2014 Doctor's Thesis

The Labor Allocation of Household Members and Farm Technical Efficiency in Chinese Agriculture

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Chapter 1. Introduction

1.1. Main Issues Tackled in this Dissertation

China's economy has developed dramatically from 1980s, during which both rural and urban labor market developed rapidly. Such development in the labor market caused two contrasting phenomena for Chinese rural households. One is increased off-farm work opportunities for male members and the other is more women left-behind on the farm. Theoretically, farmers can choose to reallocate their time from the agricultural sector to the non-agricultural sector in the form of part-time or full-time if the off-farm work offers higher returns. However, because of the different accessibility of male and female to off-farm labor market, the off-farm labor participation rate is much higher for males than for females. Zhang et al. (2004) use China National Rural Survey and conduct a detailed analysis of off-farm work in rural China. They showed that in the year 2000, only youngest age cohort (16-20 years old) of females have fair access to labor market as males (with off-farm labor participation rates around 75% for both young males and females) and that most females remain working on the farm: On-farm labor participation rate is 66% and 27% for females and males at age cohort 26-30 years old, 77% and 29% for age cohort 31-35, 80% and 30% for 36-40, and 81% and 39% for 41-50.

More engagement in off-farm work of household heads has been shown to have important effects on farm productivity. On the one hand, a farm household's participation in wage work could raise its farm productivity for several possible reasons. Wage incomes can be used to facilitate farm management through a more flexible purchase of inputs, and participation in wage work can also increase information about farm inputs and technology through better access to urban areas (Herdt and Mandac, 1981). On the other hand, Goodwin and Mishra (2004) argue that wage work participation can decrease farm households' attention to the optimal use of variable inputs and farm technology, which may cause a decrease in farm productivity. If increased participation of rural households in wage work deteriorates farm productivity, further economic development will threaten stable domestic supply of farm commodities in China.

Women's increasing participation in Chinese agriculture has also caused great attention of many researchers. It is widely believed that women are more likely to have less access to resources (e.g., high quality land, credit and extension program), their responsibility is mainly related to the side work within the family (e.g., children parenting, cleaning and meal cooking), and their participation in farm work may negatively affect farm productivity. For example, Peterman et al. (2010) investigate gender differences in agricultural productivity using 2005 data of Nigeria and 2003 data of Uganda to find that female-owned plots and female-headed households have lower productivity. However de Brauw et al. (2008) find positive relation between crop plot-revenue and female management for Chinese households. They argued that China is different from rest of the world in that males and females do farming together and there is no obvious discrimination on females. Similarly Zhang at al. (2004) find that women do not have lower efficiency in crop production when they are the heads of farm in China. It is crucial to both urbanization and industrialization of rural China to understand the raised question: Do more females working on the farm have positive effects on farm productivity? More detailed research is needed.

1.2. Objectives of this Dissertation

The first objective is to investigate the effects of a household head's participation in wage work on farm productivity in China. We focus on the working status of household head is because in typical Chinese farm household, the head and wife are main work force on a farm while their children take off-farm work because of easier access to off-farm labor market for younger members. The Chinese Household Income Project survey of 2002 (hereinafter CHIP2002; Li,

2002) verifies that the average farm work hours are 1,021, 1,140, 655, and 636 for the head, his wife, other adult males, and other adult females, respectively. Also, the household head is most likely to participate in local wage work, while his wife is least likely to do so. Few studies have investigated the effects of more wage work on farm productivity and especially on technical efficiency even for other countries. Some studies show that household with migrants have higher farm technical efficiency (Mochebelele and Winter-Nelson, 2000; Pfeiffer, Lopez-Feldman, and Taylor, 2009), while others show the opposite result (Chang and Wen, 2011). To our knowledge, no studies have estimated the effects of more wage work on technical efficiency for Chinese households. This is the objective for the empirical analysis in Chapter 3.

The second objective is to investigate the effect of female labor on farm technical efficiency in China. In assessing the effect of more females' participation in agriculture, the widely applied method is to check if women-headed households or women-managed households are linked with higher yields and higher revenues. If they are linked positively, a result of "women have higher productivity in agriculture than men" or "women have at least the same productivity in agriculture as men do" is concluded (de Brauw et al. 2008; Zhang et al. 2004). It is worth mentioning that there is no female-headed household according to Chinese legislation and that unlike African and South Asian households, it is not common to see farm households solely run by female in China (only 3-4% nationally according to de Brauw et al. 2008). Therefore, rather than defining "female-headed" households, "female-managed" households are more appropriate in our situation. Without this definition, it is inconvenient to study the effect of more females on farm productivity. The objective in Chapter 4 is to clarify this definition of "female-managed household" and investigate the effect of more female managed households on farm productivity in China.

1.3. Brief Theoretical Consideration and Data Used in this Dissertation

There are complex effects of off-farm work on farm productivity. For illustration, we consider the following production frontier:

$$Y = A\, f(L, X),$$

where Y is total outputs, L is on-farm labor (we denote on-farm labor as *FWH--farm working hours* in empirical analysis, for general illustration here we use L), X is other inputs, and A is taken as total factor productivity (TFP). The effect of wage (ω) increase on outputs can be expressed as

$$\frac{\partial Y}{\partial \omega} = \frac{\partial A}{\partial \omega} + \frac{\partial L}{\partial \omega} * \frac{\partial f}{\partial L} + \frac{\partial X}{\partial \omega} * \frac{\partial f}{\partial X}$$

An increase in wage may affect TFP either positively or negatively. Suppose that farmers participate in the labor market and send wage income to their households in rural areas and they use this increased income for investing on farming. Then, while the term $\frac{\partial X}{\partial \omega} * \frac{\partial f}{\partial X}$ is positive, the term $\frac{\partial L}{\partial \omega} * \frac{\partial f}{\partial L}$ is negative and the sign of $\frac{\partial A}{\partial \omega}$ is indefinite. On the other hand, if farmers use wage incomes for human capitals and invest in education and health care instead, then the term $\frac{\partial X}{\partial \omega} * \frac{\partial f}{\partial X}$ will be 0. Therefore, the total effect of an increased wage on outputs is indefinite.

If we extend this model and decompose total labor L into female labor L_f and male labor L_m (in later context *F_FWH, M_FWH*), the production frontier is written as

$$Y = A\, f(L_f, L_m, X),$$

The marginal wage effect becomes

$$\frac{\partial Y}{\partial \omega} = \frac{\partial A}{\partial \omega} + \frac{\partial Lf}{\partial \omega} * \frac{\partial f}{\partial Lf} + \frac{\partial Lm}{\partial \omega} * \frac{\partial f}{\partial Lm} + \frac{\partial X}{\partial \omega} * \frac{\partial f}{\partial X}$$

This effect is even more complicated. When the male household head works off farm, the effect of off-farm work participation via male labor, $(\frac{\partial Lm}{\partial \omega} * \frac{\partial f}{\partial Lm})$, is negative. On the other hand, its effect via female labor, $\frac{\partial Lf}{\partial \omega} * \frac{\partial f}{\partial Lf}$, seems to be positive, as many researchers found (de Brauw et al., 2008 and Song, 1999). Without more detailed information, we cannot tell how the left-behind-farm members (housewife and other elder women) perform on the farm, what kind of farm technology women adopt, or how women utilize agricultural inputs, which makes the sign of the other terms remain unknown.

In summary, to understand effects of off-farm work on farm productivity and effects of more female farm workers on farm productivity, we need further empirical analysis. To study these effects in more details, it is important to recall the idea of Nishimizu and Page (1982). If we write a stochastic production frontier (SPF) as

$$Y = f(L, X) + e, \qquad e = v + u.$$

In this equation, v denotes a disturbance term which cannot be controlled in agricultural production (e.g. weather), while u denotes a deviation of actual outputs from outputs which can be produced using the best production technology available to farm households. This relation implies that we can decompose changes (or differences) in TFP into those in technology level and "technical efficiency". Consequently, we use this framework throughout this dissertation to examine effects on farm productivity of participation in wage work or more females on farm production.

Empirical analysis in Chapters 3 and 4 of this dissertation uses data of 9200 rural households in CHIP2002. Gustafsson, Li, and Sicular (2008) and Knight, Deng, and Li (2011) provide a detailed description of the survey. We examine about 4000 households for which data on relevant variables are not missing and the following conditions are satisfied: 1) revenues from grains, economic crops, and livestock production are positive; 2) both crop production costs and cultivated land areas are positive; and 3) the household head is a married male and he as well as his wife works on his own farm. The empirical analysis also uses data on village-level variables from the Administrative Village Questionnaire annexed to CHIP2002. To allow for regional differences in farm production and labor market, we classify 22 provinces, autonomous regions, and directly administered municipalities into Eastern, Central, and Western regions.[1] Production frontiers are estimated by regional data for Chapter 3 due to the "regional characteristic" of off-farm work and on-farm work, by both national data and regional data for Chapter 4, however we focus only on the results from estimation of national data for Chapter 4 because of the complexity of our definition of female-managed households.

1.4. Organization of this Dissertation

Organization of this dissertation is as follows. Chapter 2 reviews studies relative to effects of off-farm work on farm productivity, effects of more female farm work on farm productivity, and estimation of SPF for farm production. Chapter 3 tackles the first objective proposed in the last subsection, that is, how household heads' participation on wage work affects farm technology level and technical efficiency in rural China. Chapter 4 deals with the second objective, that is, how more female labor affects farm technology level and technical efficiency in rural China. Chapter 5 concludes this dissertation.

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[1] The Eastern region includes Beijing, Hebei, Liaoning, Jiangsu, Zhejiang, Shandong and Guangdong. The Central region includes Shanxi, Jilin, Anhui, Jiangxi, Henan, Hubei and Hunan. The Western region includes Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu and Xinjiang.

Chapter 2. Literature Review

This chapter review studies on relation between wage work and farm productivity (or outputs), those on labor division within rural Chinese households, and those on stochastic production frontiers (SPF) estimation for farm households.

Regarding relation between wage work and farm production (or technical efficiency (TE)), Rozelle, Taylor and de Brauw (1999) analyze relationship between migration and farm productivity based on the new economics of labor migration. They find a negative effect of migration (and remittances) on maize outputs. They suggest the policy makers not to neglect improving efficiency of rural markets to alleviate this negative effect. Goodwin and Mishra (2004) empirically show a negative relation between off-farm labor supply and farming efficiency and emphasize the importance of joint determination of off-farm labor supply and farming efficiency. Mochebelele and Winter-Nelson (2000) estimate Cobb-Douglas SPF separately for households with and without migrants in Lesotho to show that TE is 12% higher for households with migrants. Conversely, Chang and Wen (2011) estimate a similar SPF for rice farmers in Taiwan to show that technical efficiency of households without off-farm workers is slightly higher.

Regarding labor division within Chinese farm households, Chang, Dong, and Macphail (2011) address the issue of left-behind elderly people and children in rural China and examine impacts of labor migration on their time allocation. Using data from the China Health and Nutrition Survey between 1997 and 2006, they show that migration of household members increases the burden of left-behind elderly in domestic and farm work. Mu and van de Walle (2011) examine a similar issue to find little impacts of migration on the health outcomes but more farm work for women left behind in rural areas. They emphasize that left-behind women work longer in farm work at the cost of fewer off-farm works and without any increase in decision-making responsibility over the household's farming activities.

Furthermore, Fan (2009) study complicated division of labor between migration work and farm work. She uses a traditional model of husband-work-outside and wife-work-inside and an outside-outside model to find that the household labor allocation has been changed profoundly and that this is due to support of the extended family assisted by intergenerational and inter-household division of labor. In relation to this study, Ma and Zhou (2009) find that interprovincial migration contributes to income transfer to the elderly and that the elderly are more likely to be satisfied economically for households with migrant children.

Regarding effects of more female farm labor on farm productivity, Quisumbing.(1996) surveys this issue and points out that most studies estimating sexual difference in technical efficiency use too strict or flawed assumption. The allocative efficiency within the household originates from differences of relative scarcities of labor and gender division of labor which should not be neglected. He believes appropriate estimation methods, endogenous input choice, the headship variable, and the implications of intra-household resource allocation should call for more attention of researchers.

Zhang, de Brauw, and Rozelle (2004) discuss the development of rural labor markets in China and use a fixed effects regression to show that women do not have lower efficiency in crop production when they are the head of the farm. de Brauw et al. (2008) debunked the myth that feminization is undergoing in Chinese agriculture. They argue that women take on a large part of on-farm work, but their share of farm work is no more than half of the agricultural labor, this share is not increasing, and women's role in management is also relatively minor. They also find that farms taken care of by women can be more efficient, women face similar constraints to men, the plot-level earnings for farms managed by women is at least equivalent to those managed by men, and income per capita of women-managed farm households is higher than that of a men-managed farm households.

In relation to these studies, Moock (1976) investigates sexual difference in production knowledge for small-scale maize farmers in Kenya. He concludes that effect of education is greater for women than for men, primary education helps small-scale farming to acquire useful farming information, and women have poorer accessibility to extension than men. Furthermore, Peterman et al. (2010) investigates gender differences in agricultural productivity using 2005 data from Nigeria and 2003 data from Uganda. The results show that female-owned plots and female-headed households have lower productivity. They suggest that more detailed data and analysis of agricultural research for diverse regions can help examine better policy making to increase productivity and program effectiveness for male and female farmers.

Finally, we review two papers on estimation of SPF for farm households. Chen, Huffman, and Rozelle (2009) estimate a translog SPF to examine farm technology level and the technical efficiency for four regions in China. They find that industrial inputs are overused in the eastern region, capital input is inefficiently used in the northern region, and the marginal product of labor is low for most regions. They also found similar TE across regions and relate it to farmer's age, land fragmentation, and the village migration rate after controlling for year and regional fixed effects.

Rezitis et al. (2003) investigate factors affecting TE for Greek farms. The results show that value of liabilities, number of hours of mechanical operation, land size and rental land have positive effects on TE, while subsidies from EU, off-farm family income, and hired labor have the opposite effects. Furthermore, investment of farm households which participate in the 1994 credit program does not increase TE significantly and the average TE of participants is even lower than their TE before participation, which leads to the conclusion that the program failed to increase their TE.

Chapter 3. Effects of Household Heads' Wage Work on Farm Technology Level and Technical Efficiency in China

3.1. Background of this Chapter

As China's economy develops, farm households have more opportunities in the wage employment sector. More farmers will choose to reallocate their time from the agricultural sector to the non-agricultural sector if the latter offers higher wages than the reward from farming. For example, the Chinese Household Income Project survey of 2002 (hereinafter CHIP2002; Li, 2002) verifies that wage work has recently gained economic importance in rural China: nearly 60% of household heads participate in wage work and the share of wage income in total income exceeds 30%.

Such increased participation of rural households in wage work has been shown to have important effects on farm productivity. A farm household's participation in wage work could raise its farm productivity for several reasons. Wage income can be used to facilitate farm management through a more flexible purchase of inputs. Participation in wage work can also increase information about farm inputs and technology through better access to urban areas (Herdt and Mandac, 1981). However, on the other hand, farm productivity could decline if households increase wage work. According to Goodwin and Mishra (2004), wage work participation decreases farm households' attention to the optimal use of variable inputs and farm technology. It also changes the quality of inputs. More specifically, Mu and van de Walle (2011) and Chang, Dong, and Macphail (2011) explain that the migration of males increases farm work hours of females and the elderly left behind in rural areas. If increased participation of rural households in wage work deteriorates farm productivity, further economic development will threaten stable domestic supply of farm commodities in China.

Nonetheless, only a few studies have investigated the effects of more wage work on farm productivity and especially on technical efficiency. Mochebelele and Winter-Nelson (2000) estimate Cobb-Douglas stochastic production frontiers (SPF) separately for households with and without migrants in Lesotho. They find that the technical efficiency of households with migrants is 12% higher. Chang and Wen (2011) estimate a similar SPF for rice farmers in Taiwan. They find that the technical efficiency of households without off-farm workers is slightly higher than that of households with off-farm workers. Pfeiffer, Lopez-Feldman, and Taylor (2009) specify technical inefficiency as a function of off-farm incomes. They find for Mexican households that more off-farm incomes have a positive effect on farm technical efficiency. For Chinese households, many studies, including Chen, Huffman, and Rozelle (2009), have estimated farm technical efficiency, but no studies have estimated the effects of more wage work on technical efficiency.

Furthermore, it is important to decompose productivity into technology level and technical efficiency when estimating the effects of more wage work on farm productivity. Technology level represents the best production technology that is potentially available for all households. On the other hand, technical efficiency represents how efficiently each household actually produces its outputs in comparison with those that could be produced using the best technology. The distinction between technology level and technical efficiency is important because some policies might have different implications. For example, improved education of farmers will raise the technology level through their use of new inputs and crop varieties. However, it may not always raise technical efficiency. While education improves farmers' managerial ability, it also induces them to participate in off-farm activities, thereby reducing their attention toward farm production. Few studies have estimated the effects of more wage work on technology level and technical efficiency separately.

Using data from CHIP2002, this study estimates Cobb-Douglas SPF for farm households with and without a wage worker separately to compare the technology level and technical efficiency of the two groups of households.[2] After estimating the two frontiers, we follow the method of Kumbharkar, Tsionas, and Sipiläinen (2009) to compare them. We focus on wage work participation of household heads because they are most likely to participate in wage work, as we will see in the next section, and because their decisions on wage work are likely to have the greatest effect on farm technology and technical efficiency.[3] We adopt a similar approach to that of Mochebelele and Winter-Nelson (2000), rather than following Pfeiffer, Lopez-Feldman, and Taylor (2009), because there are no plausible ways to split the sample if we use wage incomes or hours to explain technical efficiency.[4] Finally, we examine factors affecting technical efficiency as most other studies estimating technical efficiency do.

The second section describes wage work participation of Chinese rural households and makes some inferences on the effect of this participation on farm productivity. The third section introduces SPF with a heteroskedastic error term and its estimation method. It also briefly explains procedures to compute technical efficiency and production frontiers. The fourth section examines estimated parameters of SPF, technical efficiency, production frontiers, and factors to determine technical efficiency. The final section summarizes the analysis and concludes the paper.

[2] This chapter prefers SPF to DEA method partly because the stochastic disturbance plays an important role in agricultural production due to weather shocks and partly because heteroskedasticity of technical inefficiency term is assumed to test its homoskedasticity.
[3] Some studies are interested in the effect of migration (mostly by young family members rather than the household head) on farm outputs for Chinese farm households (e.g., Yang, 2003). However, their results show that this effect is not significant.
[4] This method might suffer from sample selection bias. However, a standard way to correct this bias (i.e., adding the inverse Mills ratio as a regressor) does not solve the problem, as Kumbharkar, Tsionas, and Sipiläinen (2009) explain. For this reason, we just follow Mochebelele and Winter-Nelson (2000) and Chang and Wen (2011), although we need to carefully interpret our empirical results.

3.2. Wage Work Participation and Farm Production in Rural China

This empirical analysis uses data of 9,200 rural households in CHIP2002. Gustafsson, Li, and Sicular (2008) and Knight, Deng, and Li (2011) provide a detailed description of the survey. We specifically examine 4,391 households for which data on relevant variables are not missing and the following conditions are satisfied: 1) total production value from grains, economic crops, and livestock production is positive, 2) both crop production costs and cultivated land areas are positive, 3) the household head is a married male and he, as well as his wife, works on his own farm, and 4) each village includes at least two sample households.[5] The empirical analysis also uses data on village-level variables from the Administrative Village Questionnaire annexed to CHIP2002. To allow for regional differences in farm production and labor markets, we classify 22 provinces, autonomous regions, and directly administered municipalities into eastern, central, and western regions.

3.2.1. Wage Work Participation of Rural Households

We first examine wage work participation of 4,391 rural households in CHIP2002. Table 3.1 presents the participation rate of wage work by the household head, his wife, other adult males (excluding the head) and other adult females (excluding the head's wife). Wage work includes migration (working out of his or her home county at least 90 days in the survey year), the rate of

Table 3.1 Rate of Wage Work Participation by Rural Households (%)

	Head	Wife	Other males	Other females
Eastern Region	65.1 (6.2)	17.4 (0.7)	50.5 (13.5)	31.3 (10.2)
Central Region	62.9 (7.0)	10.1 (1.1)	44.2 (24.8)	26.7 (17.8)
Western Region	55.4 (8.0)	11.0 (0.9)	36.3 (19.2)	20.1 (11.7)

Note: Rate of migration is shown in parentheses.

[5] We need at least two households in each village to estimate the coefficient of village dummy variables (or to control for village fixed effects) in estimating SPF.

which is shown in parentheses. Over 50% of the household heads participate in wage work in all regions, but only 6–8% of them migrate. The participation rate of the wife is the lowest, and it is only 17% in the most developed region. Other adult males (most of them are the household head's sons) work for wages at a relatively high rate in all regions, and their migration rate (14–25%) is much higher than the household head. The participation rate of other adult females (most of them are the household head's daughters) is lower than other adult males, but it is much higher than the head's wife. These results are consistent with those found by Mu and van de Walle (2011) who use the China Health and Nutrition Survey over the period 1997–2006.

In summary, migrants are mainly composed of young adults, while most of the household heads and wives do not migrate but engage in farm work and/or local wage work – CHIP2002 shows that the average farm work hours are 1,021, 1,140, 655, and 636 for the head, his wife, other adult males, and other adult females, respectively. Also, the household head is most likely to participate in local wage work, while his wife is least likely to do so. Consequently, it seems plausible to focus on the household head when we examine the relationship between farm production and the wage work participation of rural households. For this reason, the subsequent analysis separates households with and without a wage worker depending on wage work participation of the head.

3.2.2. Comparison of Relevant Variables for Two Types of Households

We next compare farm inputs and outputs of households with and without a wage worker. Output Y is the sum of gross revenues from grains, economic crops, and livestock products and 10% of the livestock value.[6] When the gross revenues are not available, values consumed of

[6] Jacoby (1993) adds 20% of the livestock value in computing the value of outputs, although many other studies do not. The present study uses the intermediate value.

those commodities produced by the household are used. [7] Labor *FWH* (farm working hours) is the sum of work hours of the family and hired workers in the production of grains, economic crops, and livestock products.[8] Variable input *VC* for crop production is the sum of production costs of grains and economic crops (excluding costs of hired labor) and the value of grains used for seeds and seedlings. Variable input *VL* for livestock production is the sum of costs in livestock production (excluding costs of hired labor) and the value of grains used for feed. Farm capital *K* is the sum of the value of large- and medium-sized tools, machinery and equipment for farming, and livestock used for labor and food. Land *T* is the sum of cultivated own and rented land.[9] The share *irr_share* of irrigated land areas is used to control for the quality of land.

Table 3.2 presents means and standard deviations of these variables. In all regions, households without a wage worker produce a higher amount of output than those with a wage worker: the former produce 92%, 41%, and 47% more output in the eastern, central, and western regions, respectively. The much higher output of households without a wage worker is quite natural because their farm work hours should be much longer. In fact, their farm work hours are 61%, 42%, and 30% longer in the eastern, central, and western regions, respectively.

They also use much larger amounts of other inputs. In the eastern region, they use 45–68% more inputs (excluding *VL*) to produce 92% more output. They use 167% more of *VL* partly because they tend to produce more livestock products when the household head does not participate in wage work: the revenue share of livestock products is 22% and 25% for households with and without a wage worker in this region, respectively. In the western region, households

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[7] For households which miss the data on gross revenues, they are assumed to consume exactly what they produce on their farm. Of the 9,200 households originally included in the survey, the shares of households that miss the data for gross revenues from grains, economic crops, and livestock production are 6%, 8%, and 15%, respectively.
[8] We focus on total work hours because hours of hired workers occupy only about 1% in the total hours of family and hired workers on average.
[9] Most households in our sample do not rent land from other households. The average share of rented land in total land *T* is about 8%.

Table 3.2 Means and Standard Deviations of Variables for Households with and without a Wage Worker

Region	Eastern Region		Central Region		Western Region	
With or without a wage worker	With worker	Without worker	With worker	Without worker	With worker	Without worker
Sample size	852	456	1062	627	772	622
X [yuan]	6434	12332	6526	9209	6426	9424
	(7727)	(22766)	(5121)	(7622)	(5108)	(8747)
FWH[hours]	2002	3225	2061	2925	2933	3810
	(1538)	(2297)	(1358)	(1716)	(1719)	(2206)
VC [yuan]	1248	2098	1142	1634	1056	1811
	(1235)	(3021)	(1123)	(1482)	(1435)	(2394)
VL [yuan]	1485	3962	1164	1480	2012	2084
	(5518)	(19940)	(3091)	(4285)	(3409)	(5200)
K [yuan]	1970	3317	2068	3212	1601	3126
	(4444)	(4943)	(4190)	(4923)	(2584)	(5467)
T [mu]	5.477	7.962	7.968	10.297	5.808	9.850
	(5.000)	(9.531)	(8.005)	(9.639)	(4.841)	(10.10)
irr_share	0.679	0.609	0.573	0.452	0.497	0.511
	(0.391)	(0.411)	(0.421)	(0.424)	(0.358)	(0.397)
large_scale	0.266	0.439	0.282	0.394	0.206	0.407
	(0.442)	(0.497)	(0.450)	(0.489)	(0.405)	(0.492)
educ6	0.388	0.452	0.503	0.445	0.418	0.354
	(0.488)	(0.498)	(0.500)	(0.497)	(0.494)	(0.479)
educ9	0.383	0.296	0.261	0.255	0.281	0.159
	(0.486)	(0.457)	(0.439)	(0.436)	(0.450)	(0.366)
educ12	0.095	0.042	0.043	0.018	0.043	0.032
	(0.293)	(0.200)	(0.204)	(0.131)	(0.202)	(0.177)
age	45.97	49.33	41.72	46.55	42.62	46.61
	(9.452)	(9.646)	(8.756)	(9.911)	(9.287)	(10.90)
nonlabor_inc	0.510	0.493	0.437	0.494	0.283	0.303
[yuan/1000]	(1.646)	(1.807)	(1.710)	(1.720)	(1.052)	(1.544)
num_hh	3.609	3.950	3.920	3.997	4.187	4.682
	(1.050)	(1.195)	(0.994)	(1.194)	(1.260)	(1.531)
num_childlt6	0.092	0.138	0.179	0.169	0.210	0.259
	(0.297)	(0.364)	(0.405)	(0.419)	(0.491)	(0.494)
collective_pest	0.174	0.149	0.116	0.150	0.108	0.272
	(0.379)	(0.357)	(0.320)	(0.357)	(0.310)	(0.445)
collective_purchase	0.059	0.039	0.048	0.041	0.039	0.114
	(0.235)	(0.195)	(0.214)	(0.200)	(0.193)	(0.318)

Note: Standard deviations are shown in parentheses and units are shown in brackets. One mu is approximately equal to 0.067 ha.

without a wage worker use 70–95% more inputs (excluding *VL*) to produce 47% more output. They use only 4% more of *VL*, unlike those households in the eastern region, partly because they tend to produce more crops when the household head does not participate in wage work: the revenue share of livestock products is 41% and 34% for households with and without a wage worker in this region, respectively. Compared to the eastern and western regions, the input-output ratio seems similar between households with and without a wage worker in the central region: households without a wage worker use 27–55% more inputs to produce 41% more output.

These results allow us to make an inference about the productivity of households with and without a wage worker. The productivity of households without a wage worker is inferred to be higher in the eastern region, although they use much more amounts of inputs for livestock production. On the other hand, it is inferred to be lower in the western region, although they use much less amounts of inputs for livestock production. A similar inference for the central region is not so clear at this point. We estimate SPF to check these inferences and decompose the differences in productivity into differences in technology level and technical efficiency.

For the subsequent analysis, we introduce 10 variables to explain technical efficiency *TE* based on other studies (e.g., Chen, Huffman, and Rozelle, 2009; Sherlund, Barrett, and Adesina, 2002), which are shown in Table 3.3. The last column shows the sign of the effect of each variable on *TE*, which is explained in the following way. A household with larger farm land (*large_scale* = 1) tends to have higher *TE* because it can introduce more effective machinery or inputs in farm production. An increase in the number of household members (*num_hh*) improves *TE* partly because larger households can more easily mobilize labor to meet peak demands at the time of planting and harvesting. An increase in the number of young children (*num_childlt6*) tends to reduce *TE* because family members have to devote more time and attention to rearing young

Table 3.3 Variables to Explain Technical Efficiency (TE) and Their Expected Effects on TE

Variables	Description of the variables	Effect on TE
large_scale	Dummy variable taking value 1 if the household has larger land than the regional average.	+
educ6	Dummy variable taking value 1 if schooling years of the household head are between 6 and 8.	?
educ9	Dummy variable taking value 1 if schooling years of the household head are between 9 and 11.	?
educ12	Dummy variable taking value 1 if schooling years of the household head are more than 12.	?
age	Age of the household head	?
nonlaborinc	Household non-labor incomes [yuan]	?
num_hh	Number of household members	+
num_childlt6	Number of children younger than six years old	–
collective_pest	Dummy variable taking value 1 if the village collectively prevents and cures plant diseases and insect pests	+
collective_purchase	Dummy variable taking value 1 if the village provides the service of purchasing farm inputs unified	+

Note: In the column "Effect on TE", the signs show expected effects of the corresponding variables on technical efficiency.

children. Furthermore, collective pest control (*collective_pest* = 1) and collective purchase of inputs (*collective_purchase* = 1) are likely to facilitate farm management to raise *TE*.

Other variables are expected to have positive or negative effects on technical efficiency. More education (*educ6* = 1 or *educ9* = 1 or *educ12* = 1)[10] basically tends to raise *TE* because they increase the head's ability in farm management. On the other hand, higher education of the household head can cause lower *TE* partly because it raises the possibility for him to participate in wage work or work longer for wages, which reduces his attention to farm management. Higher age of the household head (*age*) may raise *TE* due to his longer farm experience, while it may lower *TE* due to his weaker physical strength. An increase in non-labor incomes (*nonlabor_inc*) [11]

[10] For households with *educ6* = *educ9* = *educ12* = 0, years of education of the household head are shorter than six.

[11] *nonlabor_inc* is the sum of non-wage incomes, subsidies received by joining the survey, net transfers received from the village and town (excluding taxes paid for production activities and wage work), and other incomes. This variable is deflated by the provincial price index estimated by Brandt

can raise *TE* through more flexible purchase of production inputs, while it might reduce household members' attention to farm production because those incomes in this study might include incomes from non-agricultural family operation.

Table 3.2 shows that the proportion of households whose head has more than 12 education years is 56%, 58%, and 26% smaller for households without a wage worker in the eastern, central, and western regions, respectively. It also shows that the proportion of households whose head has 9–11 years of education is 23%, 2%, and 43% smaller for households without a wage worker in the same regions. This result is consistent with the result of Jolliffe (2004): farm household members with higher education tend to engage in non-agricultural activities. Households without a wage worker also tend to have more children younger than six years old in the eastern and western regions. Finally, those households tend to receive a much larger amount of collective services of pest control and input purchases in the western region, showing that households can receive those services if the head mainly engages in farm production.

3.3. Empirical Method

A farm household uses labor *FWH*, input *VC* for crop production, input *VL* for livestock production, farm capital *K*, and land *T* to produce output *Y*. We specify its SPF as [12]

$$\ln Y = \beta_0 + \beta_1 \ln FWH + \beta_2 \ln VC + \beta_3 \ln VL + \beta_4 \ln K + \beta_5 \ln T + \beta_6 irr\_share + v - u\,, \quad (1)$$

where *irr_share* denotes the share of irrigated land areas. We assume that v is a normal random variable with mean 0 and constant variance σ_v^2 and $u \geq 0$ follows a half normal distribution with variance, σ_u^2.

Caudill, Ford, and Gropper (1995) emphasize that the heteroskedasticity of inefficiency

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and Holtz (2006).

[12] Livestock inputs *VL* and farm capital *K* take the value of 0 for some households. In this case, we follow Sherlund, Barrett, and Adesina (2002) to replace the values of these variables with $\zeta/10$ (ζ: the smallest positive value of the relevant variable in the sample).

variable u can have a serious effect on the estimated technical efficiency index. We apply this reason to specify the variance σ_u^2 as [13]

$$\ln\sigma_u^2 = \delta_0 + \sum_{k=1}^{10}\delta_k W_k \qquad (2)$$

For variable W_k, we use the 10 variables introduced in the second section.

Equation (2) not only gives a specification of heteroskedasticity of u but also represents the effects of variable W_k on an index of technical efficiency, $TE = E[\exp(-u) \mid W]$, where W includes all variables W_k, and explanatory variables in equation (1) are omitted from conditional variables for simplicity. If $\delta_k > 0$, an increase in W_k raises the variance σ_u^2, which means that non-negative inefficiency u can appear more rightward (non-positive efficiency $-u$ can appear more leftward), which in turn means $TE = E[\exp(-u) \mid W]$ decreases. Hence, variable W_k with positive coefficient δ_k is interpreted as a negative factor of *TE*. Conversely, if $\delta_k < 0$, an increase in W_k reduces the variance σ_u^2, which means that inefficiency u (and efficiency $-u$) is more likely to appear near 0, which means $TE = E[\exp(-u) \mid W]$ increases. Therefore, variable W_k with the negative coefficient δ_k is interpreted as a positive factor of *TE*.

We estimate the SPF (1) and the heteroskedasticity function (2) jointly by using the maximum likelihood method for each group of households. Specifically, the density function of the error term $\varepsilon = v - u$ under the present assumptions is written as

$$f(\varepsilon) = \{1 - \Phi(\lambda\varepsilon / \sigma)\}(2/\sigma)\phi(\varepsilon/\sigma) \qquad (3)$$

where $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\lambda = \sigma_u / \sigma_v$. ϕ and Φ respectively denote the density and cumulative distribution functions of the standard normal variable. After substituting equation

[13] A more popular way might be to assume a truncated normal distribution of technical inefficiency u and specify its mean as a function of W_k. We did adopt this method but could not obtain convergence in the parameters of SPF for our data.

(2) into $\sigma_u^2 = \exp(\ln \sigma_u^2)$ of equation (3), this density function is used to construct the likelihood function and to estimate parameters in equations (1) and (2) simultaneously. After this estimation, we follow Battese and Coelli (1988) to compute technical efficiency TE as:

$$TE = E[\exp(-u)\,|\,Y] = \{\Phi[(u^*/\sigma_*) - \sigma_*]/\Phi(u^*/\sigma_*)\}\exp[(\sigma_*^2/2) - u^*] \qquad (4)$$

where $u^* = -(v-u)\sigma_u^2/\sigma^2$ and $\sigma_*^2 = \sigma_u^2\sigma_v^2/\sigma^2$.

To compare the (deterministic) production frontiers for households with and without a wage worker, we use two approaches. The first is to compare the two sets of coefficients $\beta_1,\cdots,\beta_5$ in equation (1) using the Wald test. The second is to compute an index of predicted output in a manner similar to that of Kumbhakar, Tsionas, and Sipiläinen (2009). Let $\hat{Y}_1$ and $\hat{Y}_0$ denote outputs that can be predicted using deterministic frontiers (the right hand side of equation (1) excluding the terms u and v) of households with and without a wage worker. We compute both these predicted outputs for each household by substituting the actual amount of the five inputs and the actual share of irrigated land into the two deterministic frontiers.

To explain the second method in more detail, we simply express the production frontier of households with a wage worker as $Y = f_1(X)$ and that of households without a wage worker as $Y = f_0(X)$, where X denotes vector of inputs. Suppose household i has a wage worker and uses the amount X_i of inputs. Then, we can compute two predicted outputs $\hat{Y}_{1,i} = f_1(X_i)$ and $\hat{Y}_{0,i} = f_0(X_i)$ for household i. Whereas $\hat{Y}_{1,i}$ represents the largest amount of output when this household uses its own technology $Y = f_1(X)$, $\hat{Y}_{0,i}$ represents the largest amount of output if it could use the other technology $Y = f_0(X)$. Comparison of $\hat{Y}_{1,i}$ and $\hat{Y}_{0,i}$ for the same household allows us to control the amount of inputs and therefore to compare the distributions of $\hat{Y}_1$ and $\hat{Y}_0$.

3.4. Empirical Results

The SPF specified by equations (1) and (2) is estimated for each region and each type of household after adding village dummy variables.[14] [15] Table 3.4 presents the estimation results. Production elasticities of *FWH*, *VC*, *VL*, *K*, and *T* are estimated to be significantly positive at the 5% level for all groups of households. Although the coefficient of *irr_share* is not statistically significant for most cases, we keep this variable to achieve convergence in the parameter estimation and obtain plausible results for technical efficiency.[16]

Our production elasticities for the eastern and western regions can be compared with those for the eastern and southwestern regions estimated by Chen, Huffman, and Rozelle (2009) (hereinafter CHR) and those for Jiangsu (eastern) and Sichuan (western) provinces estimated byLiu and Zhuang (2000) (hereinafter LZ). Although our production elasticity of labor (0.29 or 0.23 for east and 0.07 or 0.13 for west) tends to be higher than that of CHR and LZ, it is similar to CHR (0.12 for east and 0.07 for southwest) because the elasticity is higher in the eastern region. On the other hand, our production elasticity of land (0.24 or 0.25 for east and 0.23 or 0.26 for west) is much lower than that of CHR and LZ, which is higher than 0.40. Our production elasticity of farm capital (0.03 for east and 0.05 or 0.02 for west) also tends to be lower than that of CHR and LZ, which is between 0.01 and 0.20. The differences in these results arise probably

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[14] The numbers of villages in our sample are 204, 242, and 189 for households with a wage worker in the eastern, central, and western regions, respectively. The corresponding numbers for households without a wage worker are 133, 171, and 175.

[15] Output Y includes both crops and livestock products in our empirical study. If we estimate equations (1) and (2) using this output, the difference in production frontiers or technical efficiency between different groups can arise from the difference in the revenue share of livestock products between them. To examine this possibility, equations (1) and (2) were re-estimated by adding the revenue share of livestock products as a regressor in the two equations. The result showed that our essential conclusion was not affected by this consideration. In addition, when this share was computed for households with and without a wage worker, it was 22% and 25% for the eastern region, 24% and 23% for the central region, and 41% and 34% for the western region. The result shows that the difference in composition of farm products is negligible between the two groups for the eastern and central regions, although it might not for the western region.

[16] When *irr_share* is excluded, convergence in parameter estimation is not achieved for one group of households and estimated technical efficiency *TE* extremely concentrates near 1 for two groups of households.

Table 3.4 Estimated Parameters of Stochastic Production Frontiers and Variance Functions for Households with and without a Wage Worker

Region	Eastern Region		Central Region		Western Region	
With or without a wage worker	With worker	Without worker	With worker	Without worker	With Worker	Without worker
Sample size	852	456	1062	627	772	622
ln*FWH*	0.2857	0.2268	0.1619	0.1199	0.0732	0.1306
	(9.15)	(4.66)	(6.28)	(3.00)	(2.65)	(3.44)
ln*VC*	0.2486	0.2438	0.2149	0.2578	0.2612	0.1542
	(10.45)	(6.23)	(10.97)	(8.09)	(11.81)	(6.33)
ln*VL*	0.0723	0.0768	0.0831	0.0851	0.0943	0.0903
	(11.44)	(8.32)	(15.23)	(10.27)	(11.63)	(9.72)
ln*K*	0.0306	0.0268	0.0274	0.0185	0.0536	0.0181
	(3.51)	(2.04)	(4.72)	(2.15)	(5.91)	(2.44)
ln*T*	0.2368	0.2523	0.3202	0.2998	0.2283	0.2572
	(5.60)	(4.36)	(10.20)	(6.62)	(7.12)	(6.14)
irr_share	0.1286	0.2041	0.0767	-0.0655	0.0024	0.5213
	(1.24)	(1.47)	(0.77)	(0.52)	(0.03)	(4.54)
Variance function						
large_scale	-2.6660	1.2399	-0.5028	-0.0532	0.2481	-0.9241
	(1.56)	(1.90)	(0.83)	(0.07)	(0.55)	(2.57)
educ6	0.0589	-1.2710	-1.1264	-1.1913	0.5948	-0.3349
	(0.12)	(0.84)	(2.77)	(1.13)	(1.32)	(1.30)
educ9	-0.2438	1.8546	-1.1666	-1.6632	0.3884	0.3105
	(0.46)	(1.84)	(2.74)	(1.18)	(0.79)	(1.00)
educ12	-1.7068	2.5133	-2.3071	0.2469	-0.7545	-1.7696
	(1.46)	(2.01)	(1.58)	(0.18)	(1.01)	(1.74)
age	-0.0054	0.0010	-0.0164	-0.0145	-0.0639	0.0092
	(0.30)	(0.02)	(0.77)	(0.34)	(2.70)	(0.83)
nonlaborinc	-0.0896	0.4776	-0.7884	0.2446	0.2017	0.2859
	(0.57)	(2.43)	(1.60)	(1.87)	(2.07)	(3.28)
num_hh	-0.5781	-0.3531	-0.1058	-0.2104	-0.8946	-0.0202
	(1.96)	(0.95)	(0.60)	(0.53)	(3.44)	(0.25)
num_childlt6	1.1339	-4.2839	0.5063	0.6688	0.4211	0.1387
	(2.07)	(1.28)	(1.53)	(1.21)	(1.39)	(0.62)
collective_pest	-1.7716	5.3993	1.4708	2.5197	3.0937	-0.6131
	(0.78)	(3.78)	(2.12)	(1.45)	(5.05)	(1.24)
collective_purchase	1.0109	1.8216	-0.1508	-5.1524	-0.5240	-27.6097
	(1.05)	(0.65)	(0.16)	(1.14)	(0.79)	(0.02)
constant	-0.2193	-6.2973	-1.5029	-2.7877	1.5701	-2.1557
	(0.15)	(2.11)	(1.40)	(1.11)	(1.12)	(2.99)
σ_v	0.3633	0.3858	0.2779	0.2793	0.2426	0.2157
	(24.25)	(27.64)	(22.85)	(19.96)	(25.31)	(14.94)
log-likelihood	-405.34	-241.67	-227.68	-114.00	-89.30	-104.35
LR test of homoskedasticity	26.08 [0.00]	36.44 [0.00]	26.90 [0.00]	16.71 [0.08]	Not available	44.22 [0.00]

Note: Absolute values of the *t* statistics are shown in parentheses and the upper tail area for χ^2 (10) is in brackets. To save space, the estimated coefficients of the village dummy variables and the constant term of SPF are not shown.

because outputs and inputs in this study cover livestock production, whereas those in CHR and LZ do not.

3.4.1. Comparison of Production Frontiers

First, we briefly compare the production elasticities between households with and without a wage worker. Although production elasticities of *VL* and *T* are similar between the two groups for any region, those of *FWH, VC*, and *K* differ for most cases. We use the Wald test to check equivalence across the five production elasticities between the two groups. The test statistics are computed as 1.29 [0.94], 2.53 [0.77], and 24.89 [0.00] for the eastern, central, and western regions, respectively, which can be compared with critical values of χ^2 distribution with five degrees of freedom (p-values are shown in brackets). The result shows that equivalence of the deterministic production frontiers of the two groups is not rejected for the eastern and central regions, whereas it is rejected for the western region.

Next, we compare the deterministic frontiers between the two groups of households by following the method of Kumbharkar, Tsionas, and Sipiläinen (2009).[17] The averages of the predicted outputs $\hat{Y}_1$ and $\hat{Y}_0$ (maximum outputs that can be produced using technologies of households with and without a wage worker) are 7,792 (6,557) and 9,560 (18,347) for the eastern region, 7,942 (4,795) and 8,493 (8,409) for the central region, and 8,116 (5632) and 9,641 (6,801) for the western region, where standard deviations are shown in parentheses. Therefore, on

[17] Because villages in the sample differ for the two groups of households, we evaluate the intercept of the SPF in the following way. For a village that includes both groups of households, we evaluate its intercept using the constant term and the coefficient of the corresponding village dummy. For a village that includes only households with a wage worker in the sample, we evaluate its intercept to compute $\hat{Y}_1$ in the same way as above. For this village, however, we evaluate its intercept to compute $\hat{Y}_0$ using the constant term and the average of available coefficients of village dummies. A similar procedure is applied to the evaluation of the intercept for a village that includes only households without a wage worker in the sample.

average, the deterministic frontier is higher for households without a wage worker in all regions after controlling for input amounts.

Because the average of $\hat{Y}_1$ and $\hat{Y}_0$ can be sensitive if their distributions are skewed, we compare their kernel density (a smoother version of the histogram) for each region in Figure 3.1 (a)–(c). In these figures, the horizontal axis measures the amount of predicted output ($\hat{Y}_0$ or $\hat{Y}_1$) and the vertical axis measures its density, with the dotted and solid lines respectively drawn for $\hat{Y}_0$ and $\hat{Y}_1$. For the eastern and central regions, $\hat{Y}_0$ and $\hat{Y}_1$ seem to have a similar distribution, although $\hat{Y}_1$ has a little higher density at smaller output and $\hat{Y}_0$ tends to have a little higher density at larger output. For the western region, the distribution of $\hat{Y}_0$ is located more rightward for any output level. Consequently, the deterministic frontier of households without a wage worker is higher only for households with relatively large output in the eastern and central regions, whereas it is always higher in the western region. This finding is consistent with the result of the Wald test above.

The higher production frontier of households without a wage worker can be attributed to their higher production elasticities, their higher coefficient on irrigation share, or the higher intercept of their production frontier. For the eastern region, the production elasticities are similar between the two types of households and the production elasticity of labor is lower for households without a wage worker.[18] Therefore, their higher production frontier is inferred to come from their higher intercept or their higher managerial ability and land quality which cannot be observed by researchers. A similar explanation seems to apply to the result for the central region, although households without a wage worker have a slightly higher production elasticity of crop inputs.

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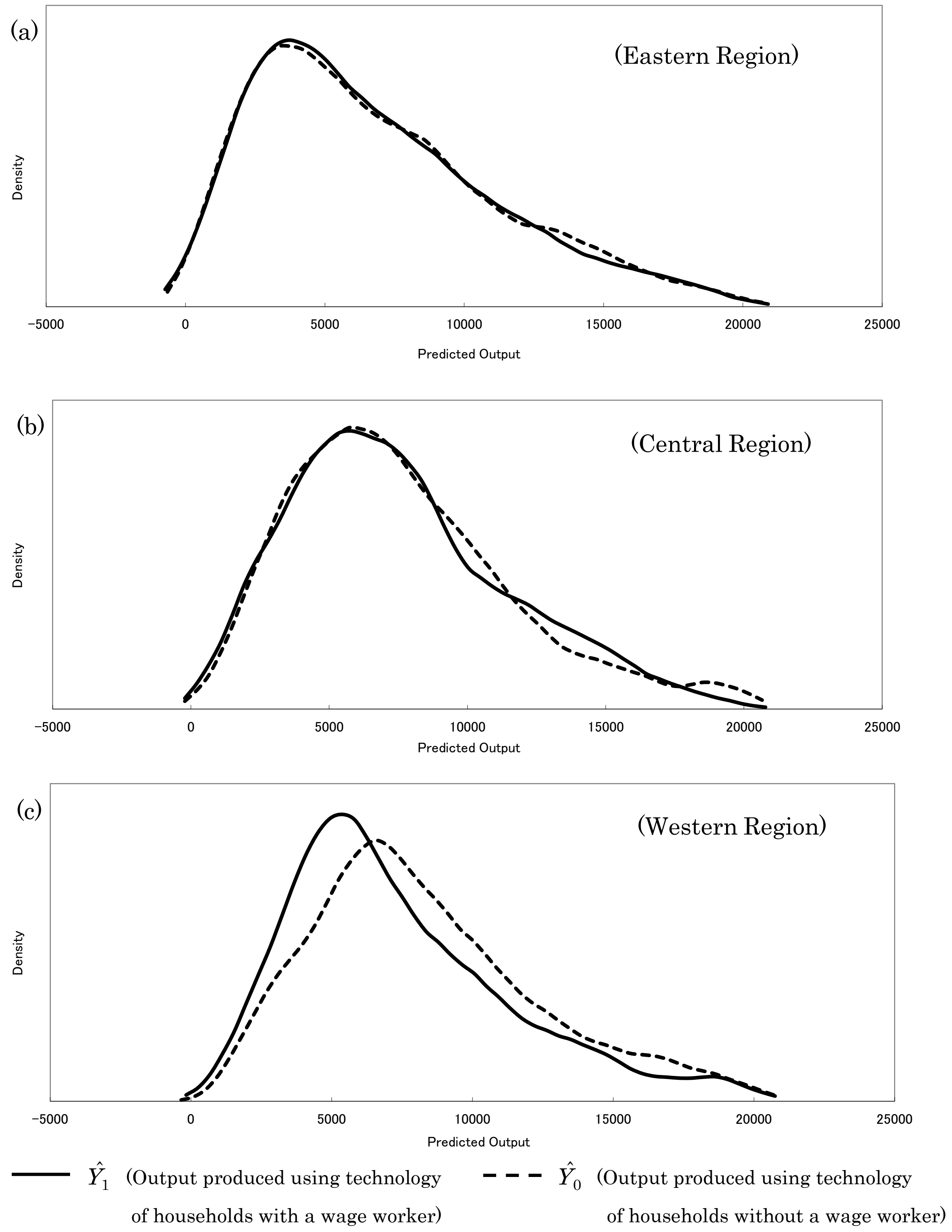
[18] The lower production elasticity of labor for households without a wage worker in the eastern region suggests the increasing number of farm households which are managed by the elderly. In fact, Table 3.2 shows that the average age of the household head is the highest for households without a wage worker in this region.

Figure 3.1 Distributions of Predicted Outputs under Production Technologies of Households with and without a Wage Worker (Regional)



For the western region, households without a wage worker have a higher production elasticity of labor and a higher coefficient of irrigation share. Their higher coefficient of irrigation share suggests that it is difficult to effectively manage water use without the household head working on farm actively because the western region is more likely to suffer from natural disasters.[19] Regarding the higher production elasticity of labor, the household head tends to have lower farm productivity due to lower quality (or effort) of his labor when he engages in full-time wage employment and works on farm only at peak seasons.

3.4.2. Comparison of Technical Efficiency and its Determinants

Table 3.4 also presents the estimated coefficients of the heteroskedasticity function (2). Many of the individual coefficients are statistically insignificant at the 5% level, suggesting some difficulty in estimating effects of those factors on technical inefficiency using the variance σ_u^2. Nonetheless, the likelihood ratio test for homoskedasticity of technical inefficiency u reveals joint significance of coefficients δ_k $(k=1,\cdots,10)$ in equation (2), as shown at the bottom of Table 3.4.[20] For this reason, we use the results under heteroskedasticity for the subsequent discussion.[21]

Before interpreting the significant coefficients in Table 3.4, we compare technical efficiency (*TE*) between households with and without a wage worker, which is estimated using equation (4). The average *TE* for households with and without a wage worker are 0.86 (0.09) and 0.92 (0.13) for the eastern region, 0.88 (0.07) and 0.92 (0.07) for the central region, and 0.88 (0.10) and 0.81

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[19] The Administrative Village Questionnaire annexed to CHIP2002 shows that 45%, 49%, and 66% of villages in the eastern, central, and western regions had natural disasters in 2002.

[20] For households with a wage worker in the western region, we cannot compute the test statistic because parameter convergence is not achieved under homoskedasticity of *u*. However, the individual coefficients of *age*, *nonlabor_inc*, *num_hh*, and *collective_pest* are significant, suggesting rejection of homoskedasticity for this case.

[21] Another reason to use all those factors is to achieve parameter convergence and obtain plausible results for technical efficiency. When we assume homoskedasticity of *u*, parameter convergence is not achieved for one case and technical efficiency extremely concentrates near 1 for four cases.

(0.13) for the western region, where standard deviations are shown in parentheses. The average *TE* is higher for households without a wage worker in the eastern and central regions, while it is higher for those with a wage worker in the western region. The two studies CHR and LZ cited above estimate *TE* at 0.73–0.77 for the eastern region and 0.55–0.69 for the (south) western regions using the data on crop production in China. Our estimates are higher than theirs but are similar in that the average *TE* is lower in the western region. Our higher estimates seem plausible partly because our inputs and outputs cover livestock production, for which Latruffe et al. (2004) find a 15% higher *TE* than for crop production in Poland.

Figure 3.2 (a)–(c) depict the kernel density of *TE* for the two groups of households in each region. The horizontal axis measures *TE* and the vertical axis measures its density, with the solid and dotted lines respectively drawn for households with and without a wage worker. Unlike Figure 3.1, Figure 3.2 exhibits distinct distributions for the two groups in all regions. For the eastern and central regions, *TE* for households without a wage worker concentrates around 0.95-0.99, whereas *TE* for households with a wage worker has a wider distribution with its mode locating around 0.90–0.94. For the western region, on the contrary, the former has a wider distribution with its mode locating around 0.85, whereas the latter concentrates around 0.92.

In summary, households without a wage worker are more technically efficient in the eastern and central regions, whereas those with a wage worker are more technically efficient in the western region. To investigate reasons for this result, we first examine effects of the variables W_k in equation (2) on technical efficiency *TE*. Table 3.5 presents the result of regression of estimated *TE* on these variables. Although this method might cause biased estimates of the parameters, as pointed out by Wang and Schmidt (2002), we find the result in Table 3.5 to be plausible because we obtain a similar result by applying the interpretation of the coefficient δ_k (variable W_k with $\delta_k > 0$ has a negative effect on *TE*) to their estimates in Table 3.4.

Figure 3.2 Distributions of Technical Efficiency Index for Households with and without a Wage Worker (Regional)

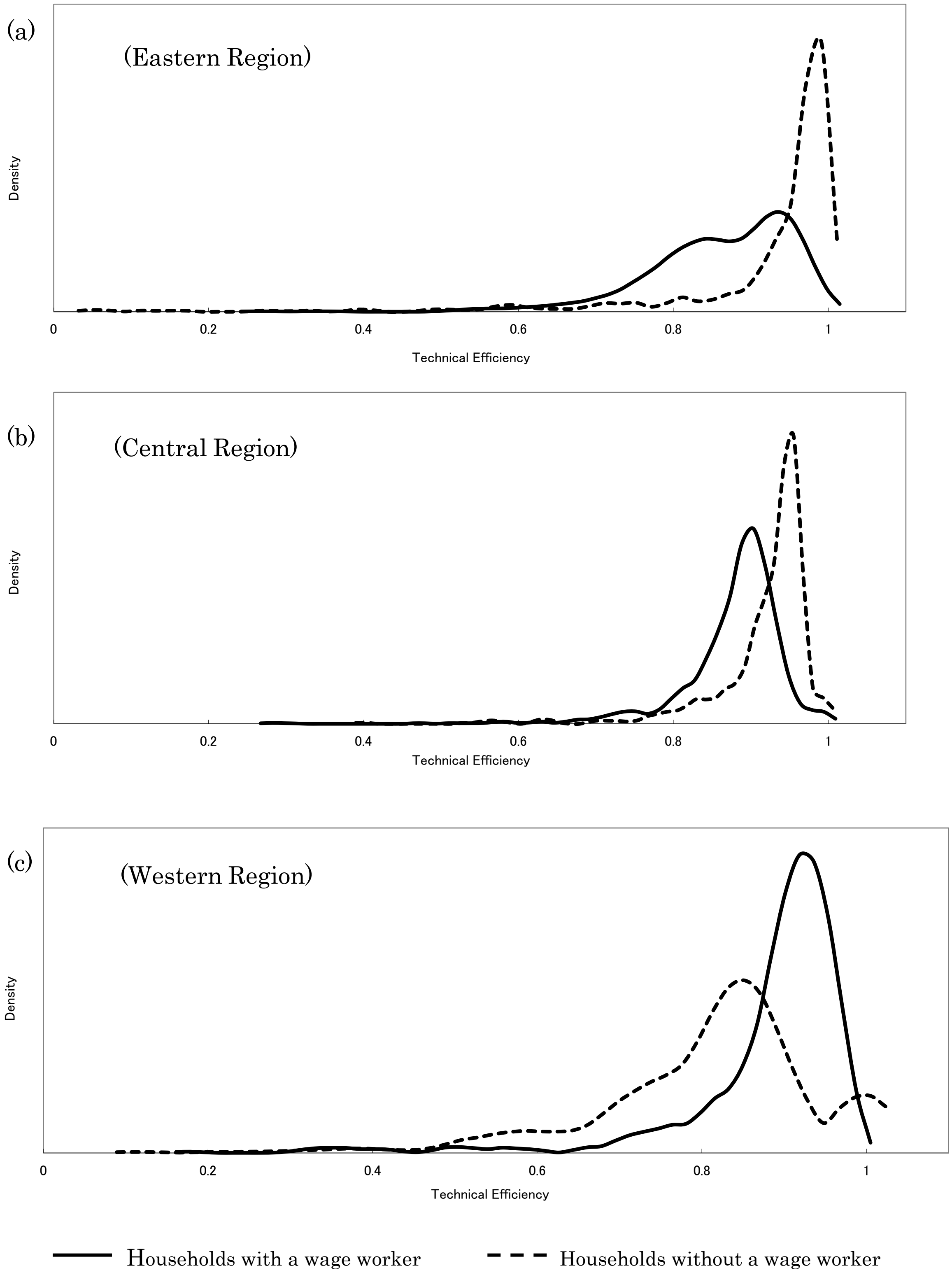


Table 3.5 Results of Ordinary Least Squares Regression of Technical Efficiency

Region	Eastern Region		Central Region		Western Region	
With or without a wage worker	With worker	Without Worker	With worker	Without worker	With worker	Without worker
Sample size	852	456	1062	627	772	622
large_scale	0.1101	-0.0351	0.0248	-0.0068	-0.0170	0.0713
	(14.07)	(1.80)	(4.16)	(0.93)	(1.62)	(3.69)
educ6	-0.0081	0.0149	0.0653	0.0494	-0.0265	0.0266
	(1.08)	(1.11)	(10.32)	(8.45)	(3.34)	(2.38)
educ9	0.0119	-0.0556	0.0671	0.0621	-0.0212	0.0097
	(1.49)	(3.82)	(10.55)	(11.67)	(2.35)	(0.53)
educ12	0.0777	-0.0471	0.1039	-0.0167	0.0382	0.1035
	(8.50)	(0.90)	(11.32)	(1.11)	(1.94)	(2.75)
age	0.0001	0.0004	0.0008	0.0004	0.0024	-0.0013
	(0.32)	(1.01)	(4.13)	(2.15)	(7.81)	(2.17)
nonlaborinc	0.0039	-0.0204	0.0106	-0.0122	-0.0112	-0.0065
	(3.15)	(6.42)	(5.08)	(7.37)	(3.06)	(0.57)
num_hh	0.0306	0.0068	0.0046	0.0078	0.0339	0.0094
	(10.99)	(1.83)	(2.63)	(4.67)	(13.12)	(2.21)
num_childlt6	-0.0593	0.0372	-0.0295	-0.0276	-0.0286	-0.0292
	(7.15)	(3.04)	(5.20)	(3.59)	(4.51)	(2.79)
collective_pest	0.1451	-0.0698	-0.0367	0.0466	-0.1912	0.1967
	(2.34)	(1.23)	(1.59)	(1.51)	(3.69)	(0.79)
collective_purchase	-0.1087	0.0162	-0.0061	0.0482	0.0727	0.1244
	(1.68)	(0.30)	(0.33)	(4.29)	(1.38)	(3.73)
$\bar{R}^2$	0.5995	0.7071	0.4892	0.7072	0.5920	0.2964

Note: Absolute values of the t statistics (based on robust standard errors) are shown in parentheses. To save space, the estimated coefficients of the village dummy variables and the constant term are not shown. $\bar{R}^2$ denotes the adjusted coefficient of determination.

Therefore, we use the result in Table 3.5 to examine statistically significant effects of W_k on *TE*.

Variables *large_scale*, *num_hh*, *num_childlt6*, *collective_pest*, and *collective_purchase* have expected effects on *TE* in most cases. As we examined in Table 3.3, larger cultivated land, more household members, fewer children, and more collective pest control and input purchase raise technical efficiency. The three education dummies have positive coefficients for most cases, implying that households with higher education (than those with schooling years shorter than six years) have higher *TE*. The negative coefficient for households without a wage worker in the eastern region suggests that the household head tries harder to search for wage work if he has relatively high education (*educ9* = 1) but he does not participate in the labor market, which can lower *TE*. The negative coefficient for households with a wage worker in the western region suggests that the household head tends to have a relatively stable job (rather than a seasonal or temporary job) as wage work, which can reduce attention to farm production to lower *TE*.

Furthermore, age of the household head (*age*) has a positive effect on *TE* for most cases, implying that longer farm experience tends to raise technical efficiency. Non-labor incomes (*nonlabor_inc*) have a negative effect on *TE* for households without a wage worker partly because their family members might engage in non-agricultural family operation and they might lose their attention to farm production. On the other hand, non-labor incomes tend to have a positive effect on *TE* for those with a wage worker partly because non-labor incomes in addition to wage incomes further facilitate flexible purchase of production inputs.

Finally, we find some reasons for the different *TE* between households with and without a wage worker by comparing the regression coefficients in Table 3.5 and the sample means of W_k in Table 3.2.[22] If we focus only on statistically significant coefficients and marked difference in sample means of W_k, we find the following factors important to explain higher *TE* for the relevant households. For the eastern region, households without a wage worker are more technically efficient because the higher coefficient of *num_childlt6* and the higher mean of *large_scale* contribute to the higher *TE* for these households.[23] For the central region, households without a wage worker are more technically efficient because the higher coefficient of

[22] The idea is similar to the Oaxaca-Blinder decomposition.
[23] Note that *num_childlt6* has a positive effect on *TE* for these households.

collective_purchase and the higher mean of *large_scale* contribute to the higher *TE* for these households. Therefore, households without a wage worker in both the eastern and central regions are more technically efficient partly because of their larger farm land. For the western region, households with a wage worker are more technically efficient because the higher coefficient of *age* and *num_hh* and the higher mean of *educ12* contribute to the higher *TE* for these households.[24] Therefore, they have higher *TE* because they have more members with higher education and because they are better at raising technical efficiency from longer experience on farm and more family members.

3.5. Concluding Remarks

This study uses a Chinese household income survey from 2002 to estimate stochastic production frontiers for farm households with and without a wage worker to determine effects of the head's participation in wage work on farm productivity in China. Using the estimated frontiers, it compares deterministic production frontiers (technology levels) and technical efficiency of the two groups of households and examines determinants of technical efficiency.

In the eastern and central regions, typical households with a wage worker tend to have lower farm productivity because of their lower technical efficiency. We can attribute this lower technical efficiency to their smaller farm land. One implication of this result is that domestic food supply in these regions will stagnate or deteriorate as rural household heads participate more in wage work as economic development provides more opportunities to increase nonfarm income. To improve the lower technical efficiency in these regions, an important policy is to make the land market more active and allow farm households to expand their cultivated land.

[24] Note that *age* has a negative effect on *TE* for households without a wage worker probably because weaker physical strength of older members can decrease *TE* in the western region where the value share of livestock production is much higher.

In the western region, typical households with a wage worker may have higher farm productivity because of their higher technical efficiency. We can attribute this higher technical efficiency to better education of the household head and better utilization of farming knowledge and family members. One implication of this result is an increase in domestic food supply in this region along with further economic development. This improvement, however, might be limited because it depends on more farm work by women and the elderly. To make the domestic food supply sustainable, it is important to encourage farmers in this region to use more farm machinery and a newer variety of crops, which not only helps women and the elderly improve farm production but also boosts the production frontier to increase the domestic food supply in this region.

Chapter 4. Effects of More Female Labor on Farm Productivity in China

4.1. Background of this Chapter

Performance of female labor in Chinese agriculture has been a popular and important topic in the literature on studying Chinese agriculture. The proverbs "Men plough, women weave", "Men rule outside, women rule inside" used to depict the domestic labor allocation in rural Chinese traditional households that men work mainly on farm and other work outside the households while women mainly do domestic work such as housework and taking care of children and elders.

After the Chinese economic reforms started in the late 1970s, rural and urban labor markets grew rapidly, which gave rural people more opportunities to access off-farm labor market. Researchers find under this background that men are more prone to choose to work in more profitable sectors (industrial or other nonagricultural sectors), leaving women to do not just domestic work but also on-farm work (Song, et al., 2009). Zhang et al. (2004) give further explanation that only youngest age group (16-20) of females has fair access to labor market as males but middle-aged females (36-50) remain in rural area. Jacka (1997) states: "……In township enterprise sector, fewer women than men are employed, in part because the recruitment policies of some industries, especially heavy industries, discriminate against them. Some township enterprises also do not employ women after they have married nor had a child. Wage tends to be lower than men, few chances for promotion……" She also thinks that women are more likely to undertake on-farm work in combination with domestic work and child-care if they have choices.

As a result, female labor allocated on farm work becomes more than male labor. The share of average hours of farm work done by women in 1990s is averagely above 50% (de Brauw et al., 2008). In the poorer and more marginal areas, female labor even occupies 80% of total farm labor, and it is even higher to 90 percent in some remote mountainous areas (Song, 1999). Unlike the period before the economic reforms, the task of female labor has changed dramatically. Women began to play a very important role in producing livestock products. For example, their tasks include animal care (especially raising small livestock and poultry), grazing, fodder collection, cleaning of animal shed, processing of milk, etc. Furthermore, in crop production, women joined men in doing lots of jobs including sowing seeds, raising rice seedlings, and transplanting, (Kelkar, 2007).

Such increasing participation of women in agriculture has attracted great attention of many researchers. Their work mainly looks at women's role in agriculture and gender differences (e.g., Song, 1999; Jacka, 1997; UNDP, 2003; Zhang et al., 2004; de Brauw, 2008). In assessing the effect of more female participation in agriculture, the widely applied method is to check if women-headed households or women-managed households[25] are related to higher yields or revenues. If they are positively related, "women have higher farm productivity than men" or "women have at least the same farm productivity as men do" is concluded (de Brauw et al., 2008; Zhang et al., 2004).

However, Nishimizu and Page (1982) point out the importance of decomposition of productivity into two factors: technology level and technical efficiency as they are useful policy parameters. Technology level represents the best production technology that is potentially available for all households. On the other hand, technical efficiency represents how efficiently each household actually produces its outputs in comparison with those that could be produced using the best technology. Understanding which source is more important helps us know more details about the effect of more female labor on farm productivity. Despite its importance, we find few studies to conduct the empirical analysis of this decomposition.

[25] Details of definition of "women-headed household" and "women-managed household" will be explained in latter subsection.

Another issue to be addressed in this chapter is how to define "female-managed households" in China. There are no female-headed households under the current Chinese legislation, and it is not common to see farm households solely run by female in China, unlike some African and South Asian households (de Brauw et al. (2008) report only 3-4% of these households). For this reason, we will define "female-managed" to study the effect of more female labor on farm productivity. De Brauw et al. (2008) use working status of males and females[26] to define female-managed households if males do "little work" on the farm. By "little work", they mean two situations: 1) males work full-time off the farm for a wage and 2) males work on the farm only in the busy season. Similarly to their definition, we use three alternative criteria to define female-managed households. We define a farm household to be female-managed if farm work hours of females are longer than those of males, or the male household head works as a migrant, or the male household head works as a local wage worker. We will explain the definition further in the second section.

This chapter contributes to the ongoing discussion of performance of female labor in Chinese agriculture in two ways. First, we define female-managed households using three criteria and check the robustness of results. Second, we explicitly examine productivity difference of female- and male-managed households by decomposing it into technical efficiency difference and technology level difference.

Organization of this chapter is as follows. The second section introduces data used for the empirical analysis. The third section discusses methodology related to productivity and technical efficiency estimation. The fourth section examines the results and the final section concludes the chapter.

[26] Working status of males and females includes: working (full-time) off the farm, working (full-time) on the farm, working part-time on the farm, principally working off-farm but working on the farm only in the busy season. In our data, household members allocate their time for working on the farm and off the farm for wages. Off-farm work includes working as a local worker and a migrant.

4.2. Definition of Female-Managed Households and Preliminary Analysis

The empirical analysis is based on CHIP2002. This chapter specifically examines 4701 households for which data on relevant variables are not missing.

4.2.1. Definition of Female-Managed Household and Their Characteristics

As mentioned above, China is a special case when it comes to measure gender difference on agriculture. According to de Brauw et al. (2008), female-headed households are those in which "women typically become the head of a household when the husband is no longer formally a member of the village—through death, being chronically sick or having shifted his formal household registration permit outside the village (such as by obtaining an urban *hukou*). The weakness of this definition is that it undercounts the number of women-managed farms." de Brauw et al. (2003) also explain that both women and men within the household are working on the same farm in China, unlike in West Africa, where men and women within the household are working on different plots. In the case of China there is no official indicator for whether a farm is managed by women or who makes decisions (husband or wife who takes the managerial initiative). Therefore, we need to define our own indicators for female-managed households.

We use three alternative criteria for female-managed households. Criterion 1 is based on ratio R of female farm work hours to male farm work hours. It defines a female-managed household when this ratio is greater than 1. Criterion2 is based on a dummy variable *migration* which equals 1 if the household head is a migrant, where a migrant is defined as a person who works outside his/her village for a wage more than 90 days. Criterion3 is based on a dummy variable *wagework* which equals 1 if the household head is a wage worker (including a migrant). Under Criteria 1, 2, and 3, our sample includes 2303, 319, and 2801 female-managed households, respectively. For convenience of the analysis, we call non-female-managed households as male-managed households under any criterion.

Specifically Criterion1 takes the amount of female farm work more importantly, which is simpler to understand why it is associated with female-managed households. On the other hand, Criteria 2 and 3 put more emphasis on off-farm work status of the household head. We focus on off-farm work status of the head because he and his wife participate in farm work for all households by construction of our sample, they are working much longer on the farm than other members, and the head is most likely to work off farm, as we have already discussed.

Compared with Criterion 3, Criterion 2 is a stricter definition of female-managed households in that the former includes the latter by our definition of wage work. The head's engagement in migration or local wage work gives his wife more roles in farm management, which can affect agricultural productivity in a certain way. Relation between Criteria 1 and 3 is not as obvious as relation between Criteria 2 and 3. Our sample includes 1542 households which satisfy both Criterion 1 and Criterion 3.

We estimate stochastic production frontiers for male- and female-managed households under these 3 criteria respectively to see how more females working on farm affects farm productivity nationally or, how households with "women-in-charged" character function nationally in China. Estimation under Criterion 3 in Chapter 4 is closely connected with estimation in Chapter 3. Criterion 3 defines "female-managed (male-managed) households" as households whose heads (do not) work off farms, which corresponds to the definition of "households with (without) a wage worker"---the object of study in Chapter 3. However, due to the complicated definition of female-managed households (and these definitions have not yet been universally verified by other researches), out of prudency we do not intend to emphasize regional differences of male- and female-managed households and leave it to the further research. Therefore we perform regional estimations of stochastic production frontiers for male- and female-managed households under the 3 criteria merely for verifying the results of Chapter 3.

We find the results of regional estimation under Criterion 3 are very similar to Chapter 3. The detailed results are not analyzed here[27].

4.2.2. Description of Variables

Since Chapter 3 has already defined most variables for the empirical analysis and has explained why we use them, we introduce only new variables here. In the SPF, we use separate farm work hours *M_FWH* and *F_FWH* of males and females. As additional variables to explain technical inefficiency, we use separate age and education years for the household head and his wife (*age_head*, *age_wife*, *educ_head*, *educ_wife*) and use real per capita net income of the village (unit: yuan), *percap_income* to reflect regional difference in economic conditions.

Table 4.1 presents means of variables used in the empirical analysis. As presented above, the number of female-managed households is much bigger for Criteria 1 and 3 than for Criterion 2. We now compare means of main variables under different criteria. While both male and female farm work hours are shorter for female-managed households under Criteria 2 and 3, only male farm work hours are shorter for female-managed households under Criterion 1. Under all three Criteria, the amounts of output and other inputs than labor are bigger for male-managed households. These results show that both females and males tend to work shorter and they use smaller amount of other inputs to produce smaller amount of outputs in female-managed households. This is consistent with other results observed in Africa, which shows that input levels are usually lower for women-run plots than for men-run plots (Adesina and Djato, 1997; Udry, 1996). We also find that household heads and wives are younger and have higher education for female-managed household under the three criteria.

[27] Tables and figures with regional estimation results are presented in Appendix.

Table 4.1 Means of Variables for Male- and Female-Managed Households

	Criterion 1 ($R > 1$)		Criterion 2 (*migration* = 1)		Criterion 3 (*wagework* = 1)	
	Male-managed	Female-managed	Male-managed	Female-managed	Male-managed	Female-managed
Number of obs.	2398	2303	4382	319	1900	2801
Dependent variable						
Y [yuan]	8544	7175	8100	4765	9887	6508
Independent variables						
M_FWH[hours]	1684	976	1379	741	1692	1045
F_FWH [hours]	1126	1612	1367	1324	1543	1243
VC [yuan]	1572	1245	1450	896	1774	1166
VL [yuan]	1899	1729	1869	1081	2281	1500
K [yuan]	4305	3853	4225	2145	5106	3390
T [mu]	8.347	7.038	7.913	4.877	9.293	6.629
irr_share	0.541	0.58	0.560	0.562	0.527	0.583
Variance function						
R	0.714	2.730	1.577	3.401	1.265	1.997
migration	0.028	0.110	0.000	1.000	0.000	0.114
wagework	0.525	0.670	0.567	0.994	0.001	0.114
largescale	0.354	0.271	0.327	0.121	0.396	0.257
num_hh	3.952	4.116	4.036	3.981	4.218	3.906
num_childlt6	0.168	0.177	0.172	0.178	0.191	0.160
age_head	46.4	43.61	45.5	38.9	47.6	43.4
age_wife	44.4	41.82	43.6	37.4	45.5	41.6
educ_head	7.1	7.4	7.2	7.6	6.8	7.6
educ_wife	5.3	5.6	5.4	6.0	5.1	5.7
nonlaborinc	0.395	0.481	0.456	0.189	0.461	0.422
percap_income	2.528	2.274	2.430	2.041	2.327	2.455
collect_pest	0.161	0.152	0.160	0.112	0.189	0.135

Notes: For saving space standard deviations are not listed. *R* is a ratio of female farm work hours to male work hours. Dummy variable *migration* equals 1 if the household head migrates. Dummy variable *wagework* equals 1 if the household head works for wages (including migration).

4.2.3. Productivity of Male- and Female-Managed Households

Most studies on gender difference in farm productivity seem to have given a clear explanation of the reasons why male- and female-managed (or headed) households can have different farm productivity. Recall the decomposition of productivity difference into technology difference and technical efficiency difference. Regarding technical efficiency, different efficiency between the two types of households may result because labor division of women and men may induce use of different effort or quality of inputs. Regarding production technology, different technology may be used between the two types of households because labor division of women and men may induce different agricultural production activities. For example, Bossen (2000) finds that labor in the production of rice and beans requires several bursts of intense activity in which male labor is mainly needed,[28] which may give us a guess that male-managed households have a higher production frontier for producing grains. She also finds that women mainly have responsibility of taking care of animals (especially raising small livestock and poultry). For example, women need to do all kinds of jobs including grazing, fodder collection, cleaning of animal shed, and processing of milk. Therefore, it might not be hard to conclude women-managed households should have a higher production frontier when their main incomes come from livestock production.

4.3. Empirical Method

A farm household produces a farm commodity Y using male labor M_FWH and female labor L_FWH, costs VC of producing crops, costs VL of producing livestock products, capital K, and land T. An SPF might be specified as

$$\ln \mathrm{Y} = \beta_0 + \beta_1 \ln M\_FWH + \beta_2 \ln F\_FWH + \beta_3 \ln VC + \beta_4 \ln VL$$

[28] Li, Feng and Xu (1985) write " In China nearly 1/4 of the total area devoted to grain crops is grown with rice and its yield accounts for almost 1/2 that of the total grain production in the country."

$$+ \beta_5 \ln K + \beta_6 \ln T + \beta_7 \, irr\_share + \varepsilon \quad (1)$$

Variable *irr_share* denotes the share of irrigated land areas and it is included to control for land quality. The error term $\varepsilon = v - u$ is composed of a normal disturbance $v \sim N(0, \sigma_v^2)$ and inefficiency $u \geq 0$ which follows a half normal distribution $N^+(0, \sigma_u^2)$.

As explained above we assume different technology for male- and female-managed households. Then, we modify the SPF (1) as

$$\ln Y = \gamma_0 + \gamma_1 \ln M\_FWH + \gamma_2 \ln F\_FWH + \gamma_3 \ln VC + \gamma_4 \ln VL$$

$$+ \gamma_5 \ln K + \gamma_6 \ln T + \gamma_7 \, irr\_share + \varepsilon \quad (2)$$

where $\gamma_j = \alpha_{j0} + \alpha_{j1} * D_{female}$ (j =0,.....,7). Dummy variable D_{female} equals 1 if the household is female-managed under Criterion 1, 2, or 3. The correspondence between D_{female} and the variables used to define Criteria 1-3 is as follows

D_{female} = 1 if R > 1 for Criterion 1 ($R = F\_FWH/M\_FWH$)

D_{female} = 1 if *migration* = 1 for Criterion 2

D_{female} = 1 if *wagework* = 1 for Criterion 3

A positive coefficient α_{j1} implies that the production frontier is higher for female-managed households. Furthermore, unlike the SPF (1), the output elasticity of capital $\partial \ln Y / \partial \ln K$, for example, is not constant but it can change with the dummy variable D_{female} (the elasticity of capital of SPF (2) is $\gamma_5 = \alpha_{50} + \alpha_{51} * D_{female}$. It is higher for female-managed households if $\alpha_{51} > 0$. In this sense, the SPF (2) is more flexible than the Cobb-Douglas production frontier and is easier to interpret than the translog production frontier for our purpose.

After estimating the SPF (2) by the maximum likelihood method, we adopt two ways to check whether the estimated production frontiers actually differ between the two types of households. One is to check the joint significance of coefficients γ_{j1} (j = 0, ..., 7) using a likelihood ratio test. The other is to compute an index of production frontier in a similar way to

Kumbhakar, Tsionas and Sipiläinen (2009). Let $\hat{Y}_1$ and $\hat{Y}_0$ respectively denote outputs which can be predicted using deterministic frontiers (the right hand side of equation (2) excluding ε) of female-managed and male-managed households. We compute both of these predicted outputs for each household by substituting the actual amount of the six inputs and the share of irrigated land areas into the two deterministic frontiers.

In addition to estimating different frontiers for the two types of households, we are also interested in impacts of female-managed indicators on technical inefficiency *u*. For this purpose, the assumption on inefficiency *u* should be modified. A popular way seems to assume that *u* is distributed as a truncated normal with its mean depending on female-managed indicators. Alternatively, we can follow Caudill, Ford and Gropper (1995) and assume that inefficiency *u* has a half normal distribution with mean 0 but with variance σ_u^2 depending on the variable to define Criteria 1–3.:

$$\ln\sigma_u^2 = \delta_0 + \delta_1 I_{female} + \sum_{K-2}^{n} \delta_k controls_k \qquad (3)$$

where I_{female} equals *R* for Criterion 1, *migration* for Criterion 2, and *wagework* for Criterion 3. The variable $controls_k$ denotes factors other than I_{female} to explain the variance of technical inefficiency. Interpretation of the coefficient δ_1 is the same as that in Chapter 3: A positive coefficient δ_1 means lower technical efficiency for female-managed households, with other things being equal.

After estimating the parameters in equations (2) and (3), we can compute TE in farm production in a usual way:

$$TE = E[\exp(-u)\,|\,\varepsilon] = \left\{\Phi\left(\frac{u_*}{\sigma_*}\right)\right\}^{-1} \Phi\left(\frac{u_*}{\sigma_*} - \sigma_*\right)\exp\left(\frac{\sigma_*^2}{2} - u_*\right), \qquad (4)$$

where $u_* = -(\sigma_u^2/\sigma^2)\varepsilon$, $\sigma_*^2 = \sigma_u^2\sigma_v^2/\sigma^2$ and $\sigma^2 = \sigma_u^2 + \sigma_v^2$, with ϕ and Φ respectively denoting the density and cumulative distribution functions of standard normal distribution. As examined above, we can refer to the coefficient δ_1 in equation (3) to know the effect of I_{female} on *TE*.

4.4. Empirical Results

4.4.1. Estimated Parameters of the Production Frontier and Their Comparison for Two Types of Households

The SPF specified by equations (2) and (3) are estimated under the three criteria after adding relevant province dummy variables. The results are presented in Table 4.2. Most coefficients of factor inputs themselves are positive and statistically significant at the 5% level. Furthermore, the likelihood ratio test for the joint significance of the seven interaction terms, $D_{female}*X$ (*X*: six inputs and irrigation share), shows that they are jointly significant, as *LR test* in the last row of Table 4.2 presents.

Now, we examine individual interaction terms between factor inputs and the dummy variable D_{female} for female-managed households. Regarding labor inputs, Bossen (2000) and Jacka (1997) explain that when males work for non-agricultural work, females work more on the farm and males would help with farm work only at peak seasons or on un-continued base such as doing plowing, preparing the land, and threshing rice. Their explanation suggests that males are unlikely to show higher performance on farm for female-managed households, while females might show higher performance on farm for them because of their specialization on the farm. In this case, we expect a negative coefficient of M_FWH*D_{female} and a positive coefficient of F_FWH*D_{female}. Table 4.2 shows there are only two interaction terms of labor inputs are significant: M_FWH*D_{female} under Criterion 1 and F_FWH*D_{female} under Criterion 3, both of which are negative. The lower production elasticity of male labor for female-managed households is consistent with the discussion above. On the other hand, the lower production elasticity of

Table 4.2 Estimated Parameters of Stochastic Production Frontiers and Variance Functions under Different Criteria for Male- and Female-managed Households

	Criterion 1 ($R > 1$)		Criterion 2 ($migration = 1$)		Criterion 3 ($wagework = 1$)	
M_FWH	0.1818	[8.28]	0.1215	[11.16]	0.1029	[5.83]
M_FWH*D_{female}	-0.0902	[-3.31]	-0.0192	[-0.54]	0.0155	[0.73]
F_FWH	0.0340	[1.88]	0.0700	[6.33]	0.0905	[5.21]
F_FWH*D_{female}	0.0513	[1.78]	-0.0705	[-1.55]	-0.0418	[-1.97]
VC	0.3477	[26.14]	0.3358	[32.97]	0.3464	[22.89]
$VC*D_{female}$	-0.0392	[-2.12]	-0.0786	[-2.02]	-0.0293	[-1.54]
VL	0.0571	[18.21]	0.0609	[23.78]	0.0524	[14.29]
$VL*D_{female}$	0.0095	[2.05]	0.0084	[0.76]	0.0164	[3.56]
K	0.0427	[8.59]	0.044	[11.56]	0.0363	[5.72]
$K*D_{female}$	0.0029	[0.41]	0.0016	[0.10]	0.0080	[1.03]
T	0.1836	[10.15]	0.2054	[13.47]	0.1784	[8.45]
$T*D_{female}$	0.059	[2.50]	0.0297	[0.58]	0.0449	[1.86]
irr_share	0.1257	[4.52]	0.1799	[8.06]	0.1685	[5.42]
$irr\_share*D_{female}$	0.1154	[2.95]	-0.0538	[-0.69]	0.0202	[0.51]
D_{female}	0.2723	[1.73]	0.9107	[2.61]	0.0232	[0.15]
σ_v	-1.4825		-1.4805	[-69.01]	-1.4889	[-69.31]

(To be continued on next page)

female labor for these households means that women do not raise their productivity by specialization on the farm but decrease it by depending on higher incomes of their husband and putting lower effort on the farm.

Regarding variable costs, $VC * D_{female}$ tends to have a negative coefficient, while $VL * D_{female}$ tends to have a positive coefficient. These results coincide with Bossen (2000)'s findings and relate to characteristic of labor allocation in farm production. Bossen explains that production of grains and crops requires intense labor activities (frequent and physical) on which man has to be the main labor, while woman is more skillful on taking care of livestock which requires daily basis care and patience.

Table 4.2 ----Cont.

Variance function						
R	-0.1954	[-0.97]				
migration			-2.1435	[-1.08]		
wagework					-1.1474	[-2.48]
largescale	0.2578	[0.76]	0.2826	[0.83]	0.0104	[0.03]
num_hh	-0.2213	[-1.96]	-0.2290	[-2.05]	-0.2522	[-2.24]
age_head	0.0370	[0.89]	0.0265	[0.63]	0.0345	[0.83]
age_wife	-0.0212	[-0.51]	-0.0156	[-0.37]	-0.0219	[-0.53]
educ_head	-0.0373	[-0.68]	-0.0618	[-1.13]	-0.0444	[-0.82]
educ_wife	-0.0726	[-1.37]	-0.0816	[-1.50]	-0.0923	[-1.70]
num_childlt6	0.5844	[2.21]	0.6172	[2.38]	0.6086	[2.26]
percap_income	-1.5533	[-5.61]	-1.5743	[-5.51]	-1.4935	[-5.27]
nonlaborinc	0.1302	[2.54]	0.1258	[2.59]	0.1332	[3.03]
collect_pest	-0.1903	[-0.47]	-0.2371	[-0.58]	-0.1423	[-0.36]
log-likelihood	-3230.428		-3235.155		-3217.622	
LR test	29.66	(0.00)	23.79	(0.00)	58.17	(0.00)

Note: t-statistics are shown in brackets and p-values are shown in parentheses. *R* is a ratio of female farm work hours to male work hours. Dummy variable *migration* equals 1 if the household head migrates. Dummy variable *wagework* equals 1 if the household head works for wages (including migration).

The interaction term $K * D_{female}$ is not statistically significant under the three criteria of female-managed households. This result may reflect the fact that farmers tend to use wage incomes for investing mainly in education and health care, rather than farm machinery and equipment, as argued by Yang (2005) and Zhang, Huang, and Rozelle (2002). The interactionterm $T * D_{female}$ tends to be positive and statistically significant, which seems to reflect the fact that females are more skillful for jobs which need more patience and carefulness: Land utilization includes such complicated tasks as land management, such as seedling, weeding, foddering, and irrigation. This reasoning also explains the positive coefficient of *irr_share* * D_{female} under Criterion 1.

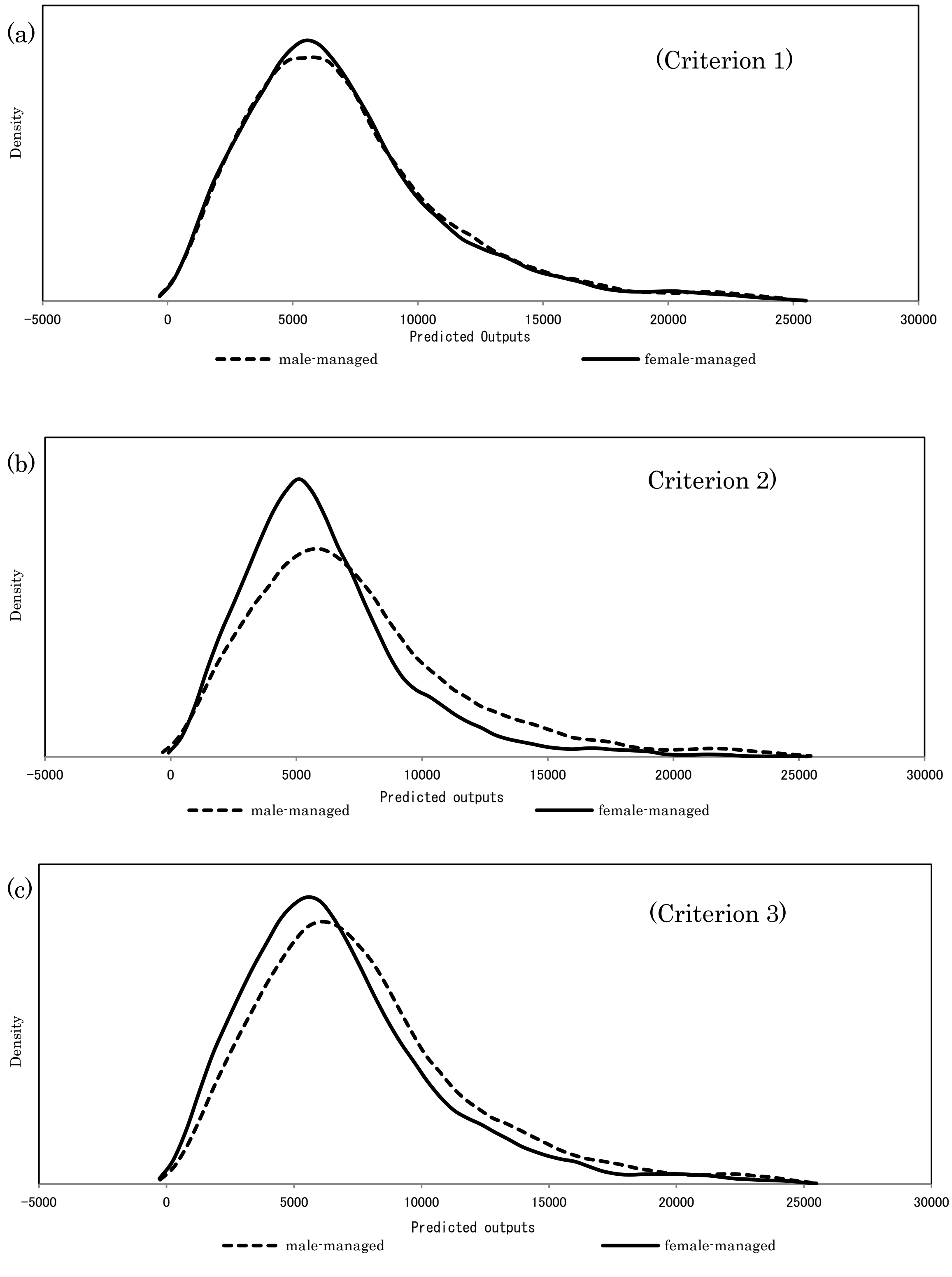
Next, we examine factors to explain the variance σ_u^2 of inefficiency u, whose estimated coefficients are also presented in Table 4.2. Most of the coefficients are insignificant at the 5% level, but we find it is necessary to keep them to achieve convergence in estimation and to obtain plausible estimates of technical efficiency. Here, we just focus on the coefficient of the indexes, *R*, *migration*, and *wagework*, which represent relation between female-managed households and technical efficiency, with other things being equal: A negative coefficient means higher technical efficiency for female-managed households. Actually, the coefficients of these variables are negative under the three criteria, although only the coefficient of *wagework* is statistically significant.

4.4.2. Comparison of the Predicted Outputs $\hat{Y}_1$ and $\hat{Y}_0$

Predicted outputs $\hat{Y}_1$ and $\hat{Y}_0$ of female- and male-managed households are 7111 (4517) and 7338 (4836) under Criterion 1; 6121 (3517) and 7501 (4878) under Criterion 2; and 7118 (4572) and 7826 (4834) under Criterion 3, where the standard deviation is shown in parentheses. On average, the deterministic frontier is higher for male-managed households under the three criteria after controlling for input amounts.

Because the average of $\hat{Y}_1$ and $\hat{Y}_0$ can be sensitive if their distributions are skewed, we compare their kernel density (a smoother version of the histogram) in Figure 4.1(a), (b), and (c). The horizontal axis measures the amount of outputs $\hat{Y}_1$ and $\hat{Y}_0$, and the vertical axis measures its density, with the solid and dotted lines respectively drawn for $\hat{Y}_1$ and $\hat{Y}_0$. The distribution of $\hat{Y}_0$ and $\hat{Y}_1$ under Criterion 1 do not show clear difference between the two types of household, implying that production technology of male- and female-managed households are similar under this criterion. On the other hand, the distribution of $\hat{Y}_0$ and $\hat{Y}_1$ under Criteria 2 and 3 show that $\hat{Y}_0$ lies rightward from $\hat{Y}_1$, implying that production technology of male-managed

Figure 4.1 Distributions of Predicted Outputs under Production Technologies of Male- and Female Managed Households (National)



households is higher than that of female-managed households under these criteria. These results can be attributed to the lower production elasticities of female labor and crop production costs, as discussed above.

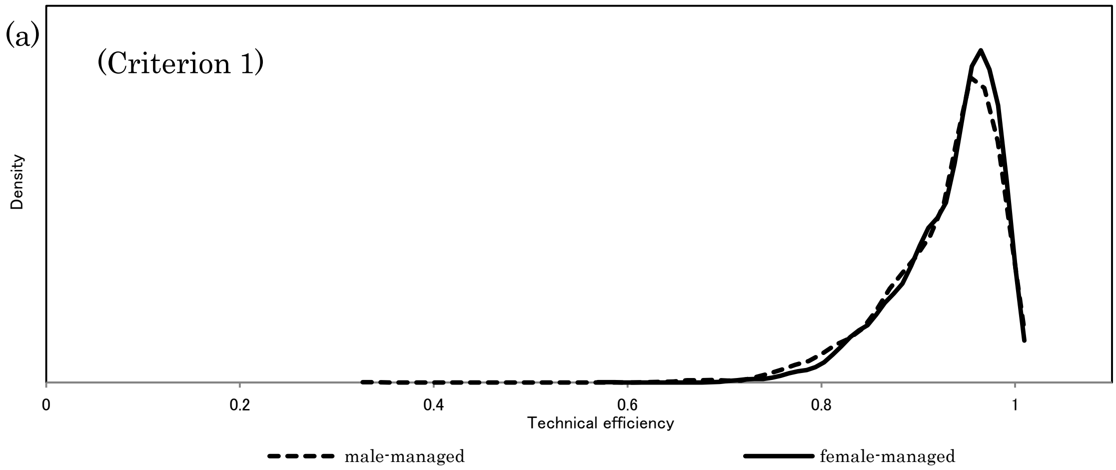
4.4.3. Comparison of Technical Efficiency

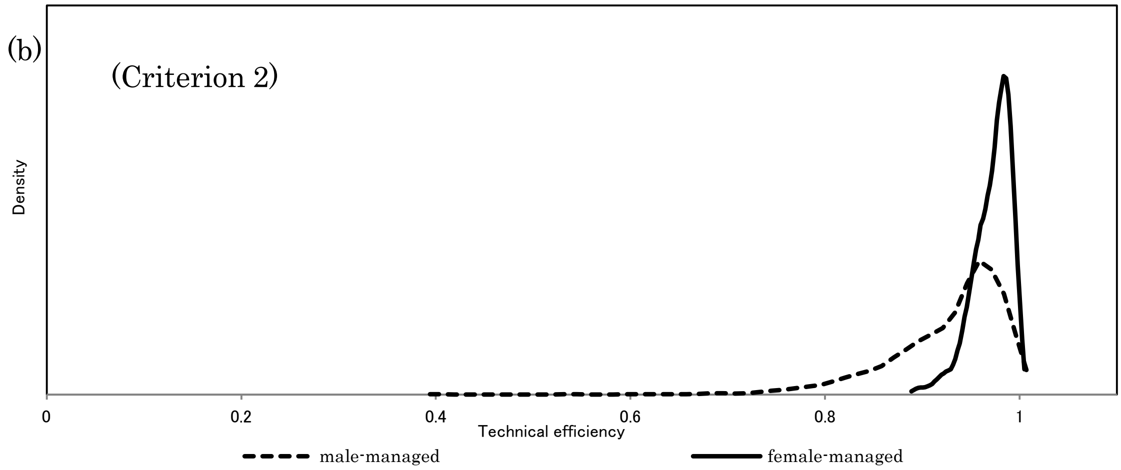
The average *TE* index tends to be higher for female-managed households. Specifically, *TE* for male-managed households is 0.93, 0.93, and 0.90 under Criteria 1, 2, and 3, while *TE* for female-managed households is 0.93, 0.97, and 0.95.

For better inspection, we examine the kernel density of this index. Figure 4.2 (a), (b), and (c) depict it for the two groups of households under the three criteria. The horizontal axis measures *TE* index and the vertical axis measures its density, with the solid and dotted lines respectively drawn for female- and male-managed households. Under Criterion 1, distributions of *TE* index are similar for the two types of households for *TE* smaller than 0.95, while it is located more rightward for female-managed households for *TE* larger than 0.95. Under Criteria 2 and 3, the distribution of *TE* is located rightward for female-managed households for all values of *TE*. Consequently, we find that female-managed households tend to have higher *TE* index under the three criteria.

Next, we run OLS regression of *TE* index on its determinants. Table 4.3 presents the estimation result under the three criteria of female-managed households. Most coefficients are statistically significant at the 1% level. The coefficients of ratio *R* of farm work hours and dummy variables *migration* and *wagework* are all statistically significant and positive, meaning that female-managed households actually have higher technical efficiency, with other things being equal. Furthermore, the results show that female-managed households have 0.17%, 3.83% and 4.87% higher *TE* than male-managed households under Criteria 1, 2, and 3, respectively.

Figure 4.2 Distributions of Technical Efficiency Index for Male- and Female-Managed Households (National)





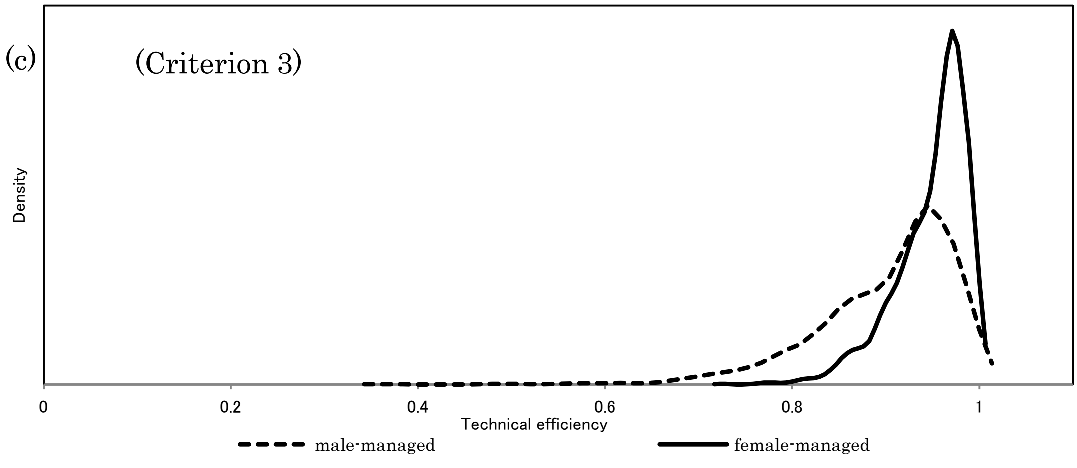


Table 4.3 Results of Ordinary Least Squares Regression of Technical Efficiency

	Criterion 1 (R > 1)		Criterion 2 (*migration* = 1)		Criterion 3 (*wagework* = 1)	
R	0.0017	[14.03]				
migration			0.0383	[40.07]		
wagework					0.0487	[28.90]
largescale	-0.0115	[-10.63]	-0.0021	[-1.82]	-0.0113	[-10.42]
num_hh	0.0074	[19.35]	0.0083	[20.39]	0.0073	[19.09]
age_head	-0.0015	[-10.21]	-0.0013	[-8.34]	-0.0010	[-6.93]
age_wife	0.0008	[5.29]	0.0008	[4.93]	0.0006	[3.83]
educ_head	0.0016	[8.49]	0.0017	[8.56]	0.0023	[12.13]
educ_wife	0.0025	[14.79]	0.0031	[17.06]	0.0027	[15.74]
num_childlt6	-0.0234	[-22.31]	-0.0239	[-21.25]	-0.0242	[-23.03]
percap_income	0.0299	[64.03]	0.0285	[56.91]	0.0301	[64.04]
nonlaborinc	-0.0045	[-17.78]	-0.0051	[-18.46]	-0.0045	[-17.62]
collect_pest	0.0070	[5.46]	0.0044	[3.20]	0.0076	[5.95]
R-squared	0.7556		0.7521		0.7637	

Note: t-statistics are shown in brackets. *R* is a ratio of female farm work hours to male work hours. Dummy variable *migration* equals 1 if the household head migrates. Dummy variable *wagework* equals 1 if the household head works for wages (including migration).

Most of the other determinants also have expected signs under the three criteria. More household members, more education of the head and wife, and more work experience of wife raise *TE* index, better economic conditions in the village also raise *TE* index, and pest control assisted by the village further raise *TE* index. Children younger than six years old decreases *TE* index because they need more care from their parents and this reduces the parents' attention in farm production.

On the other hand, larger land (*largescale*), age of the household head (*age_head*), and non-labor income (*nonlaborinc*) have unexpectedly negative effects on *TE* index. The negative coefficient of *largescale* may show that farmers might not have enough skill to manage efficient farm production in larger land. Age of the household head can have a negative effect on *TE* because it may be difficult for older farmers to keep efficient farm management or higher attention to farm production. Regarding the negative coefficient of non-labor income, Rezitis, Tsiboukas, and Tsoukalas (2003) also show that subsidies and other forms of non-labor incomes negatively affect the technical efficiency of Greek farms' who participate in the 1994 European Union farm credit program.

4.5. Conclusions

To examine whether female-managed households have lower production technology or technical efficiency in rural China, this chapter estimate SPFs and regressing TE index on its determinants using CHIP 2002.

This chapter makes two contributions to the literature of relation between feminization and farm productivity. First, we define female-managed households by three criteria from different perspectives and examine robustness of the relation between female-managed households and farm productivity. Second, we decompose the productivity difference between female- and male-managed households into technology level difference and technical efficiency difference and examine which one is more important.

Several conclusions can be drawn from our empirical analysis. First, for the three definitions of female-managed households, we have shown that production technology tends to be higher for male-managed households, whereas technical efficiency tends to be higher for female-managed households. Second, female-managed households tend to have higher production elasticity of livestock production costs, while male-managed households tend to have higher production elasticity of crop production costs. These results reflect the different types of households are better at producing different products. Specifically, female-managed households are better at taking care of husbandry or land maintenance with patience and constant care, whereas male-managed households are better at producing crops with physical strength of male labor.

Finally, there may be some policy implications regarding Chinese agriculture. Firstly, policies are needed such as offering extension programs which help women get more skill to raise lower production technology of female-managed households and help them improve farm management. In particular, introduction of more farm machineries and equipment will help women and the elderly produce crops more efficiently. Also, it is important to introduce policies which help women free from child rearing for enhancing welfare of women, increasing farm outputs, and hence further agricultural development.

Chapter 5. Summary and Conclusions

This dissertation examines relation between labor allocation within the household and farm productivity under the background of increased off-farm labor supply of Chinese farm households. Specifically, it examines this theme in two ways.

In Chapter 3, we estimate SPF for two types of farm households in the eastern, central, and western regions: One has the household head who works for wages outside the household and the other does not. In the eastern and central regions, typical households with a wage worker tend to have lower farm productivity because of their lower technical efficiency. We can attribute this lower technical efficiency to their smaller farm land. One implication of this result is that domestic food supply in these regions will stagnate or deteriorate as rural household heads participate more in wage work as economic development provides more opportunities to increase nonfarm income. To improve the lower technical efficiency in these regions, it is important to make the land market more active and allow farm households to expand their cultivated land.

In the western region, typical households with a wage worker may have higher farm productivity because of their higher technical efficiency. We can attribute this higher technical efficiency to better education of the household head and better utilization of farming knowledge and family members. One implication of this result is an increase in domestic food supply in this region along with further economic development. This improvement, however, might be limited because it depends on more farm work by women and the elderly. To make the domestic food supply sustainable, it is important to encourage farmers in this region to use more farm machinery and a newer variety of crops, which not only helps women and the elderly improve farm production but also boosts the production frontier to increase the domestic food supply in this region.

In Chapter 4, we estimate SPF with male and female labor inputs for male- and female-managed households. It defines female-managed households by three criteria from different perspectives and examines robustness of the relation between female-managed households and farm productivity. Furthermore, it decomposes the productivity difference between female- and male-managed households into technology level difference and technical efficiency difference and examines which one is more important.

The empirical analysis shows that for the three definitions of female-managed households, production technology tends to be higher for male-managed households, whereas technical efficiency tends to be higher for female-managed households. Furthermore, female-managed households tend to have higher production elasticity of livestock production costs, while male-managed households tend to have higher production elasticity of crop production costs. These results reflect the different types of households are better at producing different products. Specifically, female-managed households are better at taking care of husbandry or land maintenance with patience and constant care, whereas male-managed households are better at producing crops with physical strength of male labor.

These results include policy implications for Chinese agriculture. Firstly, policies are needed such as offering extension programs which help women get more skill to raise lower production technology of female-managed households and help them improve farm management. In particular, introduction of more farm machineries and equipment will help women and the elderly produce crops more efficiently. Also, it is important to introduce policies which help women free from child rearing for enhancing welfare of women, increasing farm outputs, and hence further agricultural development.

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Appendix

Table A-1-1 Means of Variables for Male- and Female-Managed Households in 3 Regions (Criterion 1)

Region	WesternRegion		Central Region		Eastern Region	
Households type	Male-managed	Female-managed	Male-managed	Female-managed	Male-managed	Female-managed
Sample size	681	812	902	889	815	602
Y [yuan]	8800	7109	8143	6849	8773	7745
M_FWH [hours]	2199	1173	1473	842	1485	819
F_FWH [hours]	1423	1919	1007	1440	1009	1452
VC [yuan]	1711	1157	1488	1166	1548	1482
VL [yuan]	2073	2074	1317	1220	2396	2016
K [yuan]	4689	3283	4018	3502	4302	5139
T [mu]	9.257	6.455	9.611	8.053	6.187	6.327
irr_share	0.479	0.518	0.477	0.590	0.665	0.649
R	0.710	2.440	0.722	2.548	0.708	3.386
migration	0.029	0.117	0.029	0.109	0.025	0.105
wagework	0.446	0.623	0.541	0.684	0.573	0.711
largescale	0.386	0.228	0.365	0.273	0.315	0.326
num_hh	4.404	4.416	3.887	4.024	3.648	3.846
num_childlt6	0.238	0.224	0.172	0.178	0.107	0.111
age_head	46.4	43.1	44.7	42.5	48.4	45.9
age_wife	43.9	41.1	42.8	40.7	46.6	44.5
educ_head	6.4	7.0	7.2	7.5	7.6	8.0
educ_wife	4.7	5.2	5.5	5.7	5.7	6.0
nonlaborinc [yuan/1000]	0.319	0.286	0.319	0.648	0.543	0.499
percap_income [yuan/1000]	1.553	1.566	2.292	2.209	3.603	3.324
collect_pest	0.217	0.151	0.124	0.128	0.155	0.188

Notes: For saving space standard deviations are not listed here. *R* is a ratio of female farm work hours to male work hours. Dummy variable *migration* equals 1 if the household head migrates. Dummy variable *wagework* equals 1 if the household head works for wages (including migration).

Table A-1-2 Means of Variables for Male- and Female-Managed Households in 3 Regions (Criterion 2)

Region	Western Region		Central Region		Eastern Region	
Households type	Male-managed	Female-managed	Male-managed	Female-managed	Male-managed	Female-managed
Sample size	1378	115	1670	121	1334	83
Y [yuan]	8139	4782	7678	5056	8587	4315
M_FWH [hours]	1721	932	1205	646	1244	680
F_FWH [hours]	1702	1593	1225	1187	1200	1152
VC [yuan]	1465	753	1356	936	1550	1035
VL [yuan]	2120	1521	1290	981	2337	594
K [yuan]	4102	1796	3904	1802	4751	3158
T [mu]	7.972	4.868	9.100	5.224	6.362	4.382
irr_share	0.501	0.491	0.529	0.587	0.660	0.631
R	1.443	4.141	1.533	2.952	1.773	3.010
migration	0.000	1.000	0	1	0	1
wagework	0.504	1.000	0.584	1	0.609	1
largescale	0.316	0.104	0.335	0.099	0.328	0.181
num_hh	4.425	4.243	3.958	3.909	3.733	3.711
num_childlt6	0.232	0.209	0.174	0.190	0.108	0.120
age_head	45.1	38.5	44.0	38.2	47.8	40.3
age_wife	42.9	36.7	42.1	36.9	46.1	39.3
educ_head	6.7	7.1	7.3	7.7	7.7	8.2
educ_wife	4.9	5.5	5.6	5.6	5.8	7.0
nonlaborinc [yuan/1000]	0.316	0.125	0.501	0.232	0.548	0.148
percap_income [yuan/1000]	1.565	1.494	2.273	1950.143	3.520	2.916
collect_pest	0.189	0.087	0.130	0.074	0.166	0.205

Notes: For saving space standard deviations are not listed here. *R* is a ratio of female farm work hours to male work hours. Dummy variable *migration_head* equals 1 if the household head migrates. Dummy variable *wagework* equals 1 if the household head works for wages (including migration).

Table A-1-3 Means of Variables for Male- and Female-Managed Households in 3 Regions (Criterion 3)

Region	Western Region		Central Region		Eastern Region	
Households type	Male-managed	Female-managed	Male-managed	Female-managed	Male-managed	Female-managed
Sample size	683	810	695	1096	522	895
Y [yuan]	9527	6492	8969	6570	11581	6445
M_FWH [hours]	2004	1371	1511	949	1671	942
F_FWH [hours]	1800	1603	1374	1126	1431	1061
VC [yuan]	1799	1081	1590	1162	1986	1248
VL [yuan]	2151	2008	1448	1155	3559	1463
K [yuan]	5254	2802	4819	3092	5294	4286
T [mu]	9.708	6.067	10.120	8.025	7.647	5.429
irr_share	0.508	0.494	0.471	0.573	0.625	0.677
R	1.256	1.984	1.238	1.877	1.314	2.156
migration	0	0.142	0	0.110	0	0.093
wagework	0	1	0	1	0	1
largescale	0.401	0.215	0.376	0.284	0.418	0.263
num_hh	4.662	4.199	4.001	3.925	3.927	3.618
num_childlt6	0.255	0.210	0.168	0.179	0.136	0.093
age_head	46.9	42.6	46.6	41.7	49.5	46.1
age_wife	44.4	40.7	44.7	39.9	47.9	44.4
educ_head	6.2	7.1	7.0	7.5	7.3	8.0
educ_wife	4.6	5.2	5.2	5.9	5.6	6.0
nonlaborinc [yuan/1000]	0.324	0.281	0.539	0.447	0.535	0.518
collect_pest	0.258	0.117	0.142	0.116	0.161	0.173
percap_income [yuan/1000]	1.518	1.596	2.261	2.244	3.472	3.492

Notes: For saving space standard deviations are not listed here. *R* is a ratio of female farm work hours to male work hours. Dummy variable *migration* equals 1 if the household head migrates. Dummy variable *wagework* equals 1 if the household head works for wages (including migration).

Table A-2-1 Estimated Parameters of Stochastic Production Frontiers and Variance Functions (Criterion 1, Regional)

Region/ Sample size	Western Region /1493		Central Region /1791		Eastern Region /1417	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
M_FWH	0.1353	[3.63]***	0.1068	[2.62]***	0.2753	[6.72]***
M_FWHD_{female}	-0.051	[-1.08]	0.0693	[1.43]	-0.2132	[-4.08]***
F_FWH	0.0035	[0.12]	0.0331	[0.92]	0.0378	[1.12]
F_FWHD_{female}	-0.026	[-0.55]	-0.0706	[-1.48]	0.1914	[3.56]***
VC	0.3143	[14.89]***	0.3139	[13.86]***	0.3703	[14.46]***
VCD_{female}	-0.0597	[-2.06]**	-0.0189	[-0.63]	-0.0386	[-1.02]
VL	0.0698	[9.84]***	0.0595	[10.90]***	0.0588	[11.07]***
VLD_{female}	0.045	[4.21]***	0.0181	[2.35]**	-0.0063	[-0.77]
K	0.0574	[4.99]***	0.0491	[6.83]***	0.0386	[4.19]***
KD_{female}	-0.0024	[-0.16]	0.006	[0.60]	-0.0196	[-1.39]
T	0.0872	[2.63]***	0.1962	[6.93]***	0.1747	[5.14]***
TD_{female}	0.1091	[2.69]***	0.0579	[1.63]	0.1215	[2.44]**
irr_share	0.1754	[3.75]***	0.1	[2.58]***	0.0857	[1.37]
irr_shareD_{female}	0.0749	[1.18]	0.053	[0.98]	0.2518	[2.82]***
D_{female}	0.4524	[1.59]	-0.1943	[-0.78]	0.1891	[0.65]
σ_v	-1.8059	[-38.48]***	-1.7296	[-46.32]***	-1.1828	[-30.87]***
Variance function						
R	-0.213	[-0.90]	-1.1638	[-1.79]*	-0.3007	[-0.80]
largescale	-0.1802	[-0.41]	-0.3118	[-0.68]	-0.5162	[-0.70]
num_hh	-0.4843	[-2.90]***	-0.0559	[-0.39]	0.0244	[0.08]
num_childlt6	0.3257	[0.96]	0.8791	[2.75]***	0.5356	[0.74]
age_head	0.0758	[1.60]	0.0493	[1.14]	-0.0696	[-0.59]
age_wife	-0.0644	[-1.37]	-0.0455	[-1.01]	0.0471	[0.40]
educ_head	0.001	[0.01]	-0.0817	[-1.26]	-0.0315	[-0.19]
educ_wife	-0.0118	[-0.18]	-0.0364	[-0.61]	-0.0038	[-0.03]
nonlaborinc	0.1644	[2.58]**	-0.1761	[-0.87]	0.2265	[2.26]**
collect_pest	0.5539	[1.34]	-1.6523	[-1.16]	0.0389	[0.03]
percap_income	-1.2091	[-2.70]***	-1.4443	[-4.98]***	-1.7867	[-2.13]**
log-likelihood	-816.7211		-1030.9997		-1179.7429	
LR test	24.88	0.00	16.83	0.03	29.76	0.00

Notes: For saving space constant terms and province dummy variables are not listed here. *LR test*: *LR test* for the Joint significance of interaction terms. *R* is a ratio of female farm work hours to male work hours.
*, **, *** indicate significance at 10%, 5%, 1% level.

Table A-2-2 Estimated Parameters of Stochastic Production Frontiers and Variance Functions (Criterion 2, Regional)

Region/ Sample size	Western Region/1493		Central Region /1791		Eastern Region /1417	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
M_FWH	0.0656	[3.49]***	0.1306	[7.76]***	0.1409	[6.88]***
*M_FWH*D$_{female}$*	0.0521	[1.05]	-0.0501	[-0.86]	-0.0321	[-0.36]
F_FWH	0.0255	[1.37]	0.0228	[1.34]	0.1377	[6.56]***
*F_FWH*D$_{female}$*	-0.086	[-1.07]	-0.0932	[-1.33]	-0.0387	[-0.42]
VC	0.2834	[17.54]***	0.3079	[19.25]***	0.3756	[18.65]***
*VC*D$_{female}$*	-0.0139	[-0.23]	-0.0372	[-0.61]	-0.1885	[-1.90]*
VL	0.0872	[14.24]***	0.0667	[15.37]***	0.0566	[13.18]***
*VL*D$_{female}$*	0.006	[0.28]	0.0034	[0.18]	0.0219	[0.95]
K	0.056	[6.72]***	0.0515	[9.66]***	0.0326	[4.46]***
*K*D$_{female}$*	0.0085	[0.30]	0.0171	[0.79]	-0.0211	[-0.66]
T	0.1458	[5.31]***	0.2093	[9.15]***	0.2097	[7.19]***
*T*D$_{female}$*	0.0021	[0.03]	0.1953	[1.98]**	0.0499	[0.43]
irr_share	0.1999	[5.68]***	0.1356	[4.35]***	0.1703	[3.15]***
*irr_share*D$_{female}$*	0.0912	[0.71]	-0.0773	[-0.69]	0.107	[0.60]
D_{female}	0.0858	[0.15]	0.6665	[1.30]	1.3747	[1.82]*
σ_v	-1.7989	[-36.49]***	-1.7215	[-46.23]***	-1.172	[-30.67]***
Variance function						
migration	-2.6396	[-0.79]	-1.2732	[-0.80]	-27.3063	[-0.02]
largescale	-0.1124	[-0.27]	-0.427	[-0.81]	-0.6217	[-0.80]
num_hh	-0.4557	[-2.87]***	-0.0944	[-0.63]	-0.0538	[-0.16]
num_childlt6	0.3552	[1.14]	0.9013	[2.73]***	1.1725	[1.53]
age_head	0.0583	[1.30]	0.0663	[1.48]	-0.1439	[-1.02]
age_wife	-0.0498	[-1.12]	-0.0538	[-1.14]	0.1192	[0.85]
educ_head	-0.0282	[-0.46]	-0.1136	[-1.70]*	0.0417	[0.24]
educ_wife	-0.0125	[-0.19]	-0.041	[-0.66]	-0.0269	[-0.21]
nonlaborinc	0.1528	[2.50]**	-0.2294	[-1.11]	0.2496	[2.43]**
collect_pest	0.5299	[1.37]	-3.048	[-1.00]	-0.7116	[-0.43]
percap_income	-1.292	[-2.70]***	-1.2806	[-4.24]***	-1.7678	[-2.41]**
log-likelihood	-816.7211		-1030.9997		-1179.7429	
LR test	5.06	0.75	11.30	0.19	17.31	0.03

Notes: For saving space constant terms and province dummy variables are not listed here. *LR test: LR test* for the Joint significance of interaction terms. Dummy variable *migration* equals 1 if the household head migrates.
*, **, *** indicate significance at 10%, 5%, 1% level.

Table A-2-3 Estimated Parameters of Stochastic Production Frontiers and Variance Functions (Criterion 3, Regional)

Region/ Sample size	Western Region /1493		Central Region /1791		Eastern Region /1417	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
M_FWH	0.0537	[1.97]**	0.1238	[4.36]***	0.105	[2.98]***
M_FWHD_{female}	0.0287	[0.85]	0.0074	[0.22]	0.0317	[0.74]
F_FWH	0.0462	[1.72]*	0.0331	[1.16]	0.1562	[4.61]***
F_FWHD_{female}	-0.0598	[-1.70]*	-0.0268	[-0.78]	-0.027	[-0.66]
VC	0.2842	[13.14]***	0.27	[9.83]***	0.4373	[13.86]***
VCD_{female}	-0.0008	[-0.03]	0.0451	[1.37]	-0.1196	[-3.07]***
VL	0.0774	[10.45]***	0.0569	[8.55]***	0.0493	[7.79]***
VLD_{female}	0.0263	[2.53]**	0.0152	[1.92]*	0.0157	[1.94]*
K	0.0498	[4.46]***	0.0348	[3.70]***	0.0275	[2.18]**
KD_{female}	0.0091	[0.60]	0.0214	[1.92]*	0.0028	[0.18]
T	0.1168	[3.24]***	0.2311	[7.31]***	0.171	[4.11]***
TD_{female}	0.0356	[0.85]	-0.0178	[-0.48]	0.0749	[1.51]
irr_share	0.1597	[3.33]***	0.0838	[1.92]*	0.2367	[2.98]***
irr_shareD_{female}	0.0692	[1.05]	0.07	[1.28]	-0.1018	[-1.10]
D_{female}	-0.2631	[-0.93]	-0.4652	[-1.83]*	0.5583	[1.97]**
σ_v	-1.8212	[-37.47]***	-1.7325	[-44.75]***	-1.1827	[-30.97]***
Variance function						
wagework	-1.3827	[-2.18]**	0.1897	[0.29]	1.0847	[0.96]
largescale	-0.309	[-0.76]	-0.4565	[-0.92]	-0.2983	[-0.39]
num_hh	-0.3844	[-2.78]***	-0.1191	[-0.84]	0.1006	[0.30]
num_childlt6	0.3373	[1.14]	0.8567	[2.62]***	0.7768	[1.11]
age_head	0.0449	[1.05]	0.0625	[1.42]	-0.1846	[-1.31]
age_wife	-0.0316	[-0.74]	-0.038	[-0.85]	0.1454	[1.05]
educ_head	-0.0239	[-0.41]	-0.1043	[-1.70]*	-0.1539	[-0.94]
educ_wife	-0.0356	[-0.59]	-0.0326	[-0.56]	-0.0367	[-0.28]
nonlaborinc	0.1193	[1.98]**	-0.238	[-0.96]	0.2294	[2.14]**
collect_pest	0.4807	[1.32]	-1.7085	[-1.21]	-1.0112	[-0.46]
percap_income	-1.2593	[-2.86]***	-1.2879	[-4.54]***	-1.5377	[-2.62]***
log-likelihood	-816.7211		-1030.9997		-1179.7429	
LR test	21.46	0.01	14.53	0.07	27.62	0.00

Notes: For saving space constant terms and province dummy variables are not listed here. *LR test*: *LR test* for the Joint significance of interaction terms. Dummy variable *wagework* equals 1 if the household head works for wages (including migration). *, **, *** indicate significance at 10%, 5%, 1% level.

Table A-3-1 Results of Ordinary Least Squares Regression of Technical Efficiency (Criterion 1, Regional)

Region	Western Region		Central Region		Eastern Region	
Sample size	1493		1791		1417	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
R	0.0045	[13.82]***	0.0114	[21.88]***	0.0013	[6.80]***
percap_income	0.0518	[33.90]***	0.0583	[34.31]***	0.0286	[39.14]***
nonlaborinc	-0.0097	[-14.31]***	0.0049	[8.20]***	-0.0082	[-14.70]***
num_hh	0.0233	[32.61]***	0.0026	[2.46]**	-0.0009	[-0.94]
largescale	0.0099	[4.19]***	0.0137	[4.83]***	0.0097	[4.01]***
age_head	-0.0032	[-12.21]***	-0.0026	[-6.53]***	0.0023	[6.51]***
age_wife	0.0024	[8.73]***	0.0022	[5.28]***	-0.0017	[-4.64]***
educ_head	0.0003	[0.87]	0.0044	[9.16]***	0.0006	[1.45]
educ_wife	0.0004	[1.10]	0.0019	[4.34]***	0.0009	[2.25]**
num_childlt6	-0.0176	[-9.31]***	-0.046	[-16.90]***	-0.0204	[-6.56]***
collect_pest	-0.0308	[-11.29]***	0.0411	[11.99]***	0.0049	[1.74]*
R-squared	0.7189		0.6618		0.6483	
Technical Efficiency						
Households type	Male-headed	Female-headed	Male-headed	Female-headed	Male-headed	Female-headed
Sample size	681	812	902	889	815	602
Mean of TE	0.88	0.90	0.88	0.93	0.94	0.95
	0.89		0.90		0.94	

Note: For saving space constant terms are not listed here. *R* is a ratio of female farm work hours to male work hours. *, **, *** indicate significance at 10%, 5%, 1% level.

Table A-3-2 Results of Ordinary Least Squares Regression of Technical Efficiency (Criterion 2, Regional)

Region	Western Region		Central Region		Eastern Region	
Sample size	1493		1791		1417	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
migration	0.0857	[24.30]***	0.0491	[15.90]***	0.072	[16.01]***
percap_income	0.0578	[35.75]***	0.0539	[44.07]***	0.0266	[33.94]***
nonlaborinc	-0.0087	[-12.14]***	0.0056	[12.88]***	-0.009	[-15.02]***
num_hh	0.023	[30.39]***	0.0024	[3.10]***	0.0011	[1.07]
largescale	0.0081	[3.25]***	0.02	[9.79]***	0.0077	[2.96]***
age_head	-0.0026	[-9.15]***	-0.0035	[-12.22]***	0.0041	[11.03]***
age_wife	0.002	[6.86]***	0.003	[9.84]***	-0.0033	[-8.47]***
educ_head	0.0016	[3.73]***	0.0054	[15.39]***	-0.0008	[-1.65]*
educ_wife	0.0005	[1.30]	0.0022	[6.83]***	0.0016	[3.89]***
num_childlt6	-0.0191	[-9.55]***	-0.0439	[-22.46]***	-0.0366	[-11.03]***
collect_pest	-0.0323	[-11.21]***	0.0642	[26.02]***	0.0139	[4.61]***
R-squared	0.7345		0.7785		0.6339	
Technical Efficiency						
Households type	Male-headed	Female-headed	Male-headed	Female-headed	Male-headed	Female-headed
Sample size	681	812	902	889	815	602
Mean of TE	0.88	0.90	0.88	0.93	0.94	0.95
	0.89		0.90		0.94	

Note: For saving space constant terms are not listed here. Dummy variable *migration* equals 1 if the household head migrates. *, **, *** indicate significance at 10%, 5%, 1% level.

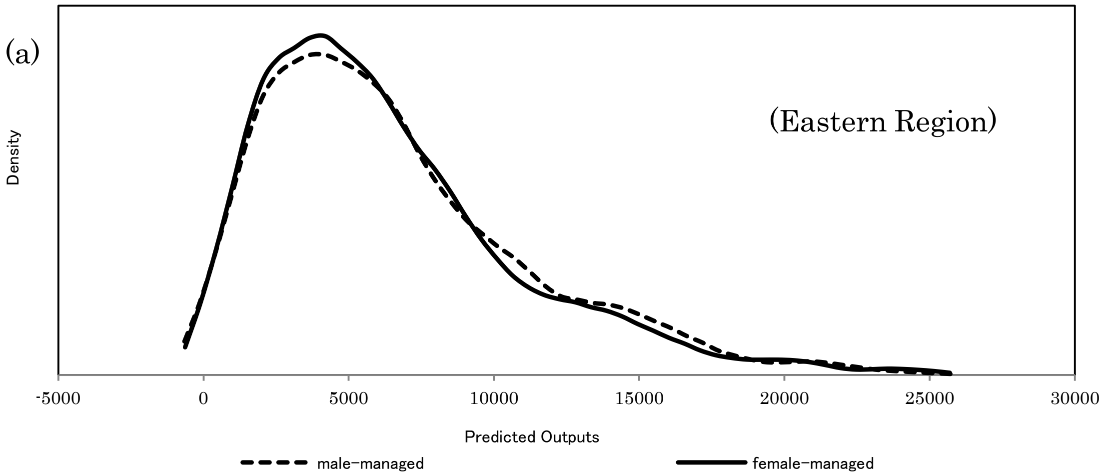
Table A-3-3 Results of Ordinary Least Squares Regression of Technical Efficiency (Criterion 3, Regional)

Region	Western Region		Central Region		Eastern Region	
Sample size	1493		1791		1417	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
wagework	-0.0264	[-13.01]***	-0.0045	[-2.63]***	0.073	[31.80]***
percap_income	0.0241	[33.65]***	0.0586	[46.53]***	0.0571	[30.88]***
nonlaborinc	-0.008	[-14.60]***	0.0063	[14.03]***	-0.0072	[-8.81]***
num_hh	-0.002	[-2.16]**	0.0043	[5.46]***	0.0208	[23.98]***
largescale	0.0041	[1.74]*	0.023	[10.97]***	0.017	[5.93]***
age_head	0.0052	[15.16]***	-0.0035	[-11.80]***	-0.002	[-6.16]***
age_wife	-0.004	[-11.12]***	0.0024	[7.78]***	0.0011	[3.44]***
educ_head	0.0041	[9.27]***	0.0052	[14.44]***	0.0017	[3.49]***
educ_wife	0.0012	[3.12]***	0.0021	[6.33]***	0.0014	[3.09]***
num_childlt6	-0.0306	[-10.07]***	-0.0451	[-22.35]***	-0.0187	[-8.16]***
collect_pest	0.0196	[7.10]***	0.0492	[19.31]***	-0.0317	[-9.58]***
R-squared	0.6645		0.7749		0.72	
TE						
Households type	Male-headed	Female-headed	Male-headed	Female-headed	Male-headed	Female-headed
Sample size	681	812	902	889	815	602
Mean of TE	0.88	0.90	0.88	0.93	0.94	0.95
	0.89		0.90		0.94	

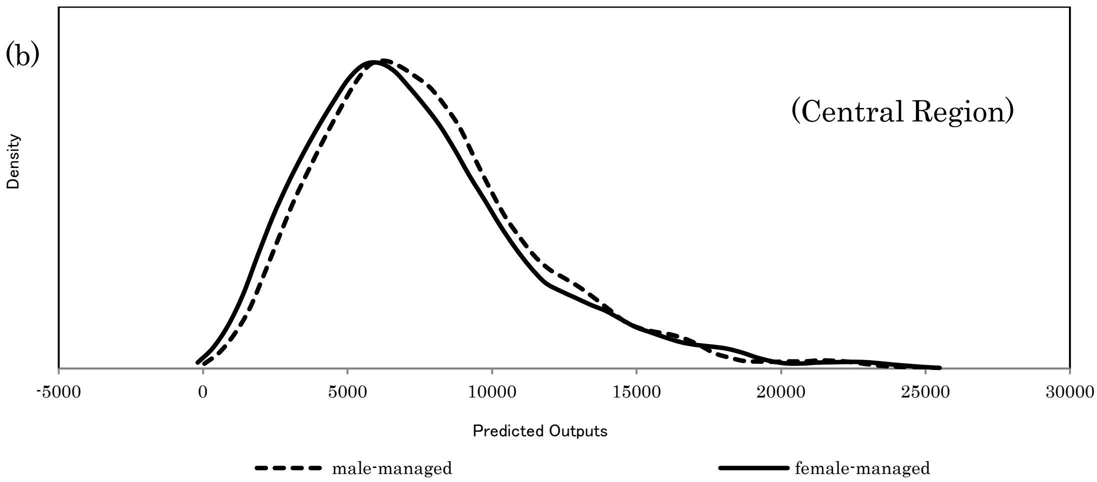
Note: For saving space constant terms are not listed here. Dummy variable *wagework* equals 1 if the household head works for wages (including migration). *, **, *** indicate significance at 10%, 5%, 1% level.

Figure A-1-1 Distributions of Predicted Outputs under Production Technologies of Male- and Female-managed Households (Criterion 1, Regional)

(a)



(b)



(c)

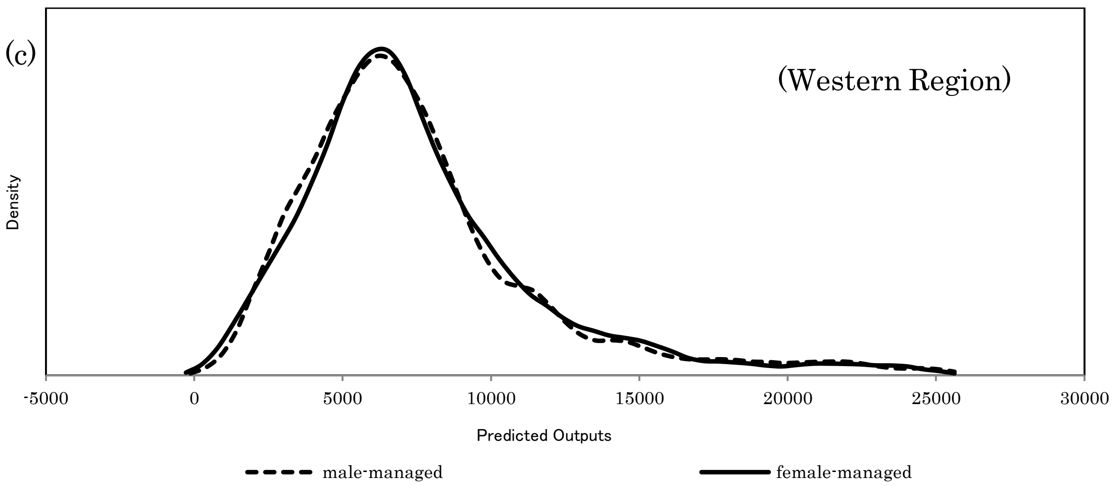
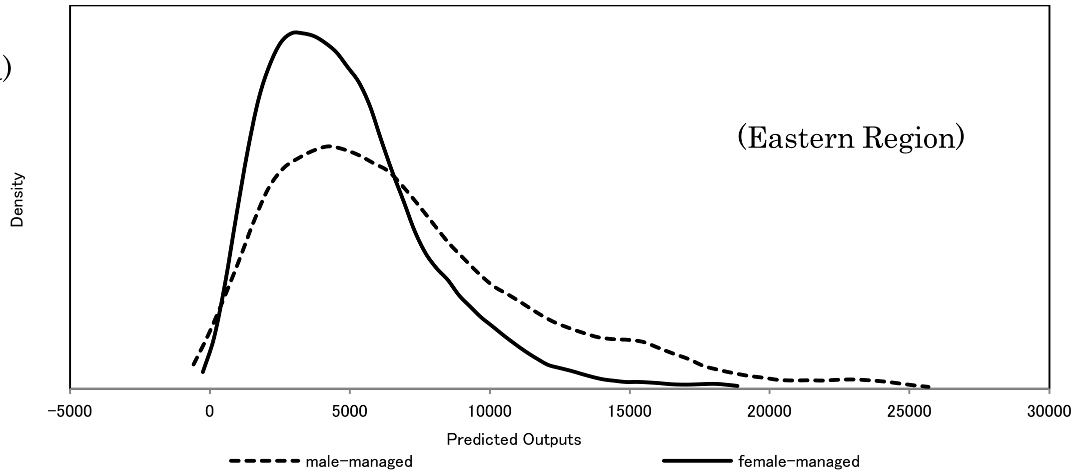
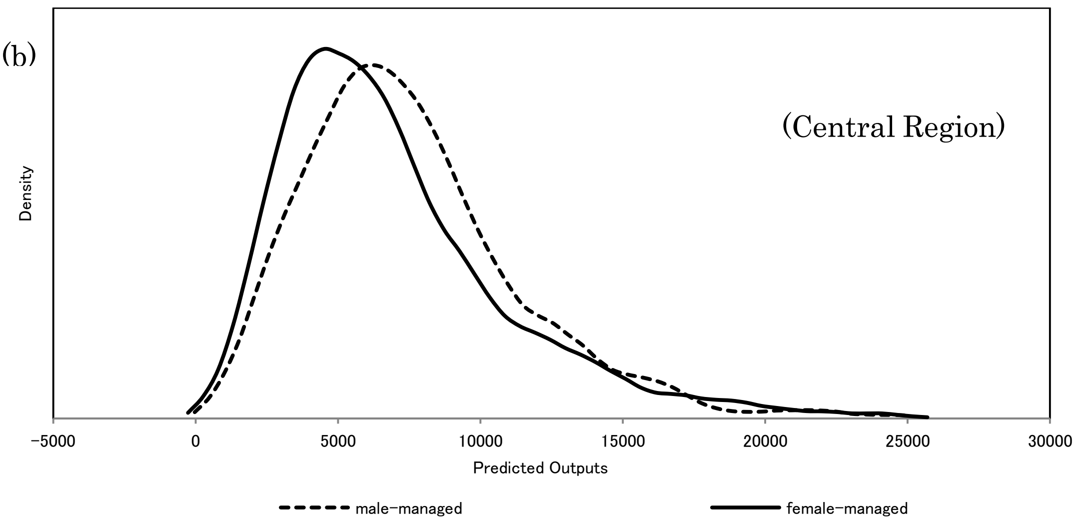


Figure A-1-2 Distributions of Predicted Outputs under Production Technologies of Male- and Female-managed Households (Criterion 2, Regional)

(a)



(b)



(c)

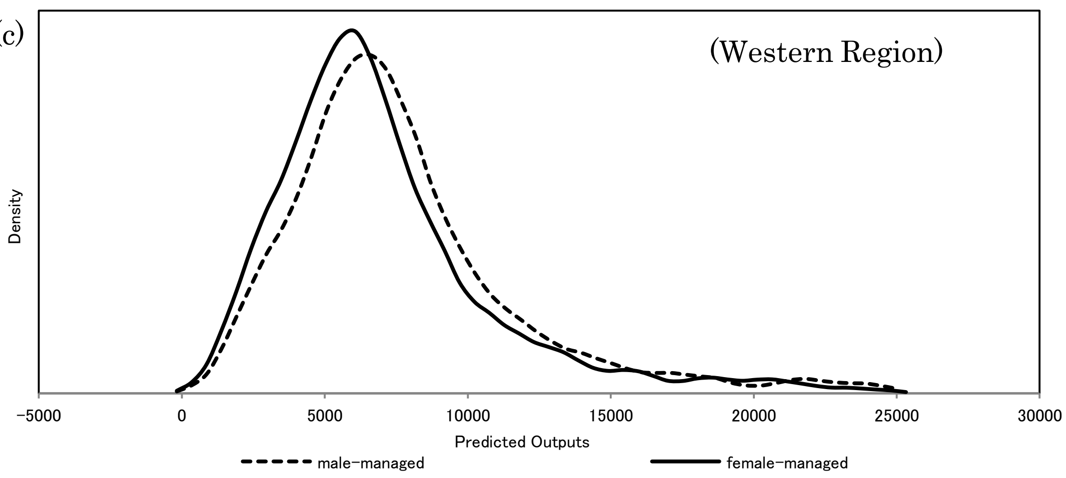


Figure A-1-3 Distributions of Predicted Outputs under Production Technologies of Male- and Female-managed Households (Criterion 3, Regional)

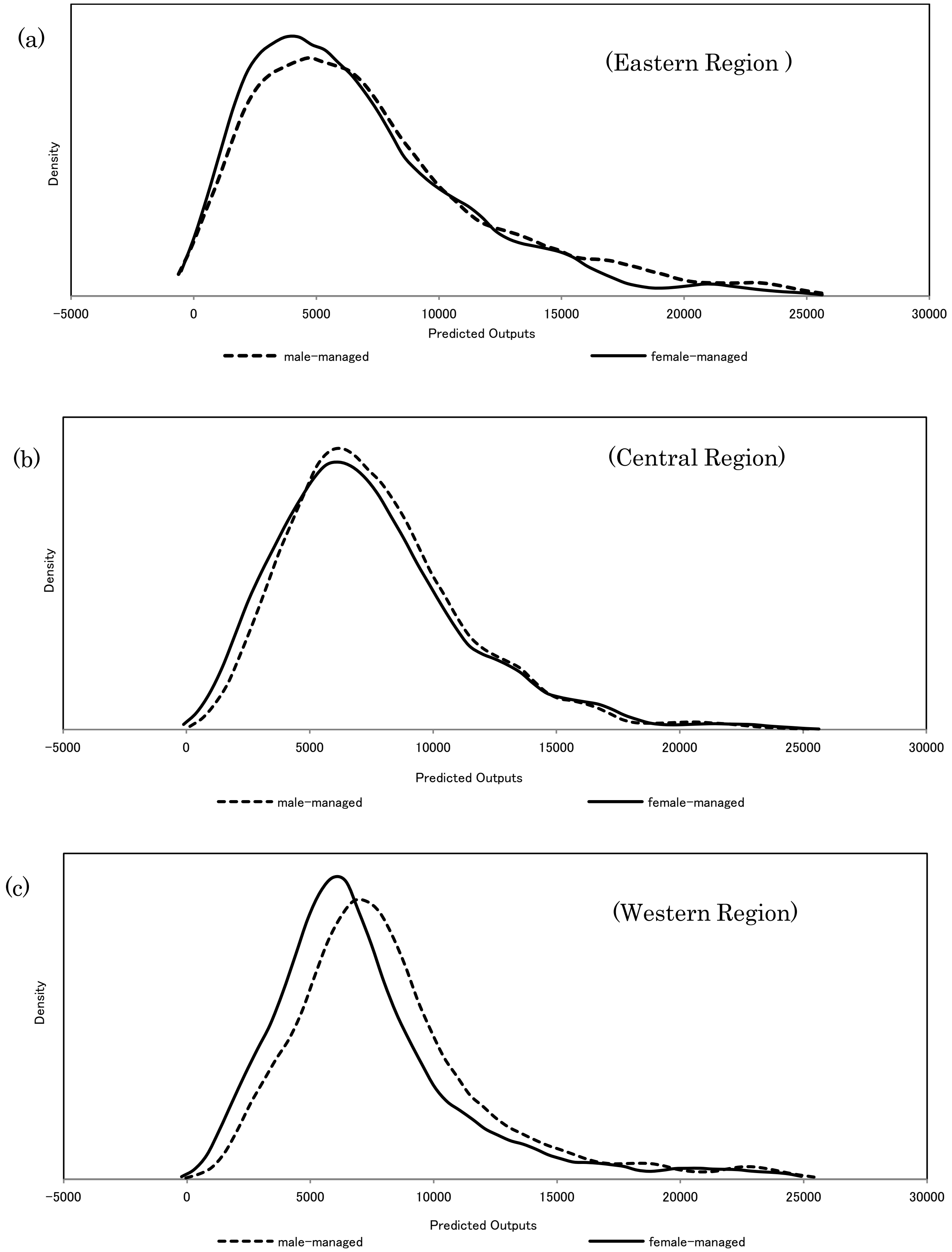
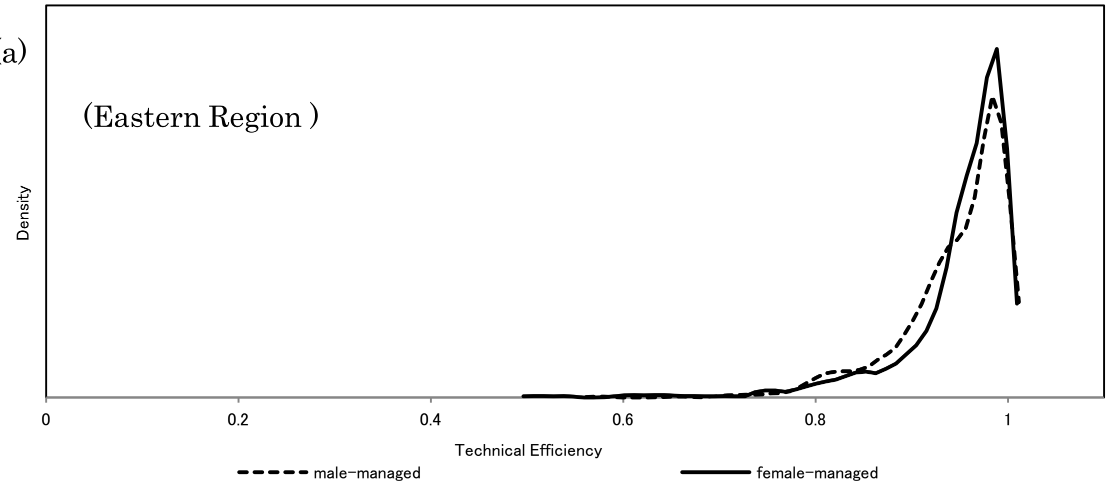
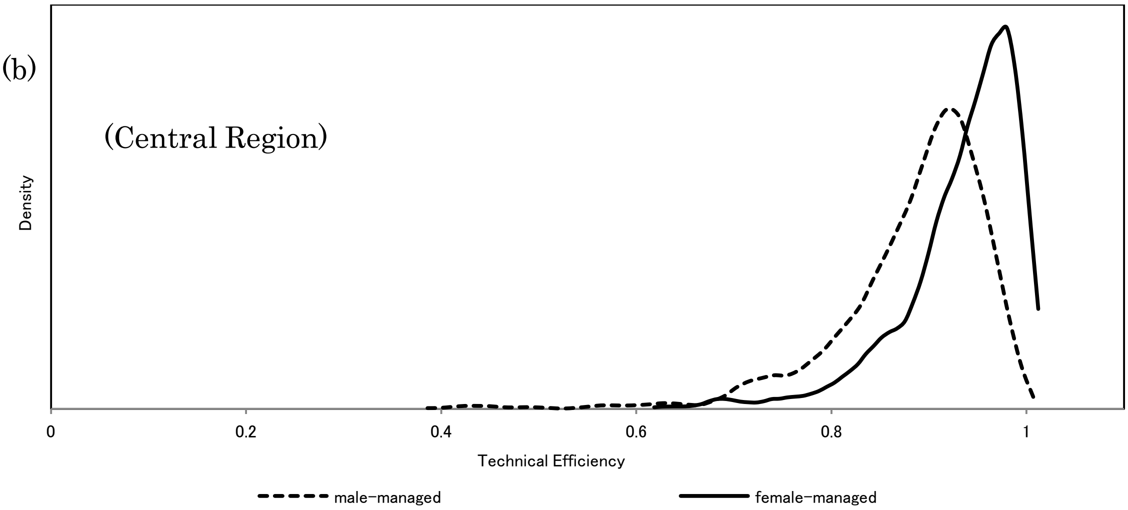


Figure A-2-1 Distributions of Technical Efficiency Index for Male- and Female-managed Households (Criterion 1, Regional)

(a)



(b)



(c)

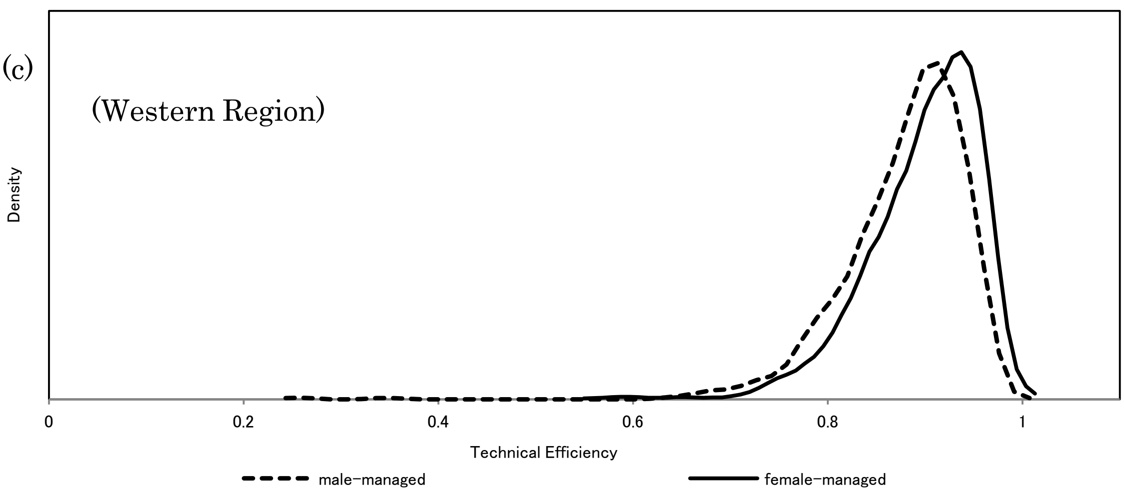


Figure A-2-2 Distributions of Technical Efficiency Index for Male- and Female-managed Households (Criterion 2, Regional)

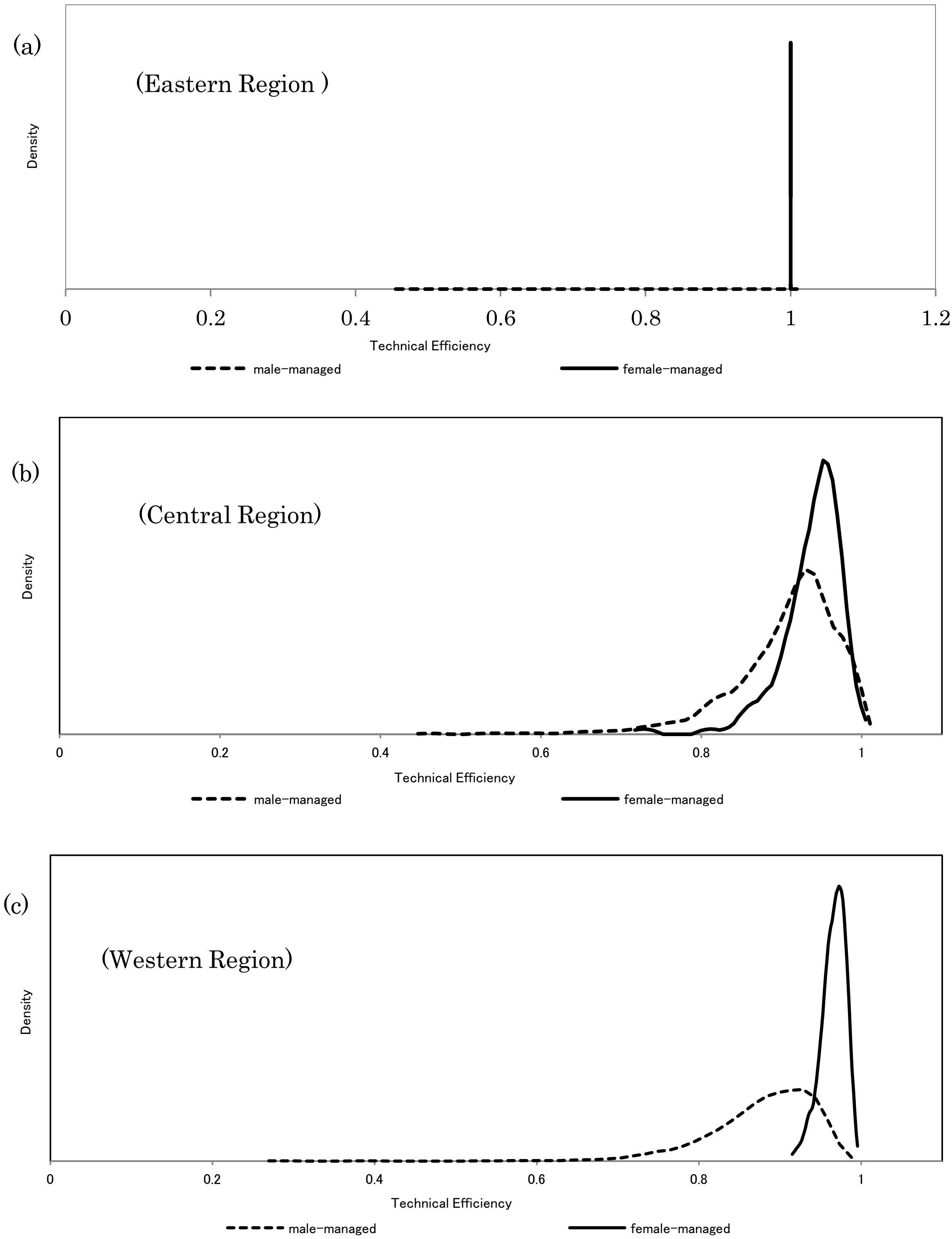


Figure A-2-3 Distributions of Technical Efficiency Index for Male- and Female-managed Households (Criterion 3, Regional)