5.3.4. Data

We primarily draw on three sources of data for this study. The first is Rural Operation and Management Statistics, sourced by the authors from the Department of Agriculture and Rural Affairs, Gansu. This source contains a wealth of statistics regarding land use and its transaction, farmers' participation in agricultural cooperatives, the economic activities of rural households and collectives, and other socioeconomic and sociodemographic information by county. The second data source is the Gansu Rural Yearbook published by the Gansu Statistics Bureau, which provides a broad range of information on the quantity of farm inputs and outputs. The third data source is the Gansu Development Yearbook, from which data on the quantity and price of farm outputs are available. To perform the econometric analysis, we compile a panel dataset for 86 counties from 2013 to 2017.

Table 5.2. Variable descriptions and summary statistics

Variables	Descriptions		Mean	SD
sec. 1 (weight)	Sector 1's production by weight (1,000 tons)	overall		114.8
		between	130.4	114.2
		within		16.1
sec. 2 (weight)	Sector 2's production by weight (1,000 tons)	overall		10.7
		between	8.77	10.4
		within		2.95
sec. 3 (weight)	Sector 3's production by weight (1,000 tons)	overall		191.0
		between	166.8	187.2
		within		41.9
sec. 1 (value)	Sector 1's output value at constant prices (million yuan)	overall		311.6
		between	347.1	309.3
		within		48.1
sec. 2 (value)	Sector 2's output value at constant prices (million yuan)	overall		126.7
		between	68.5	116.2
		within		51.8
sec. 3 (value)	Sector 3's output value at constant prices (million yuan)	overall		474.7
		between	415.6	462.0
		within		118.2
fer	Chemical fertilizer consumption (1,000 tons)	overall		10.4
		between	10.6	10.0
		within		3.00
lab	Total number of workers engaged in primary production (1,000 persons)	overall		40.4
		between	53.6	40.1
		within		5.22
cap	Farm machinery measured by power (1,000 kilowatt hours)	overall		237.1
		between	262.3	229.6
		within		63.1
lad	Contracted land area (1,000 ha)	overall		31.0
		between	39.0	30.9
		within		3.61
time	Year minus 2010	overall		1.42
		between	5.00	0.00
		within		1.42
irri	Irrigated area divided by total contracted land area	overall		0.60
		between	0.50	0.56
		within		0.25

Note: Farm output data are measured by the weight or value at constant prices alternatively.

Table 5.2 presents descriptive statistics of variables used for the estimation of the SFODF. Farm production for the three sectors (*sec. 1*, *sec. 2*, and *sec. 3*), as defined in the

Section 2, is measured by two alternative methods: the weight in tons, and the output value of agriculture at constant prices. As was pointed out in Section 2, China's Statistical Yearbook overestimated the production of vegetables, fruits, and livestock products in some provinces between 2007 and 2016. The Statistical Bureau reported statistically corrected data in 2017 based on the third Agricultural Census in 2016. It was discovered that the degree to which the production of vegetables and fruits was overestimated for this period in Gansu was around 1.7 and 1.4, respectively. Using these coefficients, we re-estimated the county-level data on horticultural output. Further, we removed three counties from the sample whose gross agriculture output value accounted for less than 10% of the primary industry's gross output value.[42]

Factor inputs include fertilizer (*fer*), farm labor (*lab*), farm machinery (*cap*), and contracted farmland (*lad*). Fertilizer is measured by the total chemical fertilizer consumption that is converted to net ingredients (1,000 tons). Farm labor is measured by the total number of workers engaged in crop farming (1,000 persons), which is not obtained directly from the Gansu Development Yearbook. Thus, we first compute the ratio of gross output value of agriculture to that of the primary industry at the county level, and then estimate farm labor by multiplying the ratio by the total labor force in the primary industry. Farm machinery is measured by the total power of agricultural machines (1,000 kilowatt hours) used for agricultural production, which includes the power of the machinery services that are provided by cooperatives or machinery service providers.

Farmland is measured by the total area of contracted land (1,000 ha). When considering multiple cropping in Sector 3, we ideally would have used the sown area instead of contracted land area. However, because the sown area of horticultural land in

[42] The gross output value of agriculture in Gansu, as a whole, accounted approximately for 70% of the recent total, which is followed by animal husbandry with 20%.

Gansu was overestimated between 2007 and 2016, we have used contracted land area instead.[43] Time trend (year minus 2010) is included as a proxy for technological progress. Finally, the variable of irrigation rate (*irri*) measures the irrigated area divided by the total contracted land area. Table 5.2 shows that just half of the contracted land area was irrigated in Gansu, although there is a huge inter-regional variance in *irri*, as shown in Figure 5.1.

5.4. Estimation results and discussion

5.4.1. Estimation result for the SFODF

Tables 5.3 and 5.4 show the estimation results of the model. In addition to trans-log, this study specifies the SFODF as the CD form, in which all quadratic and interaction terms in the right-hand side of equation (5.3) drop. Since all of the output and input variables are normalized, $\frac{\partial\, lnY_1}{\partial\, lnY_m^*}$ and $\frac{\partial\, lnY_1}{\partial\, lnX_l}$ evaluated at the sample mean values of the variables for the trans-log are given by β_m and α_l, respectively, which are comparable to the CD estimators. A joint test of parameters regarding the trans-log terms rejects the null hypothesis of a nested CD production technology ($p > \chi^2 = 0.000$), suggesting that the trans-log form is more appropriate for the SFODF specification. However, considering the advantage of a small number of parameters (parsimonious model), we show the results when the SFODF is specified as the CD form in Tables 5.4.1 and 5.4.2. Further, to check robustness of the estimators, we show the results when the two alternative types of farm production data (weight and real output value) are used for the estimation of equation (5.3).[44]

[43] The total contracted land and sown area in 2017 was 3.34 and 3.68 million ha, respectively (Jiayuguan city excluded).
[44] Lawin and Tamini (2019) measure the farm production by the quantity in kg for the estimation of the SFODF of Beninese agriculture.

The estimated trans-log function satisfies the monotonicity and convexity conditions for more than half of data domains. The CD function also satisfies the monotonicity conditions, as is evident from Tables 5.4.1 and 5.4.2. Moreover, we cannot reject the null hypothesis that the estimated SFODF exhibits constant returns to scale. As is expected, the coefficient of irrigation rate is negative and highly significant, suggesting that an increase in the irrigation rate helps expand the SFODF frontier outward.

5.4.2. Estimation results of the technical inefficiency equation

The test statistic does not reject the null hypothesis regarding the joint exogeneity of LRR and ACR, with the exception that the SFODF is specified as the trans-log form, with farm production being measured by real output value. In the case of rejection, we interpret the estimation results based on endogenous model.[45] However, we present the estimated results when the two variables of LRR and ACR are treated as exogenous and endogenous in Tables 5.3 and 5.4. The lower parts of Tables 5.3 and 5.4 show the estimation results of equation (5.4). As described by Tian and Wan (2000), there exists no formal procedure to be followed when deciding which variables should be included in the inefficiency equation. In addition to LRR and ACR, we use the following two variables, the migration ratio (MR) and the land-labor ratio (LLR), as regressors of the technical inefficiency equation.

Migratory movement of rural people from farm to non-farm sectors may play a role in determining the level of agricultural technical efficiency (Zhang et al., 2016), although previous studies do not provide unambiguous direction on the impact (Feng, 2008). The MR variable measures the number of migrants working outside their home village

[45] There is no weak instrument problem with the city level LRR and ACR because they are strongly correlated with the LRR and ACR at the county level.

continuously for more than six months of the year divided by the total number of FHs. Besides, it is likely that farm production structure is associated with technical efficiency, we used the LLR variable (the land–labor ratio at the county level) as another regressor. Appendix Table 5.1 presents descriptive statistics of variables used for the estimation of the inefficiency equation.

Tables 5.3.1 and 5.3.2 show the estimation results when the SFODF is specified as the trans-log form. When farm production is measured by weight (Table 5.3.1), the null hypothesis of the joint exogeneity cannot be rejected. Thus, we examine the estimation result based on the exogenous model. The estimator of LRR and ACR are negative and significant at the 1% and 10% level, respectively. Thus, our estimation result lends support to the assertion that the development of land rental markets and ACs helps improve the technical efficiency of farm production at the county level. Meanwhile, the other variables, such as MR and LLR have no explanatory power for technical efficiency.

Table 5.3.2 shows the estimation results when the SFODF is specified as the trans-log form, with farm production being measured by real output value. As the null hypothesis of the joint exogeneity is rejected, we examine the estimation result based on the endogenous model. Although the coefficient of LRR is negative and significant at the 1% level, that of ACR is positive but not significant. Thus, we cannot say for certain that ACs serve as a facilitator of raising technical efficiency. The coefficient of LLR is positive and significant at the 10% level, suggesting that an increase in farm size at the county level has a detrimental effect on technical efficiency. This is consistent with Gautam and Ahmed (2019) who estimate a standard stochastic frontier production function using FH data in Bangladesh. Their result indicates that large farms are more technically inefficient than small farms.

Table 5.3.1. Estimation result of the trans-log SFODF (output: weight)

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Equation (5.3)				
ln (fer)	-0.243***	0.043	-0.246***	0.043
ln (lab)	-0.215***	0.046	-0.217***	0.047
ln (cap)	0.014	0.034	0.018	0.035
ln (lad)	-0.462***	0.065	-0.469***	0.065
ln (sec. 2)	0.072***	0.015	0.077***	0.016
ln (sec. 3)	0.251***	0.019	0.247***	0.019
ln (time)	0.011	0.030	0.016	0.032
ln (fer)*ln (lab)	0.048	0.047	0.037	0.048
ln (fer)*ln (cap)	0.167***	0.057	0.187***	0.059
ln (fer)*ln (lad)	0.107	0.079	0.130*	0.079
ln (lab)*ln (cap)	-0.030	0.055	-0.016	0.056
ln (lab)*ln (lad)	0.194	0.148	0.192	0.146
ln (cap)*ln(lad)	-0.193***	0.074	-0.200***	0.075
ln (fer)*ln (fer)	-0.184***	0.044	-0.205***	0.045
ln (lab)*ln (lab)	-0.209	0.151	-0.213	0.149
ln (cap)*ln (cap)	-0.068	0.071	-0.108	0.075
ln (lad)*ln (lad)	-0.136	0.160	-0.146	0.160
ln (fer)*ln (sec. 2)	0.045**	0.019	0.055***	0.020
ln (lab)*ln (sec. 2)	-0.085***	0.033	-0.084**	0.033
ln (cap)*ln (sec. 2)	0.025	0.021	0.018	0.022
ln (lad)*ln (sec. 2)	-0.062	0.041	-0.070*	0.040
ln (fer)*ln (sec. 3)	0.046**	0021	0.043**	0021
ln (lab)*ln (sec. 3)	-0.056**	0.028	-0.047*	0.028
ln (cap)*ln (sec. 3)	-0.035	0.023	-0.037	0.023
ln (lad)*ln (sec. 3)	-0.005	0.032	-0.014	0.032
ln (fer)*ln(time)	0.048	0.047	0.036	0.048
ln (lab)*ln(time)	0.003	0.046	-0.009	0.046
ln (cap)*ln(time)	-0.209***	0.047	-0.199***	0.048
ln (lad)*ln(time)	0.070	0.062	0.086	0.064
ln (sec. 2)*ln(sec. 3)	-0.051***	0.011	-0.052***	0.010
ln (sec. 2)*ln (sec. 2)	0.084***	0.016	0.079***	0.016
ln (sec. 3)*ln (sec. 3)	0.103***	0.016	0.102***	0.016
ln(sec. 2)*ln(time)	-0.019	0.021	-0.022	0.021
ln (sec. 3)*ln(time)	-0.025	0.021	-0.020	0.021
ln (time)*ln (time)	0.589***	0.192	0.573***	0.195
irri	-0.548***	0.062	-0.536***	0.063
Equation (5.4)				
Land–rental ratio	-1.512***	0.413	-2.044***	0.543
AC participation ratio	-1.168*	0.631	-0.464	0.873
Migration ratio	0.230	0.260	0.196	0.264
Land–labor ratio	0.086	0.069	0.068	0.067
Joint endogeneity test	—	—	$\chi 2=2.67$	p=0.263
Number of observations	390		390	
Log likelihood	173.8		1080.0	
Mean technical efficiency	0.697		0.696	

Note:*, ** and *** indicate statistical significance at the 1%, 5% and 1% levels, respectively.

Table 5.3.2. Estimation result of the trans-log SFODF (output: real output value)

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Equation (5.3)				
ln (*fer*)	-0.230***	0.045	-0.222***	0.046
ln (*lab*)	-0.264***	0.049	-0.246***	0.050
ln (*cap*)	-0.025	0.038	-0.030	0.040
ln (*lad*)	-0.452***	0.074	-0.495***	0.076
ln (*sec. 2*)	0.079***	0.016	0.083***	0.016
ln (*sec. 3*)	0.287***	0.020	0.276***	0.021
ln (*time*)	0.011	0.033	0.025	0.036
ln (*fer*)*ln (*lab*)	0.058	0.055	0.005	0.052
ln (*fer*)*ln (*cap*)	0.163***	0.061	0.214***	0.064
ln (*fer*)*ln (*lad*)	0.129	0.090	0.208**	0.087
ln (*lab*)*ln (*cap*)	-0.041	0.059	-0.001	0.060
ln (*lab*)*ln (*lad*)	0.227*	0.128	0.248*	0.128
ln (*cap*)*ln(*lad*)	-0.108	0.079	-0.149*	0.077
ln (*fer*)*ln (*fer*)	-0.179***	0.047	-0.231***	0.047
ln (*lab*)*ln (*lab*)	-0.312**	0.132	-0.308**	0.127
ln (*cap*)*ln (*cap*)	-0.094	0.078	-0.175**	0.083
ln (*lad*)*ln (*lad*)	-0.268*	0.152	-0.336**	0.160
ln (*fer*)*ln (*sec. 2*)	0.022	0.020	0.049**	0.020
ln (*lab*)*ln (*sec. 2*)	-0.058*	0.030	-0.059*	0.031
ln (*cap*)*ln (*sec. 2*)	0.002	0.021	-0.010	0.022
ln (*lad*)*ln (*sec. 2*)	-0.021	0.039	-0.043	0.037
ln (*fer*)*ln (*sec. 3*)	0.060***	0023	0.060***	0023
ln (*lab*)*ln (*sec. 3*)	-0.050*	0.030	-0.028	0.029
ln (*cap*)*ln (*sec.* 3)	-0.009	0.024	-0.013	0.025
ln (*lad*)*ln (*sec. 3*)	-0.025	0.035	-0.046	0.037
ln (*fer*)*ln(*time*)	0.097*	0.051	0.079	0.053
ln (*lab*)*ln(*time*)	0.007	0.050	-0.015	0.052
ln (*cap*)*ln(*time*)	-0.133**	0.053	-0.108*	0.056
ln (*lad*)*ln(*time*)	-0.042	0.063	-0.024	0.067
ln (*sec. 2*)*ln(*sec. 3*)	-0.047***	0.011	-0.049***	0.011
ln (*sec. 2*)*ln (*sec. 2*)	0.064***	0.014	0.055***	0.014
ln (*sec. 3*)*ln (*sec. 3*)	0.099***	0.014	0.101***	0.013
ln(*sec. 2*)*ln(*time*)	0.012	0.021	0.011	0.022
ln (*sec. 3*)*ln(*time*)	-0.054**	0.021	-0.045**	0.022
ln (*time*)*ln (*time*)	0.454**	0.216	0.418*	0.226
irri	-0.423***	0.069	-0.434***	0.072
Equation (5.4)				
Land–rental ratio	-1.291**	0.516	-2.478***	0.662
AC participation ratio	-0.718	0.890	1.285	0.952
Migration ratio	0.411	0.308	0.266	0.320
Land–labor ratio	0.144***	0.054	0.098*	0.051
Joint endogeneity test	—	—	χ^2=11.24	p=0.004
Number of observations	390		390	
Log likelihood	140.8		1067.3	
Mean technical efficiency	0.639		0.701	

Note: *, ** and *** indicate statistical significance at the 1%, 5% and 1% levels, respectively.

Table 5.4.1. Estimation result of the Cobb-Douglas SFODF (output: weight)

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Equation (5.3)				
ln (*fer*)	-0.037*	0.019	-0.034*	0.020
ln (*lab*)	-0.219***	0.061	-0.229***	0.062
ln (*cap*)	-0.084***	0.031	-0.082**	0.032
ln (*lad*)	-0.579***	0.070	-0.573***	0.070
ln (*sec. 2*)	0.079***	0.018	0.077**	0.018
ln (*sec. 3*)	0.161***	0.023	0.162**	0.023
ln (*time*)	0.087***	0.031	0.086***	0.034
irri	-0.558***	0.057	-0.566***	0.058
Equation (5.4)				
Land–rental ratio	-1.676***	0.388	-1.515***	0.517
AC participation ratio	-2.778***	0.416	-3.071***	0.607
Migration ratio	-0.152	0.219	-0.148	0.220
Land–labor ratio	-0.004	0.039	-0.003	0.039
Joint endogeneity test	—	—	χ^2=0.62	p=0.733
Number of observations	390		390	
Log likelihood	81.4		886.7	
Mean technical efficiency	0.621		0.622	

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 5.4.2. Estimation result of the Cobb-Douglas SFODF (output: real output value)

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Equation (5.3)				
ln (*fer*)	-0.029	0.020	-0.031	0.021
ln (*lab*)	-0.247***	0.042	-0.246***	0.042
ln (*cap*)	-0.061*	0.033	-0.065*	0.034
ln (*lad*)	-0.600***	0.067	-0.598***	0.066
ln (*sec. 2*)	0.097***	0.017	0.096***	0.017
ln (*sec. 3*)	0.175***	0.020	0.172***	0.021
ln (*time*)	0.103***	0.032	0.098***	0.034
irri	-0.498***	0.059	-0.493***	0.059
Equation (5.4)				
Land–rental ratio	-1.595***	0.453	-1.536**	0.598
AC participation ratio	-3.372***	0.547	-3.153***	0.684
Migration ratio	0.030	0.273	0.016	0.278
Land–labor ratio	0.029	0.039	0.027	0.040
Joint endogeneity test	—	—	χ^2=0.46	p=0.796
Number of observations	390		390	
Log likelihood	62.2		868.5	
Mean technical efficiency	0.657		0.660	

Note: ** and *** indicate statistical significance at the 5% and 1% levels, respectively.

When the SFODF is specified as the CD form, the null hypothesis of the joint exogeneity cannot be rejected. However, the estimation results are robust in the sense that the coefficients of LRR and ACR are negative and highly significant, irrespective of whether the exogenous or endogenous model is used and how farm production is measured. Unlike the estimation results based on the trans-log form, LLR has nothing to do with technical efficiency.

Tables 5.3 and 5.4 show that migration has no explanatory power for technical efficiency in all cases. Due to the massive migration of rural young people to cities, Chinese agriculture is currently undertaken by women and elderly people left behind in the countryside, resulting in the "feminization" and "graying" of agriculture (Ye, 2015). This may impede improvement of technical efficiency. Meanwhile, it is likely that the migratory movement of rural people mitigates the production inefficiency associated with agricultural surplus labor (Chen et al., 2009). Our estimation result suggests that the two effects on technical efficiency cancel each other out.[46] Besides MR and LLR, we examine other control variables for the inefficiency regression, such as the ratio of part-time FHs and of contract certificate holders, and the share of small-scale FHs. We conclude, however, that these variables are neither statistically significant nor influential to the final results.

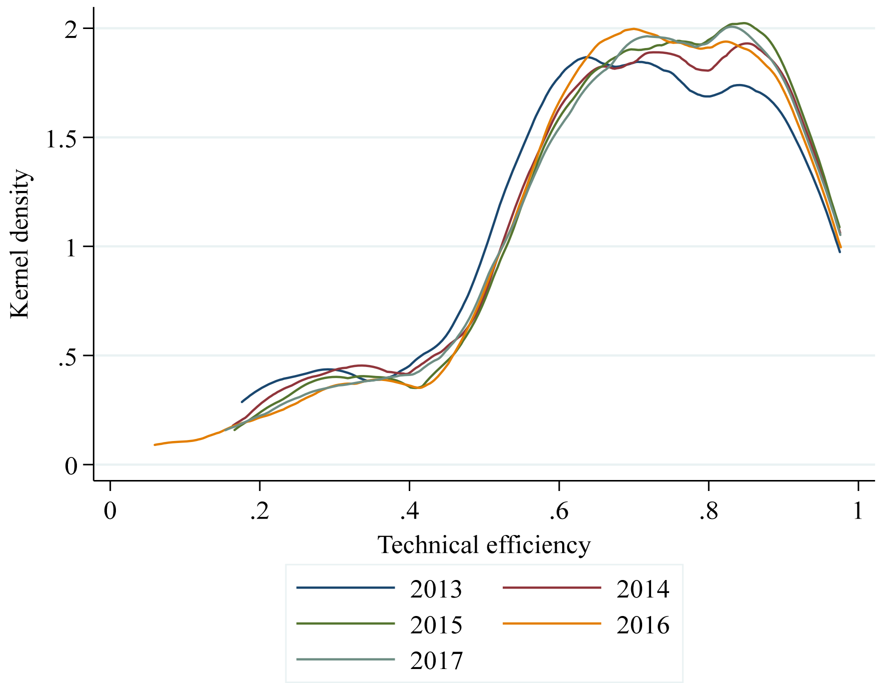

Figure 5.4. Estimated technical efficiency distributions over time

Figure 5.4 illustrates the kernel density of the estimated technical efficiency scores by year. To create this figure, we used the estimation results when the SFODF is specified as the trans-log form, with farm production being measured by real output value. The distributions are characterized by negative skew with the tail on the left. Table 5.5 shows the provincial average of technical efficiency, its standard deviation, and the minimum and maximum scores by year. Overall, the average efficiencies are within 0.6–0.7, meaning that farm production in Gansu could be increased by 30–40% by performing farm management more efficiently. A close look

[46] Yang et al. (2016) relying on a stochastic frontier model claim that neither migration nor local off-farm employment has a negative effect on the technical efficiency of China's grain production.

at Table 5.5 reveals that the average technical efficiency scores show an increasing trend between 2013 and 2017. This supports our empirical finding in this study that land rental markets have developed in Gansu over the years, and have played a central role in improving technical efficiency.

Table 5.5. Average technical efficiency

Farm production	Function form		Mean	SD	Min	Max
		2013	0.680	0.208	0.200	0.977
		2014	0.692	0.205	0.210	0.977
Weight	Trans-log	2015	0.703	0.200	0.217	0.976
		2016	0.702	0.200	0.095	0.978
		2017	0.709	0.195	0.216	0.977
		2013	0.685	0.198	0.176	0.975
		2014	0.701	0.195	0.164	0.976
Real output value	Trans-log	2015	0.710	0.190	0.166	0.975
		2016	0.700	0.197	0.060	0.976
		2017	0.707	0.191	0.154	0.976
		2013	0.589	0.233	0.099	0.965
		2014	0.608	0.230	0.120	0.969
Weight	CD	2015	0.624	0.223	0.117	0.970
		2016	0.638	0.216	0.127	0.970
		2017	0.642	0.214	0.126	0.96
		2013	0.625	0.228	0.132	0.948
		2014	0.645	0.223	0.149	0.949
Real output value	CD	2015	0.659	0.217	0.151	0.948
		2016	0.676	0.212	0.167	0.952
		2017	0.678	0.210	0.156	0.951

5.4.3. Allocative efficiency

As the estimated SFODF satisfies the convexity condition for the most data domains, we argue the crop-choice rationality based on the estimated allocative efficiency. Figure 5.5 shows the provincial average of allocative efficiency between 2013 and 2017.[47] The scores of

[47] Using the provincial average values of outputs and inputs, we estimate the allocative efficiency based on equation (5.5).

$\mathrm{AE}_{mn}(V)$ and $\mathrm{AE}_{mn}(W)$ represent the allocative efficiency when farm production is measured by real output value and weight in tons, respectively.[48] There is no serious contraction between the estimated $\mathrm{AE}_{mn}(V)$ and $\mathrm{AE}_{mn}(W)$. As evidenced by equation (5.5), we have $\mathrm{AE}_{13} = \mathrm{AE}_{12} \times \mathrm{AE}_{23}$, meaning that the pairwise allocative efficiency scores are not independent. Figure 5.5 illustrates that AE_{12} was larger than unity but moved close to unity in 2016, suggesting that the extent of over-production of Sector 1 relative to Sector 2 improved somewhat during the period examined. However, such a trend was reversed in 2017. Meanwhile, AE_{23} was also larger than unity and increased between 2013 and 2016, suggesting that the extent of over-production of Sector 2 relative to Sector 3 worsened during the period, and thereafter improved slightly.

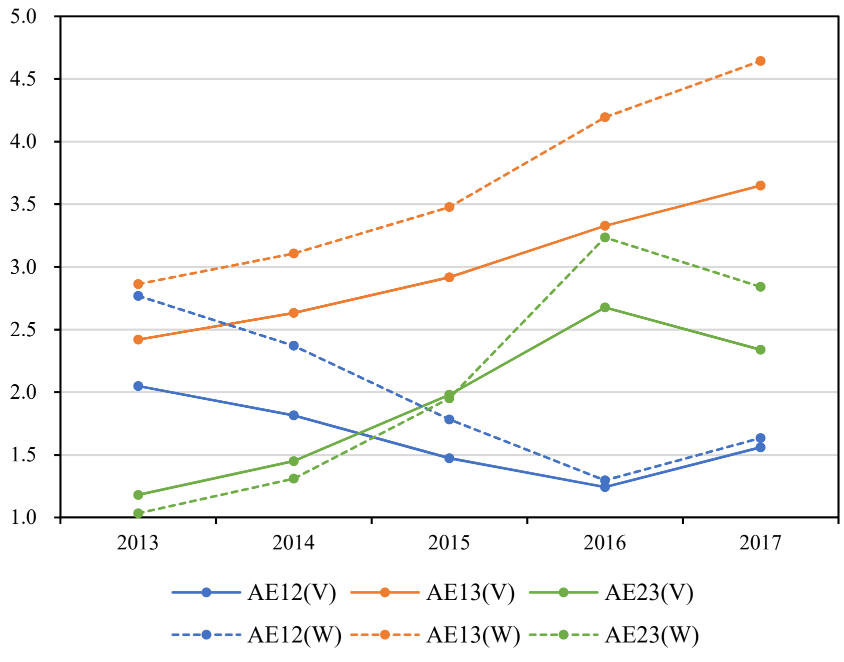

Figure 5.5. Changes in allocative efficiencies

Most noteworthy in Figure 5.5 is that the score of AE_{13} was far larger than unity and increased consistently during the period concerned, suggesting a substantial degree of

[48] As noted in Section 3, the CD form does not satisfy the convexity condition by nature. Thus, we use the trans-log function for the computation of allocative efficiency.

overproduction of Sector 1 relative to Sector 3.[49] As shown in Appendix Table 5.2, the value of MRTS_{13} demonstrated an increasing trend between 2013 and 2017. On the other hand, the relative price of $\frac{p_1}{p_3}$ decreased during the period, the reason for which was discussed at length in Section 2. We understand from equation (5.5) that an increase in AE_{13} above unity is caused by producers' failure in swiftly adjusting product mix in order to maximize their farm revenue. As noted in Section 2, the central government took the initiative to encourage farmers in western China to grow fresh fruits and vegetables. Nevertheless, they did not respond immediately to either the market signal of relative price change or the government's directive toward crop diversification. It is considered that some technical and institutional factors must be involved, but at this stage we cannot ascertain specific factors that prevent farmers from behaving rationally.

5.5. Conclusion and policy implications

Agricultural economists take it for granted that a decentralized and market-oriented means to transfer land-use rights could not only raise the wealth of lessors and lessees but also enhance the overall efficiency of land use and agricultural productivity. However, a caveat is needed before applying this theoretical prediction to the Chinese context because NFHPs, such as ACs and private enterprises, have recently entered the farming business as cultivators. To the extent that such organizations underperform FHs in terms of production efficiency, land consolidation by NFHPs does not necessarily deliver the desired outcome. As such, we empirically examine the causal effect of land rental on farm production efficiency by estimating a SFODF. Previous studies that explore the relationship between farmland exchange or administrative reallocation and technical efficiency in Chinese agriculture delve deeply into the question of whether FH

[49] This is consistent with Ito (2015), which computes the allocative efficiency using China provincial data between 1991 and 2009.

land rental behavior improves technical efficiency at the individual level. Thus, these studies do not highlight the market outcome of land exchange.

Our estimation result illustrates that the development of land rental markets has a significant effect on raising technical efficiency scores at the aggregate level. This offers unambiguous evidence that land usufruct has accumulated in the hands of cultivators whose agricultural productivity is relatively high. Meanwhile, our analysis weakly supports the assertion that ACs are an important avenue for farm producers to increase production efficiency. Therefore, there is no serious inconsistency with previous studies that show that average technical efficiency is consistently higher for participants in ACs relative to non-participants.

This study shows that cereals are excessively over-produced relative to vegetables and fruits from the perspective of farm revenue maximization. The Chinese government issued a policy directive promoting crop diversification and selective expansion of farm products in western China, which aimed to narrow the inter-regional income gap. Nevertheless, our quantitative analysis suggests that there is room for further increase in farm revenues of Gansu's producers by shifting resources away from cereal toward horticultural production.

We acknowledge that our empirical results cannot be generalized at the national level as the sample is limited to just one province in northwest China, which is not necessarily representative of the entire country. However, the examined issues are likely to be of relevance to other parts of rural China characterized by similar underdeveloped rural societies. Ensuring the efficient use of scarce resources poses serious challenges to pro-poor agricultural growth in China and other developing countries. In this context, further research efforts should be devoted to the analysis of the economic impact of land rental markets and agricultural cooperatives. Needless to say, agricultural growth is integral to Gansu's future development; raising farm income is not only important from the perspective of farmers but is most certainly in the public interest.

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Appendix Table 5.1. Variable descriptions and summary statistics

Variables	Descriptions		Mean	SD
Land–rental ratio	Land rental area divided by contracted land area	overall between within	0.24	0.13 0.12 0.06
Agricultural cooperative ratio	Number of employees working for agricultural cooperatives divided by labor force engaged in the primary sector	overall between within	0.11	0.11 0.11 0.05
Migration ratio	Number of migrants working outside their home village continuously for more than six months out of the year divided by the total number of FHs	overall between within	0.75	0.27 0.26 0.09
Land–labor ratio	Contracted land area divided by farm labor force	overall between within	0.94	1.50 2.16 0.41

Source: Rural Operation and Management Statistics (Department of Agriculture and Rural Affairs, Gansu).

Appendix Table 5.2. MRTSs and relative prices

	$MRTS_{12}$	$MRTS_{13}$	$MRTS_{23}$	p_1/p_2	p_1/p_3	p_2/p_3
2013	2.05	2.42	1.18	1.00	1.00	1.00
2014	1.88	2.39	1.27	1.03	0.91	0.88
2015	1.42	2.49	1.75	0.96	0.85	0.88
2016	1.17	2.86	2.43	0.94	0.86	0.91
2017	1.54	3.11	2.02	0.99	0.85	0.86

Note: We compute MRS_{mn} based on the SFODF, with farm production being measured by real output value.

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Chapter 6

Multiple roles of China's agricultural cooperatives in improving farm technical efficiency and promoting green agriculture

Abstract

The establishment of agricultural cooperatives (ACs) is widely viewed as an institutional arrangement to remove constraints that prevent smallholders from accessing profitable business opportunities in agriculture. ACs in China offer a wide range of agricultural services within the framework of contract farming and vertical coordination. This study's main objective is to empirically examine the multiple roles of China's ACs in improving farm production efficiency and conserving the agricultural environment. Considering that the services provided by ACs can be broadly divided into biological (BC) services and mechanical (M) services, we specify a stochastic frontier production function in a special form called the separated Cobb-Douglas. The empirical results present unambiguous evidence that Chinese ACs play essential roles in increasing agricultural productivity and protecting agroecological environment by influencing the BC and M technical efficiency of farm production. The establishment of ACs raised technical efficiency, especially for the BC process. Since the excessive use of chemical fertilizer has become a critical issue impeding the realization of sustainable agriculture in rural China, an improvement in BC technical efficiency would help solve this problem. However, the involvement of ACs as vertical coordinators is demonstrated to have conflicting consequences for the BC and M technical efficiency improvements.

Keywords: agricultural cooperative; green agriculture; technical efficiency.

6.1. Introduction

Numerous studies have empirically examined the effect of agricultural cooperatives (ACs) on the rural population's economic interests. Most of them have showed that such organizations help smallholders modernize agricultural production technologies, provide them with high-quality inputs, and access to profitable product markets. Furthermore, some ACs play a role in mediating land exchanges among farmers, thereby, helping rural communities to use their farmlands more efficiently. A significant body of literature have shown that ACs fulfil an important role in enhancing the overall economic efficiency and welfare of rural societies (Abebaw and Haile, 2013; Desai and Joshi, 2014; Hill et al., 2021; Ito et al., 2012; Lin et al., 2022; Ma et al., 2018a; Michalek et al., 2018; Verhofstadt and Maertens 2014; Zhang et al., 2020).

ACs provide various services within the framework of their contract with participating farmers, which allows farmers to exercise their farm management autonomy. Meanwhile, through vertical coordination, which is another form of contract, ACs establish large-scale agribusiness firms by renting farmlands from others and hiring locals as employees (Ba et al., 2019; Zhong et al., 2018). In either case, ACs are considered to serve as effective pathways for modernizing agricultural production technology, transforming the agrarian structure, and improving the economic status of rural populations. However, few studies have simultaneously discussed the impact of ACs on farmer's economic well-being and the conservation of agricultural environment.

Thus, this study aims to empirically examine these bimodal issues, focusing on the ACs in rural China. This is a relevant topic because the government advocated for the promotion of green agricultural development, which was formally endorsed in the 'No. 1 Document' issued jointly by the Central Committee of the Communist Party and the State Council in 2017. Methodologically, we estimate the stochastic frontier production function (SFPF) using village survey data collected by the authors. To correct the potential bias in the estimators stemming from the endogeneity problem, we employ an instrumental variable estimation method.

Following ACs' embryonic development among voluntary rural groups in the early 1990s, the central government of China accelerated this cooperative movement by promulgating the Farmers' Professional Cooperatives Law in 2007. Currently, alongside the promotion of green agriculture, the agricultural development led by ACs is a central pillar of the country's policy programs. Although the ACs in China include a wide range of organizations such as those established by groups of farmers, local governments, and private entrepreneurs (Ito et al., 2012), their services can be broadly divided into two types: biochemical (BC) services and machinery or mechanical (M) services.

BC services primarily contribute to an increase in land productivity or crop yields by efficiently using intermediate inputs. Specifically, China's ACs have recently started providing farmers with BC services that are aimed at promoting environment-friendly agriculture (Liu and Wu, 2022). This is closely associated with the fact that, in 2015, China's central government embarked on a project that curbs an excessive use of chemical fertilizers. Meanwhile, M services contribute to reduced manual work through the modernization of production techniques. This may improve the efficiency of farm machinery use if farm mechanization is accompanied by farm-size enlargement. Some ACs provide agricultural machinery services to smallholders through which they can outsource the production process of ploughing, planting, and harvesting (Qiu et al., 2021). Other ACs serve as central facilitators of land exchanges among farm households, or enter the farming business as cultivators by renting land from others (Cheng et al., 2019; Huang and Ding, 2016; Li and Ito, 2021). Overall, China' ACs offer a wide range of services within the framework of contract farming and vertical coordination, which is considered to exert a critical impact on farm production efficiency and agricultural environment.

This study's contribution is twofold. First, it empirically assesses land rental development's impact on technical efficiency at the village level. As mentioned earlier, Chinese ACs are deeply involved in land rental activities, both directly (as vertical coordinators) and indirectly (as intermediaries for land exchanges), which would positively affect land-use efficiency. However, to the best of our knowledge, few attempts have been made to explore the contribution of ACs in this direction; thus, our study fills this important gap in the literature. Second, AC involvement in farm production may have conflicting consequences for improving BC and M technical efficiencies (Zhong et al., 2018). To address this analytical challenge, this study specifies a production function in a special form called the separated Cobb-Douglas (SCD). Although it has not been frequently used in quantitative studies, the SCD form is well suited to identify BC and M processes separately.

The remainder of this study is structured as follows. Section 2 provides the background information on ACs, agricultural use of fertilizers, and land rental in rural China. Section 3 presents a theoretical model and the data processing required for econometric analysis. Section 4 presents the estimation results. Finally, Section 5 concludes the study with a summary of the findings and draws the policy implications.

6.2. Research background

6.2.1. Agricultural cooperatives

The establishment of ACs in China is widely viewed as an institutional arrangement to remove constraints that prevent smallholders from accessing profitable business opportunities in agriculture (World Bank, 2006). After the Farmers' Professional Cooperatives Law was enacted, ACs in China have developed rapidly. Table 6.1 shows that the total number of ACs increased 85 times, from 26,000 in 2007 to 2.2 million in 2019. Additionally, more than 122 million farmers participated in ACs in 2019, implying that 62.7% of the workforce in the primary industry became members of the organizations. The average membership for each AC increased from 13 in 2007 to 72 in 2014, and then decreased to 55 in 2019. In the Chinese context, Ma et al. (2018b) propose that ACs help increase crop yields by disseminating information to contracted farmers regarding how to use high-quality inputs effectively. These services are occasionally provided, even to non-contracted farmers, under a system referred to as *daidong* in China (Ito et al., 2012; Ruan et al., 2017). This system originated from the idea of an equal distribution of the economic benefits of ACs in the rural society. If this spill over is widespread in rural China, the effect of increasing crop yield should be expected ubiquitously, regardless of the extent to which ACs are densely established in the region.

Table 6.1. Agricultural cooperatives and membership in China

	Number of cooperatives (10,000)	Total membership size (10,000)	Cooperative participation rate (%)	Average membership size (person)
2007	2.60	35	0.1	13
2008	11.09	142	0.5	13
2009	24.64	392	1.4	16
2010	37.91	716	2.6	19
2011	52.17	1,196	4.5	23
2012	68.89	2,373	9.2	34
2013	98.24	2,951	12.2	30
2014	128.88	9,227	40.5	72
2015	153.11	10,090	46.0	66
2016	179.40	10,667	49.6	59
2017	196.90	11,243	53.7	57
2018	217.30	n.a.	n.a.	n.a.
2019	220.10	12,200	62.7	55

Sources: Huang and Liang (2018); China Statistical Yearbook; Farmers' Daily; Central government's website.
Note: The participation rate is given by the total membership size divided by the total number of employees in the primary industry.

6.2.2. Use of chemical fertilizer

China is the world's largest consumer of agricultural fertilizers; in 2019, it used approximately 25% of world's fertilizers by weight of nutrients although China occupied only 9% world's cropland area. The excessive use of chemicals adversely affects the environment in the form of eutrophication and air pollution (Chen et al., 2014; Gu et al., 2014). Nitrogen (N), phosphorus (P), and potassium (K) are three primary nutrients in commercial fertilizers used worldwide. Excesses of nitrogen and phosphate oxidation could have serious negative impacts on air, water, and soil. More specifically, high concentrations of N and P can lead to the formation of toxic nitrates in groundwater (Ju et al., 2006) and eutrophication of surface waters (Le et al., 2010). In addition, the overuse of N also increases the emission of acidifiers and greenhouse gases as well as a loss of biodiversity (Kahrl et al., 2010).

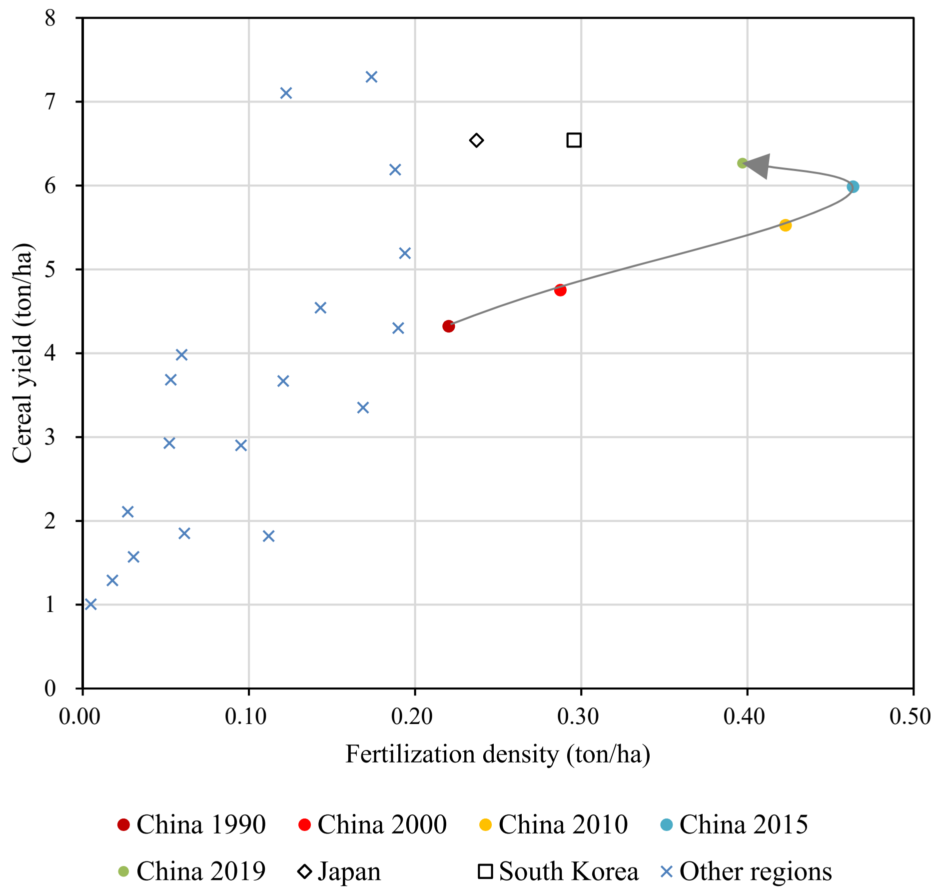

Figure 6.1. Relationship between fertilization density and cereal yield

Source: FAOSTAT (Food and Agriculture Organization of the United Nations).

Note: Fertilization density is measured by the weight of nitrogen, phosphate, and potash divided by arable land area. Other regions include Eastern Africa, Middle Africa, Northern Africa, Southern Africa, Western Africa, Northern America, Central America, Caribbean, Central Asia, Southern Asia, South-eastern Asia, Western Asia, Eastern Europe, Northern Europe, Southern Europe, Western Europe, and Oceania.

Figure 6.1 shows the relationship between the fertilization density and cereal yield in various countries and regions in 2019. As explained in Section 3, the relationship between the fertilization density and cereal yield accurately represents BC's technical process. Northern America and Western Europe maintain the highest cereal yield at moderate fertilization densities, which means that the two regions are superior to the others in terms of BC technical efficiency. The fertilization density in China increased significantly from 0.22 ton/ha in 1990 to 0.46 ton/ha in 2015, while the cereal yield also increased from 4.31 ton/ha to 5.99 ton/ha. However, the efficiency of fertilizer use in China is not as high as that in other Asian countries such as Japan and South Korea. With increasing pressures to abate agricultural-related pollutions, the Chinese central government launched the 'action plan for the zero growth of fertilizer use' in 2015, aiming to achieve a zero growth of chemical fertilizer use for key crops by 2020. In fact, as shown in Figure 6.1, between 2015 and 2019, the trend of increasing fertilization density reversed without reducing cereal yield significantly.

6.2.3. Development of land rental markets and farm machinery use

Chinese agriculture is known to be characterized by small-scale farm sizes; it had 0.57 ha arable land per agricultural labor force in 2018, which is much lower than the world average of 1.49 ha per person (FAOSTAT and World Bank Development Indicators). Under the current land tenure system in China, farmland is owned by rural collectives, and farmland sales are strictly prohibited. Thus, agricultural producers can only expand their farm size by renting land from other farmers. The Chinese government has implemented several policy programs to promote farmland consolidation via rental activities over recent years.

As emphasized in previous chapters, an important institutional reform implemented recently for this policy goal is 'the separation of three rights' scheme, which conceptually divides rural land rights into three components: non-tradable property rights, non-tradable contractual rights, and tradable land-use rights. Property rights are held by rural collectives; contract rights are the rights of individual households to use collectively owned lands; and land-use rights are their rights to use land and obtain income from their contracted land. Under this system, the farmers who are planning to stop farming have voluntarily rent out their land-use rights, because their contract rights are intact (Li and Ito, 2021). With these institutional reforms, competent farmers, ACs, and large-scale agribusiness firms (dragon head enterprises) could rent farmland, thereby enlarging their farm sizes. From 2011 to 2017, the percentage of farmland rented by ACs and dragon head enterprises increased from 21.8% to 32.5% nationwide, whereas the comparable figures for farm households are 67.6% and 57.5%, respectively (China Agriculture Yearbook).[50] ACs provide some individual producers with farm machinery services or enter farm business as cultivators, which would improve the M technical efficiency in agriculture, in the process of their farm-size enlargement. Jiang et al. (2020) claim that ACs' deep involvement in land rental combined with the efficient use of farm machinery has a positive effect on the energy-environmental performance of farm production.

6.3. Methodology and data

6.3.1. The SCD frontier function

The Cobb-Douglas (CD) or trans-log form has been most widely used to estimate the production function in an econometric analysis. However, considering the possibility that AC involvement in agriculture may have conflicting consequences for improving BC and M technical efficiencies, this study specifies the production function in a different form. We consider the following successive sub-processes in agricultural production (Evenson and Kislev, 1975; Kislev and Peterson, 1982):

[50] The farm households' figures include those of 'family farms'. Different from the general concept in other countries, 'family farms' in China are relatively large farms with family members being the main labor force engaged in farm production and sustaining their livelihood mainly through agriculture.

$$Q = f[f_m(L,K), f_b(V,S)], \tag{6.1}$$

where $f_m(L,K)$ represents M production process, in which L and K denote labor and capital input, respectively, and $f_b(V,S)$ represents the BC production process, in which V and S denote fertilizer and cultivated area, respectively. M technology is produced in the first stage, and is combined in the second stage with the intermediate input (fertilizer); that is, $S = G(L,K)$ and $Q = F(V,S)$. Mundlak (2005) and Grabowski and Self (2022) also argue that crop production technology is characterized by the BC and M processes.

To examine the effects of ACs and other factors on technical efficiency, this study employs an SFPF approach by specifying it in the following SCD form (Egaitsu, 1979; Ito, 2010; Ito et al., 2013) and assumes that the empirical model can be weakly separable between BC and M production processes:

$$Q_i = F(V_i, S_i) = \exp(\alpha_0) V_i^{\alpha_V} S_i^{\alpha_S} \xi_{bi} \exp(v_{bi}), \tag{6.2}$$

$$S_i = G(L_i, K_i) = \exp(\beta_0) L_i^{\alpha_L} K_i^{\alpha_K} \xi_{mi} \exp(v_{mi}), \tag{6.3}$$

where i is a village index, and ξ_{ji} $(j = b, m)$ and v_{ji} $(j = b, m)$ represent the level of technical efficiency and random shock, respectively. It is assumed that v_{bi} and v_{mi} are independent and identically distributed (i.i.d.), with mean zero and variance of σ_{vb}^2 and σ_{vm}^2, respectively. Meanwhile, it is assumed that $0 < \xi_{ji} \leq 1$, implying that technical efficiency is strictly positive and equal to one or less. The parameter restrictions for well-behaved production functions are $0 < \alpha_k < 1$ ($k =$ V, S, L, K). If $\alpha_V + \alpha_S = 1$ in equation (6.2), land productivity (Q/S) exhibits diminishing returns to the fertilization density (V/S), which is also known as a fertilizer response curve in crop production. Equation (6.3) indicates that labor and capital (farm machinery) inputs are used as mutual substitutes to cultivate the land area of S, which involves a mechanical technology that characterizes crop production.

Taking the natural logarithm of both sides of equations (6.2) and (6.3), we have

$$\ln Q_i = \alpha_0 + \alpha_V \ln V_i + \alpha_S \ln S_i - u_{bi} + v_{bi}, \tag{6.4}$$

$$\ln S_i = \beta_0 + \alpha_L \ln L_i + \alpha_K \ln K_i - u_{mi} + v_{mi}, \tag{6.5}$$

where $u_{ji} = -\ln\xi_{ji}$ $(j = b, m)$. From $0 < \xi_{ji} \leq 1$, we have $u_{ji} \geq 0$. Thus, the BC and M technical efficiencies can be calculated as $\text{TE}_{bi} = \exp(-u_{bi})$ and $\text{TE}_{mi} = \exp(-u_{mi})$, respectively. The terms u_{bi} and u_{mi} are i.i.d. with $N^+(\mu_b, \sigma_{ub}^2)$ and $N^+(\mu_m, \sigma_{um}^2)$, respectively. The two components *u* and *v* are also assumed to be distributed independently of one another, that is, $\sigma_{uv} = 0$. The formula that predicts the technical efficiency is provided by Karakaplan (2017).

It is assumed that the inefficiency terms of BC and M are linearly expressed as

$$-\text{TE}_{bi} = \delta_b + \boldsymbol{Z}_i' \boldsymbol{\delta}_b + \varepsilon_{bi} \tag{6.6}$$

$$-\text{TE}_{mi} = \delta_m + \boldsymbol{Z}_i' \boldsymbol{\delta}_m + \varepsilon_{mi} \tag{6.7}$$

where $\boldsymbol{Z}$ denotes a vector of explanatory variables expected to influence BC and M technical efficiencies. To obtain consistent and unbiased estimators, we must estimate the production functions and inefficiency equations simultaneously (Battese and Coelli, 1995). The key explanatory variables included in equations (6.6) and (6.7) are those related to ACs and land rental markets. We define the density of ACs (DAC hereafter) by measuring the number of ACs dealing in crop production divided by the total number of farm households in a village. If spill-over effects by '*daidong*' do not exist in the study area, the DAC is considered to have a positive relationship with BC technical efficiency. The land rental ratio (LRR) is also a key variable for the present study and is defined as the land rented area divided by the sown area in a village.

6.3.2. Estimation strategy

While estimating equations (6.4) to (6.7), we must control for potential bias due to the endogeneity problem. In this study, while considering the DAC and LRR as potential endogenous variables, we employ the instrumental variable (IV) estimation methods to obtain consistent estimators.[51] The appropriate instruments must be correlated with the DAC and LRR at the village level and be orthogonal to error terms but must not directly affect the dependent variables in equations (6.6) and (6.7). As the instruments for the DAC and LRR, we use the DAC and LRR at the township level (except village *i* itself), following Kung (2002), Li and Ito (2021), Liu et al. (2017), and Rao et al. (2020).

It is reasonable to consider that the DAC at the township level is strongly correlated with the DAC at the village level. After their embryonic development in the early 1990s, ACs have evolved nationally since the 2000s. As discussed in Section 2, the establishment of cooperatives was motivated by policy initiatives in a hierarchical method. In fact, more than 90% of the villages where we conducted the sample survey were advised by the township government to establish ACs. More importantly, ACs' activities at the township level do not directly affect technical efficiency at the village level, ensuring the validity of the instrument. Similarly, as the development of land rental market is promoted nationally since the 2000s, the LRR at the township level is correlated with the LRR at the village level. The variable is considered a valid instrument because the land rental development of townships will not directly affect technical efficiency at the village level.

6.3.3. Sampled villages

We conduct an empirical analysis, based on the data we collected from the village committees in Gansu province. Located upstream of the Yellow River basin in the northeast region of China, Gansu is a typical arid region with an average of 491 mm annual precipitation. The provincial population in 2020 was 25.01 million, of which 11.95 million (47.8%) resided in rural areas. In

[51] If the error terms of v_{1i} and v_{2i} are correlated, we must treat $\ln S_i$ as an endogenous variable because it is correlated with v_{1i}. The variables of $\ln L_i$ and $\ln K_i$ can be considered as 'excluded instruments' because they influence $\ln S_i$ strongly but do not affect $\ln Q_i$ directly. However, IV estimators violate the regulatory conditions of production function for the BC process. There is no significant difference in the estimated parameters for the inefficiency equations, regardless of whether $\ln S_i$ is treated as endogenous or not.

2020, Gansu's total gross domestic product was 901.7 billion yuan (141.5 billion US$), of which the primary industry accounted for 13.3%. The percentage of employees engaged in the primary industry was 44.9% (Gansu Development Yearbook). In 2020, the per capita gross domestic product of Gansu was 35,995 yuan, which was among the lowest in the country (China Statistical Yearbook)[52]. For rural poverty alleviation, improving agricultural technical efficiencies is desperately needed, especially in Gansu province.

In 2020 and 2021, the research team organized by the authors conducted interviews on village leaders and accountant officers, using a questionnaire that covered a broad range of information about the village's economy and agricultural production. The village committee in China is a self-governing base organization, with an average of 321 rural household in Gansu in 2020. In the village survey, 12 counties were selected along the Yellow River basin, and 410 villages were randomly extracted from them (on average, a county in Gansu has 187 villages); villages whose main industry is livestock or forestry were excluded from the sample.

Figure 6.2 shows fertilizer density (ton/ha) and the share of horticultural (vegetable and fruit) sown areas for 65 townships to which the sampled villages in this study belong administratively. Almost all townships are located within 50 km from the mainstream of Yellow River, and the share of horticultural sown area is proportional to the fertilizer density, with the correlation coefficient being 0.403 at the township level. Wu et al. (2021) argue that the largest contribution of the excessive nutrient discharges in the Yellow River is fertilizer loss. Therefore, strictly controlling the amount of fertilizer input and improving the efficiency of fertilizer use could promote the ecological conservation of Yellow River basin, which covers nine provinces including Gansu. In 2019, ecological protection and high-quality development of the Yellow River Basin became a national strategy, and Gansu province launched ecological protection and

[52] Out of the 86 counties in Gansu, approximately half are designated as national poverty area.

high-quality development of the Yellow River basin in 2021[53]. Improving chemical fertilizer use efficiency in farm production is indispensable for conserving the environment in this area as well as downstream provinces.

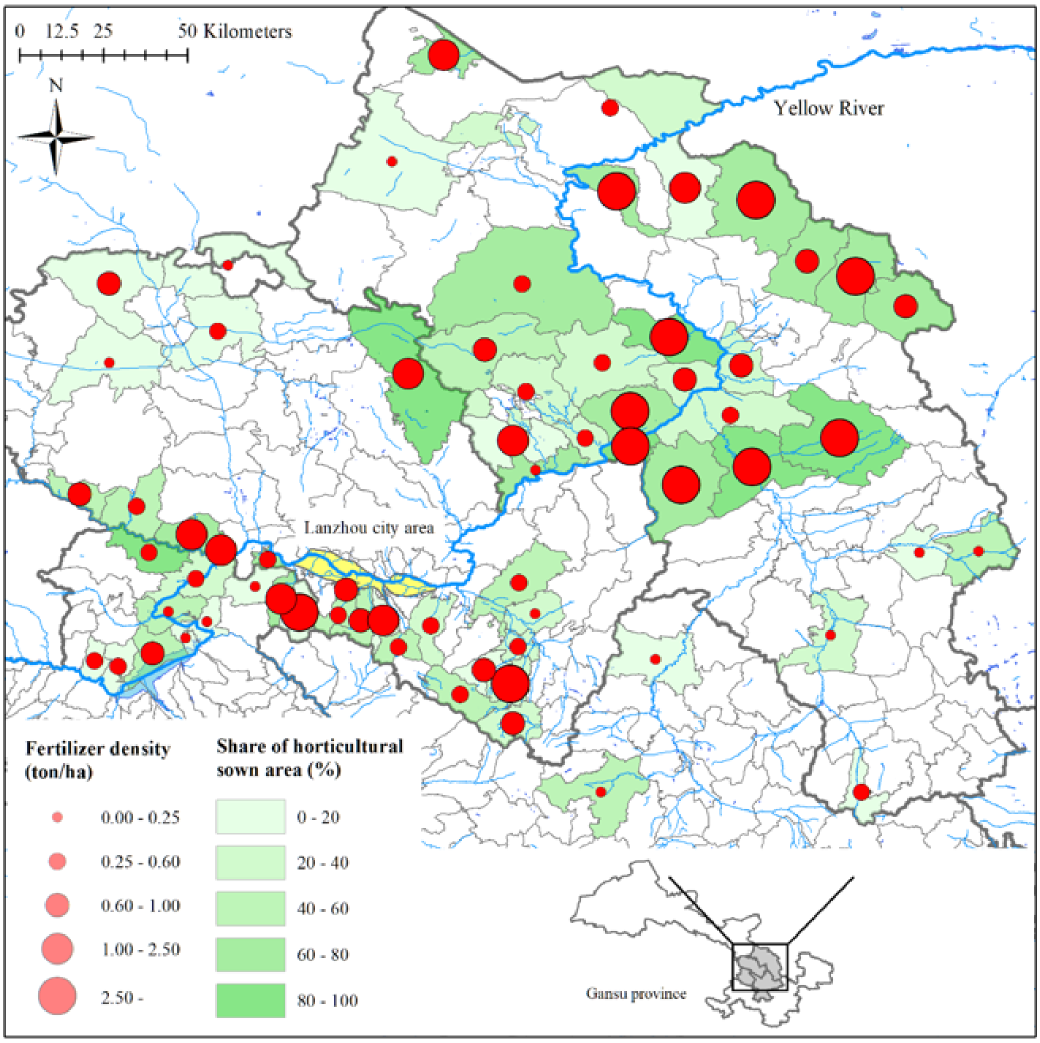

Figure 6.2. Fertilizer density and the share of horticultural sown areas for 65 townships

Source: Authors' estimates.

53 According to the provincial government, there are 3,524 pollution sources in Yellow River basin of Gansu, of which 2,717 stems from agricultural pollution (https://www.chinanews.com.cn/gn/2020 /06-02/9201480.shtml).

Table 6.2 shows the agricultural statistics of Gansu average and the sampled villages in 2020. The per capita disposal income of the rural households in the Gansu average and that of the sampled villages was 10,344 and 9,775 yuan, respectively. Agriculture accounted for approximately 73% of the agriculture, forestry, animal husbandry, and fishery production value for both regions. The AC participation rate of the province and sampled villages was 37.4% and 32.4%, respectively, whereas the LRR was 17.5% and 15.8%, respectively. Based on these statistics, the sampled villages do not deviate significantly from the Gansu average.

Table 6.2. Agricultural statistics of Gansu average and sampled villages

	Gansu average	Surveyed villages
Per capita disposal income of rural households (yuan)	10,344	9,775
Share of agricultural production value in AFAF (%)	72.5	72.9
AC participation rate (%)	37.4	32.4
Land rental ratio, LRR (%)	17.5.	15.8
Share of sown area (%)		
Grain	67.3	46.2
Oil crops	7.0	4.7
Vegetables and fruits	18.5	39.6
Chinese medicine	7.2	3.8
Others	—	5.7
Fertilization density (ton/ha)	0.20	0.87
Sown area per rural household (ha)	0.75	0.47
Agricultural land-labor ratio (ha/person)	0.89	0.39
Farm-machinery-labor ratio (kw/person)	5.29	3.84
Number of villages providing farm machinery services	—	54
Number of villages having vertically coordinated ACs	—	188

Note: To compute the fertilization density, fertilizer weight is converted to the pure ingredient amount. AFAF: agriculture, forestry, animal husbandry, and fishery.
Source: Gansu Development Yearbook. China Statistical Yearbook for Rural Operation and Management.

However, there was a significant difference in the cropping pattern. In our sampled villages, the sown area of grain accounted for 46.2% of the total area, whereas the comparable figure for the Gansu average was 67.3%. Evidently, the sampled villages, compared to the Gansu average, specialized more in vegetable and fruit production, with the share of sown area reaching 39.6%. Vegetable and fruit production are generally considered to consume more fertilizer, compared to other crop production. The table shows that the fertilization density is much higher in the sampled villages than it is in the Gansu average, with the density being equal to 0.87 ton/ha, almost four times more than that of the Gansu average. Likewise, as the horticultural sector is more labor intensive than the grain sector, the sown area per rural household and the agricultural land-labor ratio are smaller in the sampled villages than they are in the Gansu average. Meanwhile, consistent with our expectation, the farm-machinery-labor ratio in the sampled villages are 3.84 kw/person, which is lower than the province average. Of the 410 sampled villages, 54 have ACs that provide farm machinery services and 188 have vertically coordinated ACs.

6.3.4. Data of the SFPF

Farm production is measured using two alternative methods: the weight in tons, and the output value. Factor inputs include fertilizer (*fer*), farmland (*lad*), farm labor (*lab*), and capital (*cap*). Fertilizer is measured by the total chemical fertilizer consumptions (tons). Farmland is measured by the total sown area for crop production (mu). Farm labor is measured by the total number of workers engaged in crop farming (persons). Farm machinery is measured by the total agricultural machinery power (kw).

In addition to the DAC and LRR variables, we use the following regressors for the inefficiency equations: a categorical variable (VAC) that is equal to 1 for villages with vertical-coordinated ACs, and 0 otherwise. Another categorical variable is 'machinery service' that is equal to 1 when some ACs in the village provide farm machinery service to local farmers, and 0 otherwise. We add the following other control variables: 'migration ratio', 'soil quality', 'irrigation rate', and 'flat area'. The variable of 'migration ratio' measures the number of migrants working continuously outside their home village for more than six months a year divided by total number of rural households. 'Soil quality' measures the Likert-type scale ranging from 1 to 5, and the larger the value, the higher the quality. 'Irrigation rate' measures the effective irrigation area divided by total contracted land area. The variable of 'flat area' measures the percentage of flatland area in the village.

6.4. Estimation results

6.4.1. Estimation results of the trans-log SFPF

Table 6.3 shows the estimation results of the SFPF, which is specified in the following trans-log form:[54]

$$\ln Q_i = \alpha_0 + \sum_k \alpha_k \ln X_{ki} + \frac{1}{2}\sum_k \sum_l \alpha_{kl} \ln X_{ki} \ln X_{li} - u_i + v_i, \quad (6.8)$$

where $X_{ki} = V_i, S_i, L_i, K_i$. The parameters in this equation have properties of $\alpha_{kl} = \alpha_{lk}$ from the symmetric condition. A trans-log function is a second-order Taylor-series approximation centered at zero. Therefore, prior to the estimation, all the respective output and input variables are normalized such that $\ln\overline{X_k} = \ln\bar{Q} = 0$. The technical efficiency can be calculated as $TE_i = \exp(-u_i)$. Obviously, the stochastic frontier model based on the trans-log form cannot distinguish between the BC and M technical efficiencies, even if they are influenced in opposite directions by certain factors.

This study adds the ratio of grain output value to equations (6.4), (6.5) and (6.8) as a regressor to eliminate the potential bias due to the inter-village heterogeneity in the product mix.[55] We cannot reject the null hypothesis that the estimated trans-log function exhibits constant returns to scale when evaluated at the sample mean values of the variables at the 5% level. A joint test of the estimated parameters, regarding the trans-log terms, rejects the null hypothesis that the CD production technology is nested ($p > \chi^2 = 0.000$), suggesting that the

[54] We use the Stata command 'sfkk' developed by Karakaplan (2017) to estimate the SFPF and inefficiency equations simultaneously. This command is preferable as it can control for endogeneity in the frontier and inefficiency equations using a one-step procedure.
[55] Instead of the frontier function's regressor, we can use the ratio of grain output value as a factor that influence of the inefficiency equations. Either method does not affect the conclusion significantly.

trans-log form is more appropriate for the SFPF specification, compared to the CD form. However, the estimated trans-log production function does not satisfy the concavity condition for the data domains.

Table 6.3. Estimation results of the trans-log function (output: weight)

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Production function				
ln (*fer*)	0.088***	(0.028)	0.086***	(0.028)
ln (*lad*)	0.869***	(0.052)	0.870***	(0.051)
ln (*lab*)	0.057	(0.042)	0.050	(0.042)
ln (*cap*)	0.071***	(0.024)	0.079***	(0.024)
ln (*fer*)*ln (*lad*)	-0.061	(0.039)	-0.067*	(0.040)
ln (*fer*)*ln (*lab*)	0.006	(0.029)	0.021	(0.028)
ln (*fer*)*ln (*cap*)	-0.016	(0.015)	-0.017	(0.015)
ln (*lad*)*ln (*lab*)	0.078*	(0.040)	0.084**	(0.040)
ln (*lad*)*ln (*cap*)	0.016	(0.023)	0.006	(0.023)
ln (*lab*)*ln (*cap*)	-0.008	(0.017)	-0.004	(0.017)
0.5*ln (*fer*)*ln (*fer*)	-0.020	(0.042)	-0.039	(0.040)
0.5*ln (*lad*)*ln (*lad*)	0.202***	(0.056)	0.212***	(0.057)
0.5*ln (*lab*)*ln (*lab*)	-0.012	(0.048)	-0.012	(0.047)
0.5*ln (*cap*)*ln (*cap*)	-0.001	(0.011)	0.002	(0.011)
Grain output value ratio	-0.359**	(0.143)	-0.317**	(0.141)
County dummies	Yes		Yes	
Inefficiency equation				
Density of ACs (DAC)	-0.060**	(0.023)	-0.133***	(0.028)
Land rental ratio (LRR)	-1.926**	(0.822)	-1.046	(0.918)
Machinery service	0.166	(0.283)	0.238	(0.285)
Vertically coordinated AC (VAC)	0.643***	(0.216)	0.663***	(0.218)
Migration ratio	0.057	(0.040)	0.066	(0.041)
Soil quality	-0.086	(0.115)	-0.039	(0.113)
Irrigation rate	-0.012	(0.029)	-0.020	(0.030)
Flat area	-0.004	(0.003)	-0.003	(0.003)
Endogeneity test			χ^2=10.59, p=0.005	
Observations	339		339	
Log likelihood	-311.8		-1216.9	
Mean technical efficiency	0.560		0.564	

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

As for the inefficiency equations, the test statistics reject the null hypothesis regarding the joint exogeneity of DAC and LRR at the 1% significance level. Thus, we examine the estimation result based on the endogenous model. The lower parts of Table 6.3 show the estimation results of the inefficiency equation. The estimated coefficient of the DAC is negative and highly significant, suggesting that the development of ACs helps improve the technical efficiency. Meanwhile, the coefficient of the LRR is negative, but not significant for the endogenous model.[56] The VAC coefficient is positive and significant at the 1% level, which suggests that the technical efficiency declines if there is at least one vertically coordinated AC in a village. Hence, the deep involvement of ACs as cultivators in agricultural production lowers the technical efficiency. The estimator of 'machinery service' is positive, but not significant. The coefficients of other control variables are also not statistically significant. Table 6.3 shows that the mean efficiency is 0.564, implying that farm production could be increased by 43.6% on average by performing farm management more efficiently.

6.4.2. Estimation results of the SCD SFPF

Table 6.4.1 and 6.4.2 show the estimation results for the BC and M technologies, respectively. The estimated SCD (BC and M technologies) meet the monotonicity and concavity conditions. The null hypothesis of $\alpha_V + \alpha_S = 1$ cannot be rejected (p-value: 0.705), suggesting that the land productivity (Q/S) exhibits diminishing returns to the fertilization density (V/S). The re-estimation of the BC technology, with this constraint imposed, provides almost the same estimators for the inefficiency equations. Meanwhile, the M technology exhibits decreasing returns to scale ($\alpha_L + \alpha_K < 1$). As the null hypothesis of the joint exogeneity for the LRR and DAC cannot be rejected both for the BC and M technologies, as shown in Tables 6.4.1 and 6.4.2, we examine the estimation results based on the exogenous models.

[56] Instead of the LRR at the township level, the agricultural land-labor ratio at the township level can be a valid instrument. However, either method does not affect the conclusion significantly.

Table 6.4.1. Estimation results of the BC function (output: weight)

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Production function				
ln (*fer*)	0.123***	(0.027)	0.123***	(0.027)
ln (*lad*)	0.860***	(0.050)	0.852***	(0.050)
Grain output value ratio	-0.334**	(0.153)	-0.355**	(0.155)
County dummies	Yes		Yes	
Inefficiency equation				
Density of ACs (DAC)	-0.051***	(0.019)	-0.037	(0.023)
Land rental ratio (LRR)	-1.738*	(0.970)	-1.835	(1.457)
Machinery service	-0.018	(0.320)	-0.043	(0.321)
Vertically coordinated AC (VAC)	0.509**	(0.240)	0.523**	(0.245)
Migration ratio	0.058	(0.039)	0.055	(0.039)
Soil quality	-0.106	(0.133)	-0.120	(0.134)
Irrigation rate	-0.895**	(0.357)	-0.883**	(0.353)
Flat area	-0.004	(0.004)	-0.004	(0.004)
Endogeneity test			χ^2=0.58, *p*=0.746	
Observations	345		345	
Log likelihood	-345.4		-1290.9	
Mean technical efficiency	0.571		0.571	

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6.4.1 shows that the coefficient of DAC is negative and significant at the 1% level, suggesting that ACs improve the BC technical efficiency. This result supports the discussion of Liu and Wu (2022), Ma et al. (2018b), Ma et al. (2021), and Zhang et al. (2020). Some studies suggest that ACs can be an efficient institutional arrangement for the reduction of fertilizer use in China (Liu and Wu, 2022) and that cooperatives can assist members to use fertilizers efficiently for sustainable soil management (Ma et al., 2018a), all of which lead to a promotion of green agricultural development. In case the spill-over effect caused by *daidong* is strong enough to negate the economic benefits that accrue only to AC participants, the DAC estimator must be statistically insignificant. However, our estimation result does not support this argument. Thus, the more densely ACs are established in a village, the larger the economic benefit enjoyed by local farmers.

The LRR coefficient is negative and significant at the 10% level in Table 6.4.1, meaning that the development of land rental market has the potential to improve the BC technical efficiency. This is consistent with previous study that reveals a positive relationship between farm size and fertilizer overuse reduction (Heisey and Norton, 2007; Ren et al., 2021). The vertical coordination by ACs has a negative effect on the BC technical efficiency. This aligns with the argument that large-scale agribusiness firms, depending highly on hired employees, are not good at care-intensive farming activities. In contrast, small-scale farms have an advantage over such firms in terms of the BC technical efficiency because family members, as residual claimants on farm income, have a strong incentive to work diligently. Table 6.4.1 also shows that irrigation rate has a significant positive impact on the improvement of the BC technical efficiency, which seems like a natural consequence. The 'soil quality' and 'frat area' coefficients are negative but not significant.

Table 6.4.2. Estimation results of the M function

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Production function				
ln (*lab*)	0.227***	(0.042)	0.224***	(0.042)
ln (*cap*)	0.038*	(0.022)	0.035	(0.022)
Grain output value ratio	-0.240	(0.158)	-0.260*	(0.157)
County dummies	Yes		Yes	
Inefficiency equation				
Density of ACs (DAC)	-0.009	(0.012)	-0.001	(0.014)
Land rental ratio (LRR)	-1.775**	(0.851)	-2.517**	(1.167)
Machinery service	-0.793**	(0.370)	-0.752**	(0.352)
Vertically coordinated AC (VAC)	-0.918***	(0.257)	-0.828***	(0.252)
Migration ratio	0.143	(0.106)	0.137	(0.104)
Soil quality	-0.061	(0.126)	-0.041	(0.123)
Irrigation rate	0.005	(0.026)	0.006	(0.025)
Flat area	0.004	(0.003)	0.004	(0.003)
Endogeneity test			χ^2=1.67, p=0.434	
Observations	340		340	
Log likelihood	-356.1		-1285.3	
Mean technical efficiency	0.525		0.515	

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6.4.2 shows the estimation results of the M technology. The coefficient of LRR is negative and significant at the 5% level, suggesting that the development of land rental market improves the M technical efficiency.[57] The negative and significant coefficient of 'machinery service' indicates that farm machinery services provided by ACs improve the M technical efficiency, which supports the argument of (Wang et al., 2016; Yang et al., 2013). The negative and significant coefficient of VAC demonstrated that the direct involvement of ACs as vertical coordinators have a positive effect on M technical efficiency. In our sampled villages, the average rented land area for ACs is 11.83 ha, which is much larger than that for individual producers (0.33 ha). Chi et al. (2021) claim that agricultural machinery input has a more obvious and direct effect in promoting the green development of agriculture when it is combined with farm-size enlargement. Overall, the estimation results of Tables 6.4.1 and 6.4.2 indicate that the entry of large-scale ACs into the farming business has conflicting effects on technical efficiency, suggesting that it helps improve M technical efficiency but lowers the BC technical efficiency.

Figure 6.3 illustrates the BC and M technical efficiencies with a box-and-whisker plot for the villages with and without vertically coordinated ACs. The figure shows that villages with VAC have lower BC efficiencies and higher M efficiencies than those without VAC. Statistical tests of the mean difference support this argument at the conventional level of significance (*p*-values for BC and M are 0.042 and 0.000, respectively).[58] The lower rows of Tables 6.4.1 and 6.4.2 show that the mean efficiency of the BC and M technical efficiencies is 0.571 and 0.525, respectively, indicating much room to improve the efficiencies. Appendix Figure 6.1 shows the estimated BC and M technical efficiency distributions.

[57] In case individual farmers' cultivated land becomes scattered or fragmented by land rental activities, work efficiency in the field will decline, which naturally lowers the M technical efficiency. However, our estimation results contradict this negative effect (Wang et al., 2020).

[58] Note that this simplistic finding regarding the sample mean between villages with and without VCA does not enable us to identify the effect of VCA on technical efficiencies.

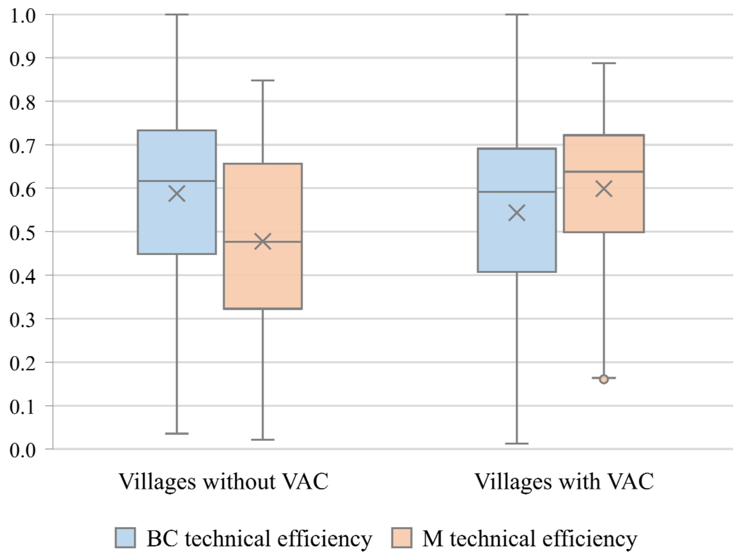

Figure 6.3. BC and M Technical efficiencies for villages with and without VAC

Source: Authors' estimates

6.4.3. Robustness

To check robustness, we estimate the SFPF for the farm production measured by the real output value. Tables 6.5 and 6.6 show the estimation results of the trans-log function and BC function, respectively. A robustness check for the M function is unnecessary. The lower rows of the two tables show that the test statistics reject the null hypothesis regarding the joint exogeneity of DAC and LRR. Thus, we interpret the estimation results based on the endogenous model. Table 6.5 shows that the coefficient of DAC is negative and significant at the 5% level, whereas that of VAC is positive and significant at the 1% level. We do not find serious contradiction in these estimators between Tables 6.3 and 6.5. However, contrary to the exogenous model in Table 6.3, the coefficient of the LRR in the endogenous model of Table 6.5 is not significant.

Table 6.6 shows that the coefficient of DAC is negative and significant, which is consistent with the result when the output is measured by weight (Table 6.4.1). Contrary to the exogenous model in Table 6.4.1, the estimators of LRR and VAC are not significant. Although a negative 'flat area' coefficient is convincing, a positive coefficient of 'soil quality' contradicts our expectation. Overall, our robustness test offers clear evidence that ACs help increase the BC technical efficiency. Meanwhile, there is a slight contradiction regarding the impact of LRR on BC technical efficiency. Finally, we perform another robustness test by specifying SFPF in the trans-log form, instead of the CD form, for the BC and M technologies (farm output is measured by weight). As shown in the Appendix Tables 6.1 and 6.2, the effects of the key variables, such as DAC, LRR, 'machinery service', and VAC, on the BC and M technical efficiency are almost the same as those when the SFPF is specified by the SCD. So, the estimators of inefficiency equations are robust, irrespective of the frontier function form.

Table 6.5. Estimation results of the trans-log function (output: value)

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Production function				
ln (*fer*)	0.271***	(0.042)	0.260***	(0.044)
ln (*lad*)	-0.014	(0.079)	-0.022	(0.078)
ln (*lab*)	0.503***	(0.063)	0.503***	(0.065)
ln (*cap*)	0.106***	(0.032)	0.104***	(0.032)
ln (*fer*)*ln (*lad*)	-0.110**	(0.053)	-0.128**	(0.055)
ln (*fer*)*ln (*lab*)	0.071*	(0.042)	0.089**	(0.044)
ln (*fer*)*ln (*cap*)	-0.093***	(0.023)	-0.099***	(0.024)
ln (*lad*)*ln (*lab*)	-0.055	(0.059)	-0.094	(0.060)
ln (*lad*)*ln (*cap*)	0.128***	(0.031)	0.123***	(0.031)
ln (*lab*)*ln (*cap*)	-0.027	(0.025)	-0.017	(0.026)
0.5*ln (*fer*)*ln (*fer*)	0.116**	(0.055)	0.136**	(0.057)
0.5*ln (*lad*)*ln (*lad*)	-0.046	(0.087)	-0.028	(0.083)
0.5*ln (*lab*)*ln (*lab*)	-0.044	(0.060)	-0.058	(0.060)
0.5*ln (*cap*)*ln (*cap*)	0.035**	(0.015)	0.039**	(0.015)
Grain output value ratio	-1.210***	(0.213)	-1.159***	(0.205)
County dummies	Yes		Yes	
Inefficiency equation				
Density of ACs (DAC)	-0.011	(0.015)	-0.075**	(0.030)
Land rental ratio (LRR)	0.171	(0.470)	-0.915	(0.783)
Machinery service	0.157	(0.325)	0.338	(0.335)
Vertically coordinated AC (VAC)	0.732***	(0.273)	0.650***	(0.248)
Migration ratio	0.074	(0.054)	0.102*	(0.059)
Soil quality	0.372**	(0.159)	0.308**	(0.134)
Irrigation rate	-0.009	(0.014)	0.010	(0.017)
Flat area	-0.001	(0.004)	0.000	(0.004)
Endogeneity test			χ^2=10.81, p=0.004	
Observations	345		345	
Log likelihood	-425.5		-1535.3	
Mean technical efficiency	0.514		0.505	

Note: *, **, and *** indicate statistical significance at the 10%, 5% and, 1% levels, respectively.

Table 6.6. Estimation results of the BC function (output: value)

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Production function				
ln (*lab*)	0.291***	(0.041)	0.274***	(0.043)
ln (*cap*)	0.326***	(0.076)	0.325***	(0.078)
Grain output value ratio	-0.867***	(0.245)	-0.936***	(0.253)
County dummies	Yes		Yes	
Inefficiency equation				
Density of ACs (DAC)	-0.001	(0.014)	-0.064**	(0.032)
Land rental ratio (LRR)	0.884	(0.746)	-1.427	(1.446)
Machinery service	0.010	(0.330)	0.054	(0.366)
Vertically coordinated AC (VAC)	0.426*	(0.249)	0.307	(0.259)
Migration ratio	0.226	(0.243)	0.183	(0.251)
Soil quality	0.266**	(0.123)	0.299**	(0.130)
Irrigation rate	-0.219	(0.218)	-0.352	(0.380)
Flat area	-0.013***	(0.004)	-0.012***	(0.004)
Endogeneity test			χ^2=16.70, p=0.000	
Observations	344		344	
Log likelihood	-494.1		-1398.5	
Mean technical efficiency	0.442		0.459	

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

6.5. Conclusion and policy implications

Over the past few decades, ACs have attracted considerable attention as a core entity that revitalizes and rejuvenates the rural economy in China. The ACs established in China offer a wide range of agricultural services within the framework of contract farming and vertical coordination. Considering this fact, we empirically investigate the impact of ACs on agricultural technical efficiency by estimating an SFPF.

Our estimation result reveal that the establishment of ACs has a significant effect on raising technical efficiency, especially in the BC process. However, the involvement of ACs as vertical coordinators is demonstrated to have conflicting consequences for the BC and M technical efficiency improvements, suggesting that they help improve the M technical efficiency but reduce the BC technical efficiency. Meanwhile, the machinery services provided by ACs increase M technical efficiency. The empirical results in this study present unambiguous evidence that Chinese ACs play essential roles in increasing agricultural productivity and protecting agroecological environment by influencing the BC and M technical efficiency of farm production.

Our findings have some policy implications. First, China's ACs have recently started to provide farmers with BC services that are aimed at promoting environmental-friendly agriculture, supported by the government action plan to prevent the overuse of chemicals that seriously challenge environmental and agricultural sustainability. This aligns with the recent policy evolution in China aimed at promoting green agricultural development. Considering that the BC process essentially involves the relationship between fertilization density (fertilizer consumption per arable land) and land productivity, an improvement in the BC efficiency undoubtedly contributes to curbing the excessive use of chemical fertilizers. Second, small-sized and fragmented farmland hampers mechanization and causes low energy efficiency and productivity in mechanized operations. Expanding farm size or removing field bunds is one of the key strategies for more effective farming. Therefore, besides directly providing machinery services, the involvement of ACs into farm sector as vertical coordinators by renting land considerably improves the M technical efficiency of farm production, and thus promotes the development of greener agriculture in China.

Third, the BC technical efficiency declines if there is at least one vertically coordinated AC in a village, which strengthens the argument that large-scale agribusiness firms that depend highly on hired employees have a disadvantage in care-intensive farming activities. This finding is consistent with a traditionally established view that farm size is negatively associated with land productivity. In contrast, the existence of vertically coordinated AC in a village improves the M technical efficiency. This also aligns with the argument that agribusiness firms can take advantage of the production efficiency associated with capital input indivisibility in the farm-size enlargement process. Thus, the pressing challenges involves accommodating the conflicting effects that the entry of ACs into agriculture has on the BC and M technical efficiencies.

The limitations of this study include the narrow focus on specific regions, for an empirical study. Moreover, this study collected cross-section data instead of panel data, which may make our estimates conservative. In this context, further research efforts should focus on refining the study for other regions and extending survey period to investigate the role of ACs and land rental market on the efficiency improvement.

Appendix Table 6.1. Estimation results of the BC with separated trans-log function

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Production function				
ln (*fer*)	0.106***	(0.026)	0.120***	(0.029)
ln (*lad*)	0.939***	(0.052)	0.895***	(0.056)
ln (*fer*)*ln (*lad*)	-0.022	(0.034)	0.017	(0.035)
0.5*ln (*fer*)*ln (*fer*)	-0.076**	(0.034)	-0.088**	(0.038)
0.5*ln (*lad*)*ln (*lad*)	0.235***	(0.059)	0.190***	(0.063)
Grain output value ratio	-0.336**	(0.149)	-0.399**	(0.160)
County dummies	Yes		Yes	
Inefficiency equation				
Density of ACs (DAC)	-0.077**	(0.030)	0.004	(0.038)
Land rental ratio (LRR)	-1.535	(0.945)	-3.539	(3.784)
Machinery service	0.120	(0.317)	0.386	(0.611)
Vertically coordinated AC (VAC)	0.657***	(0.243)	2.076**	(0.807)
Migration ratio	0.061	(0.039)	-0.000	(0.067)
Soil quality	-0.107	(0.131)	-1.267**	(0.601)
Irrigation rate	-0.586*	(0.315)	-1.580	(1.100)
Flat area	-0.003	(0.004)	-0.028*	(0.014)
Endogeneity test			χ^2=2.50, p=0.286	
Observations	345		345	
Log likelihood	-333.7		-1284.3	
Mean technical efficiency	0.585		0.813	

Note: *, **, and *** indicate statistical significance at the 1%, 5%, and 1% levels, respectively.

Appendix Table 6.2. Estimation results of the M with separated trans-log function

	Exogenous		Endogenous	
	Estimates	SE	Estimates	SE
Production function				
ln (*lab*)	0.249***	(0.047)	0.246***	(0.047)
ln (*cap*)	0.051*	(0.026)	0.050*	(0.026)
ln (*lab*)*ln (*cap*)	-0.051***	(0.018)	-0.050***	(0.018)
0.5*ln (*lab*)*ln (*lab*)	0.145***	(0.047)	0.142***	(0.049)
0.5*ln (*cap*)*ln (*cap*)	0.016	(0.012)	0.016	(0.012)
Grain output value ratio	-0.246	(0.158)	-0.249	(0.158)
County dummies	Yes		Yes	
Inefficiency equation				
Density of ACs (DAC)	-0.013	(0.012)	-0.010	(0.016)
Land rental ratio (LRR)	-2.008**	(0.879)	-2.686**	(1.227)
Machinery service	-0.837**	(0.379)	-0.801**	(0.371)
Vertically coordinated AC (VAC)	-0.907***	(0.254)	-0.845***	(0.258)
Migration ratio	0.146	(0.105)	0.147	(0.104)
Soil quality	-0.083	(0.127)	-0.069	(0.126)
Irrigation rate	0.004	(0.026)	0.005	(0.026)
Flat area	0.005*	(0.003)	0.005*	(0.003)
Endogeneity test			χ^2=0.69, p=0.707	
Observations	340		340	
Log likelihood	-349.9		-1275.9	
Mean technical efficiency	0.532		0.527	

Note: *, **, and *** indicate statistical significance at the 1%, 5%, and 1% levels, respectively.

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Chapter 7

Concluding Remarks

During the rapid urbanization in China, more attention is needed to pay to the rural decline (Feng et al., 2019; Lang et al., 2018). As responses to this, the government emphasized the pursuit of a new rural revitalization strategy, prioritizing the development of agriculture and rural areas. Optimization of the rural land system not only provides the premise to effectively solve the "three rural problems", but also constitutes the key toward a thorough implementation of the rural revitalization strategy (Liu et al., 2020).

Against this background, the China's central government has adopted a series of policy programs to promote the comprehensive development of land rental markets in rural areas over recent decades. The land rental ratio of the whole county rising sharply from 14.7% in 2010 to 34.08% in 2020. During this process, the NFHPs, including ACs are increasingly entered into farm businesses as cultivators by renting land from farm households. It is believed that land transfer, as an important part of changing the traditional agricultural production mode and realizing agricultural modernization, scale and intensification, is inseparable from the realization of the rural development (Zhang et al., 2020). Therefore, the driving force behind the rapid growth of land rental ratio and the subsequent consequences of land rental market development are worth discussing. Furthermore, it is also crucial to figure out the role of ACs and their participation into farm sector through land rental market on the agricultural production.

Chapter 3 analyzing the regional disparity of agricultural technical efficiency by applying a stochastic meta frontier approach, with panel data of 31 provinces in China from 1984 to 2020. The results imply the agricultural backwardness in the western region and its catching-up process. Therefore, the discussion of the issues on agricultural development through the case of

Gansu province, a representative of western region, may provide useful policy recommendations for the rural development in some under developed areas in China.

Chapter 4 investigates the driving forces behind the rapid growth of land rental market by estimating the land rental ratio equation at the local level, with a panel dataset of 86 counties in Gansu province. The estimation results lend strong support to the view that ACs raise the land rental ratio markedly, while transaction costs, proxied by land exchange disputes, have a detrimental effect on the development of land rental markets.

Chapter 5 examines the causal effect of land rental on farm production efficiency by estimating a SFODF, and the results suggests that the development of land rental markets and agricultural cooperatives is deeply involved in determining the level of agricultural technical efficiency. More specifically, it demonstrates that the land rental ratio has a significant effect of raising technical efficiency at the county level. Further, the quantitative analysis reveals that participation in agricultural cooperatives is an important avenue for FHs to increase farm production efficiency.

Chapter 6 explores the impact of ACs and their involvement into farm sector as vertical coordinators by renting in land on agricultural BC and M technical efficiency, respectively, by estimating the production function in a special form called the separated Cobb-Douglas. The estimation result reveal that the establishment of ACs has a significant effect on raising technical efficiency, especially in the BC process. However, the involvement of ACs as vertical coordinators is demonstrated to have conflicting consequences for the BC and M technical efficiency improvements, suggesting that they help improve the M technical efficiency but reduce the BC technical efficiency. Meanwhile, the machinery services provided by ACs increase M technical efficiency.

Based on the theoretical considerations and empirical results presented in this thesis, we can draw important policy implications. First, it emphasized the role of ACs in facilitating the development of land rental markets, which occurs with the policy orientation of the government's "No. 1 central document" issued in 2013 that encouraged and supported farmers to rent out their land to new agricultural management entities, including ACs. Meanwhile, public organizations such as the arbitration committees established in rural area play a critical role in reducing the transaction costs arising from land use disputes among lessors and lessees. Given this, rural collectives, instead of committing to land reallocation directly, could help develop the land rental market by fulfilling the role of land exchange intermediaries.

Second, the positive correlation between land rental ratio and farm technical efficiency suggests that rental markets help realize efficient reallocation among producers, in which land usufruct has accumulated in the hands of competent cultivators. Moreover, the existence of NFHPs, including ACs, is of great importance in improving technical efficiency of farm production. we can say for certain that the government's policy initiative of fostering agricultural cooperatives can be viewed as a step in the right direction.

Third, Chinese ACs play essential roles in increasing agricultural productivity and protecting agroecological environment by influencing the BC and M technical efficiency of farm production. On one hand, ACs in China have recently started to provide farmers with BC services that are aimed at promoting environmental-friendly agriculture. Considering that the BC process essentially involves the relationship between fertilization density (fertilizer consumption per arable land) and land productivity, an improvement in the BC efficiency undoubtedly contributes to curbing the excessive use of chemical fertilizers. On the other hand, small-sized and fragmented farmland hampers mechanization and causes low energy efficiency and productivity in mechanized operations. The involvement of ACs into farm sector as vertical coordinators by renting land considerably improves the M technical efficiency of farm production, and thus promotes the development of greener agriculture in China. However, the BC technical efficiency declines if there is at least one vertically coordinated AC in a village, which is consistent with a traditionally established view that farm size is negatively associated with land productivity. In contrast, the existence of vertically coordinated AC in a village improves the M technical efficiency. Therefore, the pressing challenges involves accommodating the conflicting effects that the entry of ACs into agriculture through land rental market has on the BC and M technical efficiencies.

In summary, the issues discussed in the thesis demonstrated that the development of land rental market and ACs are key factors affecting agricultural sustainable development, and are helpful to realize rural revitalization in China. We acknowledge that our empirical results cannot be generalized at the national level as the sample is limited to just one province in northwest China, which is not representative of the entire country. However, the examined issues are likely to be of relevance to other parts of rural China characterized by similar underdeveloped rural societies.

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