『経済科学』第67巻第4号（2020年3月発行）
THE ECONOMIC SCIENCE, Vol.67, No.4, March 2020

DOI:10. 18999/ecos. 67. 4. 27

Do Female-Managed Households Have Lower Productivity?*
: A Stochastic Frontier Analysis for Chinese Farm Households

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We examine farm productivity of female-managed households in which females work on farm more than males and the male household head works for wages more than for farming. Using data on 4,340 Chinese farm households in 2002, we estimate a stochastic production frontier which allows for not only different production technology between male-managed and female-managed households but also heteroskedastic technical inefficiency. The estimation result shows that female-managed households have 17% lower production frontier (predicted maximum output), whereas they have 6% higher technical efficiency than male-managed households, implying that they have 11% lower productivity. Their lower production frontier might reflect lower quality of male labor and more use of traditional inputs in crop production, while their higher technical efficiency might reflect their strong dependence on traditional production technology.

Keywords: female-managed households, farm productivity, stochastic production frontier, technical efficiency, Chinese households

* This work was supported by the Grant-in-Aid for Scientific Research (C), No. 23580299 and Grant-in-Aid for Scientific Research (A), No. 23252008 from the Japan Society for the Promotion of Sciences.
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Ⅰ. Introduction

After the economic reforms started in the late 1970s, both urban and rural labor markets developed rapidly in China. Since then, people in rural China have had more opportunities for non-agricultural wage employment, but women did not have equal opportunities for it in rural labor markets. Consequently, men became more likely to have wage work in industrial or other nonagricultural sectors, leaving women to do more farm work and more domestic work (Mu and van de Walle, 2011; Chang, Dong, and Macphail, 2011).

As women worked longer on farm, many studies began to examine feminization of Chinese agriculture (e.g., Jacka, 1997). Although their interest varies, one of the most popular topics is the effect of agricultural feminization on farm outputs or farm productivity (e.g., Jin et al., 2002). This effect is commonly estimated by using a dummy variable for female-headed households, which equals one if females dominate males in agricultural production in some sense (e.g, taking charge of farm management, working longer hours on farm). Then, higher productivity of female-headed households is concluded if the dummy variable has a positive coefficient in the agricultural production function. For China, de Brauw et al. (2008) and Zhang, de Brauw and Rozelle (2004) find that female-headed households are at least as productive as male-headed households.

There are two issues in evaluating the effect of more female-headed households on farm productivity in China. First, definition of female-headed households might not be so simple because farms or plots solely run by females are not common in China, unlike in some African countries. Most empirical studies have not given due attention to managerial aspects of agricultural feminization but they have just focused on more participation of females in farm work in comparison with the past or other regions. However, female-headed (or female-managed) households might be better defined by allowing for managerial aspects of farm households, as de Brauw et al. suggest. Facing the difficulty in defining a standard variable for farm management, they focus on work status of family members because the household head cannot practically take charge of farm management if he works full time off the farm.[1] Therefore, it is more plausible to define female-managed households by combining off-farm work status of the male household head with more participation of females in farm work.

Second, the method for measuring productivity difference between male- and female-managed households can be improved. Most empirical studies, including those for other countries, just introduce a dummy variable for female-managed households to allow for different intercepts of production functions between female- and male-managed households. Although this method is easy to implement, Nishimizu and Page (1982) emphasize the importance of studying two distinct sources of productivity: technology level and technical efficiency. 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 outputs that could be produced using the best technology. The method used so far only allows for different intercepts of the production technology between the two types of households, and it ignores different technical efficiency and different output elasticities in the production technology.

This study deals with these issues in estimating productivity difference between male- and female-managed households in China. Specifically, female-managed households in our study satisfy 1) their female members work longer on farm than their male members to reflect more participation of females in farm production and 2) their male household heads work for wage employment longer than for farm production to reflect more engagement of females in farm management. Using this definition, we estimate a stochastic production frontier similar to Mayen, Balagtas and Alexander (2010) which allows for different production technology between the two types of households and a heteroskedastic inefficiency term. Furthermore, we use the estimation results to compare predicted maximum outputs (production frontiers) and technical efficiency between the two groups. Finally, we examine determinants of productivity difference between the two groups to derive policy implications.

Next section introduces data used in the empirical analysis and makes a preliminary analysis of productivity difference between male- and female-managed households. The third section specifies a stochastic production frontier which allows the two types of households to have different production technology. It also explains procedures to compute technical efficiency and partial effects of relevant variables on this efficiency. The fourth section compares production frontiers and technical efficiency between the two types of households, explains why they have different productivity, and examines implications of the results. The final section concludes the paper.

Ⅱ. Characteristics of Female-Managed Households in Rural China

1. Description of Data and Variables

The empirical analysis of this study uses data of rural households in Chinese Household Income Project survey in 2002 (CHIP2002; Li, 2002), which covers 22 out of 31 provinces in China.[2)] Sample households are randomly drawn from the 22 provinces so that sample size for provinces is proportional to their population. We specifically examine 4,340 households for which data on relevant variables are not missing and the following conditions are satisfied: 1) the sum of production value for grains, economic crops, and livestock products is positive; 2) the household head is a married male; 3) both the household head and his wife work on their own farm; 4) costs of producing grains and economic crops and cultivated (own and rented) land are positive. The empirical analysis also uses data on village-level variables from the Administrative Village Questionnaire annexed to CHIP2002.

Output Y is the sum of production value of grains, economic crops, and livestock products and 10% of the livestock value.[3)] Value consumed of those commodities that are produced by the household is used when their production value is not available.[4)] Male and female farm labor, L_m and L_f, are work hours of male and female family members which are used for producing grains, economic crops, and livestock products.[5)] Variable input VC for crop production is the sum of costs of producing grains and economic crops (including hired labor costs) and value of grains used for seeds and seedlings. Variable input VL for livestock production is the sum of costs in livestock production (including hired labor costs) and value of grains used for feed. Farm capital K includes 1) value of large and medium sized tools, machinery, and equipment used for farm production, 2) value of livestock used for labor and food, 3) value of transportation machinery and equipment, and 4) value of structures used for production. Land T is the sum of cultivated own and rented land.[6)] Variable *irr_share* denotes the share of irrigated land areas, which is included to control for land quality.

For the subsequent analysis, we introduce ten variables to explain technical efficiency based on other studies (e.g., Chen, Huffman, and Rozelle, 2009; Sherlund, Barrett, and Adesina, 2002). Dummy variable *large_scale* takes value 1 if the household has land T larger than the sample average. As demographic variables, we use the number of household members, *num_hh*, the number of children younger than six years old, *num_childlt6*, and the number of children between six and fifteen years old, *num_childge6*. We also use age of the household head and his wife, *age_head* and *age_wife*, and their schooling years, *educ_head* and *educ_wife*. Furthermore, we use *nonlabor_inc*, which 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 and Holtz (2006). Finally, we use per capita net income of the village, *percap_income*, which is also deflated by the provincial price index.

2. Comparison of Male- and Female-Managed Households

As explained in the first section, we define female-managed households (type F households for short) to reflect not only more participation of females in farm production but also more engagement of females in farm management. Specifically, type F households satisfy two conditions: 1) farm work hours L_f of females are longer than those L_m of males and 2) the male household head works for wages (local work or migration) longer than for farm work.[7] For convenience, we call the other households as male-managed households (type M households for short). Of 4,340 sample households, 968 (22%) are type F and 3,372 (78%) are type M.

Columns (a) and (b) of Table 1 present sample means of relevant variables for type M and type F households. The means of male and female farm work hours are 1,492 and 1,389 for type M, while they are 545 and 1,251 for type F. Female members in type F households work on farm much longer than their male members, but they work shorter than females in type M households. Furthermore, type F households do not substitute other inputs (costs *VC* and *VL* of crop and livestock production, farm capital *K*, and land *T*) for the reduced work hours. Type F households have shorter farm work hours of both males and females just because they produce much smaller amount of output *Y* (5,463 yuan) than that of type M households (8,218 yuan).

All household heads of type F participate in wage work and work for 1,771 hours on average, whereas 48% of household heads of type M participate in wage work and work for 919 hours on average: the household head of type F can be regarded as full-time wage workers. Variable *migrant*, which takes on 1 if the household head is a migrant, shows that 3% and 23% of household heads migrate for type M and type F households.[8] The small share of migrants for household heads implies that most of them engage in local work for wages because they are not so young: their average age is 46 for type M and 42 for type F.

The subsequent sections will estimate stochastic production frontiers for type M and type F households to examine the difference in their production technology and technical efficiency. The rest of this section makes a preliminary analysis of this difference. To examine potential difference in the production technology, we first look at the value shares of farm products because few farm households produce

Table 1. Sample Means of Relevant Variables by Household Types

	(a) Type M households		(b) Type F households		(b)/(a) (%)
Sample size	3372		968		
Y [yuan]	8218.3	(10173.0)	5462.8	(4042.9)	66.5
L_m [hours]	1491.9	(1106.5)	544.9	(438.1)	36.5
L_f [hours]	1388.6	(1026.5)	1250.7	(776.6)	90.1
VC [yuan]	1518.6	(2171.7)	1008.4	(1035.5)	66.4
VL [yuan]	1966.3	(8020.4)	1328.2	(2891.2)	67.5
K [yuan]	4228.8	(6776.2)	3264.8	(16981.6)	77.2
T [mu]	8.021	(8.523)	5.641	(4.903)	70.3
irr_share	0.543	(0.407)	0.623	(0.387)	114.7
wagework	0.481	(0.500)	1.000	(0.000)	208.0
wagehour [hours]	918.5	(772.8)	1771.1	(713.3)	401.1
migrant	0.026	(0.160)	0.228	(0.420)	865.0

Note: Variable *wagework (migrant)* is a dummy variable which takes 1 if the household head is a wage worker (a migrant). Variable *wagehour* denotes wage work hours of the household head and its mean is computed for those who actually engage in wage work. Standard deviations are shown in parentheses and units are shown in brackets.

Table 2. Value of Farm Products by Household Types (unit: yuan)

	Type M households	Type F households
Grains	2950 (45.7)	2312 (50.0)
Economic crops	2414 (26.1)	1250 (21.3)
Livestock products	2854 (28.2)	1900 (28.7)

Note: Value shares (%) are shown in parentheses.

a single crop in China.[9] Table 2 shows production value of grains, economic crops, and livestock products, which comprise all farm products in our analysis. For both type M and type F households, the value shares of grains, livestock products, and economic crops are roughly 50%, 30%, and 20%, respectively. Furthermore, type F households produce smaller value for all three products than type M households: they produce 22% smaller value of grains, 48% smaller value of economic crops, and 33% smaller value of livestock products. Thus, although type F households tend to produce more time-saving products (grains) than time-consuming ones (economic crops), their combination of farm products does not differ so much from that of type M households.

Now, we compare the amount of inputs and total output for the two groups. The last column of Table 1 presents the ratio of inputs (or total output) of type F households to those of type M households. Overall, type F households use smaller amounts of input to produce smaller amount of output. Specifically, they use 63% less male labor (L_m), 10% less female labor (L_f), 34% less crop inputs (*VC*), 32% less livestock inputs (*VL*), 23% less capital (*K*), and 30% less land (*T*) to produce 33% less output. This result is consistent with an implication of the New Economics of Labor Migration (Stark, 1991; Massey et al., 1993), which explains two opposite effects of labor migration on farm output. As Rozelle, Taylor, and de Brauw (1999) and Taylor, Rozelle, and de Brauw (2003) examine these effects for Chinese farm households, the negative effect of reduced farm labor on farm output exceeds the positive effect of increased income (or remittance) on it. Our result further shows that all the other inputs also decrease probably because farm production is not so attractive.

To find potentially different production technology between the two groups, we first note that output of type F households is reduced by 33% even though their male labor is reduced by 63%. Therefore, their production technology might allow more substitution of female labor and/or capital for male labor, which help them avoid much reduction in output. Furthermore, male labor is mainly supplied by the household head not only for type M but also for type F households. However, male labor of type F households might have lower productivity because the head engages in full-time wage work and he does not play an active role in farm prodcution. Jacka (1997) points out that male labor is expected to have lower productivity if males help females only at peak seasons with plowing, preparing the land, and threshing rice.

Finally, we make a preliminary analysis of different technical efficiency (TE) between the two groups. The subsequent empirical analysis will express TE as a function of variables *W* (e.g., age and education of the household head). Assuming the identical production technology for the two groups, the difference in thier TE comes from the difference in their endowment of variables *W* and partial effects $\partial \mathrm{TE}/\partial W$ of these variables on TE. Here, we examine the former for a preliminary analysis. Table 3 presents means of variables *W* used in the empirical analysis. It shows that type F households have smaller farm land, longer schooling years of the household head and his wife, and greater number of children between 6 and 15 years old. The smaller farm land for type F households, which is already seen in Table 1, might lower their TE through inefficient use of farm inputs (especially farm machinery). The longer schooling years of the household head reflects the tendency that

Table 3. Sample Means of Explanatory Variables for Technical Efficiency by Household Types

	(a) Type M households		(b) Type F households		(b)/(a) (%)
Sample size	3372		968		
largescale	0.414	(0.493)	0.263	(0.441)	63.6
num_hh	4.040	(1.267)	3.956	(1.033)	97.9
num_childlt6	0.175	(0.416)	0.166	(0.407)	95.2
num_childge6	0.722	(0.831)	0.975	(0.861)	135.2
age_head	46.101	(10.19)	41.524	(8.469)	90.1
age_wife	44.177	(9.778)	39.905	(8.105)	90.3
educ_head	7.057	(2.489)	7.982	(2.326)	113.1
educ_wife	5.199	(3.029)	6.213	(2.789)	119.5
nonlabor_inc [yuan]	438.2	(1592.0)	444.8	(1461.5)	101.5
percap_inc [yuan]	2390.6	(1318.5)	2439.1	(1181.3)	102.0

Note: Standard deviations are shown in parentheses and units are shown in brackets. Real non-labor income in the household (*nonlabor_inc*) and real per capita income in the village (*percap_inc*) are deflated by the provincial price index estimated by Brandt and Holtz (2006).

individuals with higher education are more likely to participate in wage work. Furthermore, a household head with higher education tend to have a wife with higher education. Higher education of the household head and his wife is expected to facilitate efficient use of farming technology and raise their TE. Finally, more children between 6 and 15 years old for type F households imply that they need to work for wages to earn more money incomes, which might lower their TE by reducing their attention to efficient use of farm inputs and technology.

Ⅲ. Empirical Method

We specify different stochastic production frontiers (SPF) for type M and type F households to allow for their potentially different production technology. A simply way is to estimate their SPF separately (e.g., Mochebelele and Winter-Nelson, 2000; Chang and Wen, 2011). A potentially serious problem with this method is sample selection bias. In our case, whether L_f is greater than L_m or whether the household head works for wages longer than farming can be correlated with the household's technical efficiency, which is included in the error term of the SPF. A standard way to cope with this issue is to add the inverse Mills ratio that is associated with the household's choice. However, this correction does not work in the SPF model because of non-negative technical efficiency, as explained by Kumbharkar, Tsionas, and Sipilainen (2009) and Greene (2010).

For this issue, we follow Mayen, Balagtas, and Alexander (2010) to estimate SPF (1) with different output elasticities for type M and type F households using data on all households:

$$\begin{aligned} lnY &= \gamma_0+\gamma_1 lnL_m+\gamma_2 lnL_f+\gamma_3 lnVC+\gamma_4 lnVL+ \\ &\gamma_5 lnK+\gamma_6 lnT+\gamma_7 irr\_share+\varepsilon \\ &\gamma_j=\alpha_j+\beta_j DF \quad (j=0,\cdots,7) \end{aligned} \tag{1}$$

Variables Y, L_m, L_f, VC, VL, K, and T respectively denote output, male labor, female labor, variable input for crop production, variable input for livestock production, farm capital and land.[10] Variable *irr_share* denotes the share of irrigated land areas, which 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 $N^+(0,\sigma_u^2)$.

Dummy variable *DF*, which appears in the coefficient γ_j of the production frontier (1), takes 1 for type F households and 0 for type M households.

Most studies similarly specifying different SPF assume $\beta_j = 0$ ($j = 1, \cdots, 7$), which means that only the intercept differs between the two groups. However, output elasticities might also be different between them, as seen in the previous section. Furthermore, different output elasticities between the two groups help explain different contributions of the inputs to production frontiers, as we will see below.

In addition to specifying different production frontiers for the two types of households, we also allow the household types to have a direct effect on technical efficiency. Following Caudill, Ford and Gropper (1995), the variance σ_u^2 of inefficiency u is specified as[11)]

$$ln\sigma_u^2 = \delta_0 + \Sigma_{k=1}^{11} \delta_k W_k \quad (2)$$

where W_k includes the dummy variable DF and the ten variables introduced in the previous section. Intuitively, technical inefficiency $u \geq 0$ tends to appear more rightward as the variance σ_u^2 becomes larger, implying that technical efficiency index $\mathrm{TE} = \exp(-u)$ $(0 \leq \mathrm{TE} \leq 1)$ tends to decrease as σ_u^2 becomes larger. Therefore, a positive coefficient δ_k means a negative effect of W_k on TE.

To confirm this effect, we compute TE in a similar way to Battese and Coelli (1988):[12)]

$$TE = \mathrm{E}[\exp(-u) \mid Y] = \{\Phi[(u^*/\sigma_*) - \sigma_*]/\Phi(u^*/\sigma_*)\}\exp[(\sigma_*^2/2) - u^*], \quad (3)$$

where $u^* = -(v-u)\sigma_u^2/\sigma^2$, $\sigma_*^2 = \sigma_u^2\sigma_v^2/\sigma^2$, and $\sigma^2 = \sigma_u^2 + \sigma_v^2$. Φ denotes the cumulative distribution function of the standard normal variable. For continuous variables, the partial effect of W_k on TE is computed as

$$\frac{\partial TE}{\partial W_k} = \frac{\delta_k \sigma_v}{2\sigma\sigma_u \Phi_*^2} \exp\left(\frac{\sigma_*^2}{2} - u^*\right) [\{\phi(u^{**}) - (2\sigma_*\Phi_* + \phi_*)\Phi(u^{**})\}u^* + \sigma_*^2\Phi_*\{\sigma_*\Phi(u^{**}) - \phi(u^{**})\}], \quad (4)$$

where $\Phi_* = \Phi(u^*/\sigma_*)$, $\phi_* = \phi(u^*/\sigma_*)$ and $u^{**} = (u^*/\sigma_*) - \sigma_*$, with ϕ denoting the standard normal density. For discrete variables, the effect of W_k on TE is computed by the difference between TE indexes evaluated at the base and reference values of W_k,[13)] with other variables being evaluated at their sample means.

After substituting equation (2) into the likelihood function of SPF (1), all the parameters are jointly estimated by the maximum likelihood method. Using the estimation result, we examine productivity difference of type M and type F households by comparing their production frontiers and their TE indexes in equation (3). The production frontiers will be compared in two ways. First, we test the single and joint significance of coefficients β_j in the SPF (1) using t tests and likelihood ratio tests. Second, we compute an index of deterministic production frontier (or predicted maximum output) in a similar way to Kumbhakar, Tsionas and Sipiläinen (2009). For this purpose, let $\hat{Y}_M$ and $\hat{Y}_F$ denote outputs that can be predicted using deterministic frontiers (the right hand side of the SPF (1) excluding ε) with $DF = 0$ and $DF = 1$, respectively. We compute both $\hat{Y}_M$ and $\hat{Y}_F$ for each household by substituting actual amounts of the six inputs and the share of irrigated land into the two deterministic frontiers. This method allows us to compare the deterministic frontiers for type M and type F households after controlling for input levels and the irrigation share.

Ⅳ. Empirical Results

Parameters of the SPF (1) and the variance function (2) are jointly estimated after adding province dummy variables to (1). Table 4 presents the estimation results.

1. Estimated Parameters of the SPF and Variance Function

The coefficients of lnL_m, lnL_f, $lnVC$, $lnVL$, lnK, and lnT in Table 4 represent output elasticities of these inputs for type M households, all of which are positive and statistically significant at the 5% level. These estimates might be compared with estimates of two studies. Liu and Zhuang (2000) (LZ for short) estimate a translog SPF for approximately 8,000 households in Sichuan and Jiangsu provinces in 1990, where their outputs only include crops. Their estimated output elasticities of labor, fertilizers, capital, and land are 0.17, 0.16, 0.13, and 0.55, respectively. Furthermore, Chen, Huffman, and Rozelle (2009) (CHR for short) estimate a similar SPF for approximately 600 households in nine provinces over the period 1995 - 1999. They estimate output elasticities of the above inputs at 0.15, 0.22, 0.09, and 0.44 on average.

Table 4. Estimated Parameters of the Production Frontier and Variance Function

Parameters in production frontier		
DF	0.1919	(0.94)
lnL_m	0.0950	(6.68)
$lnL_m \times DF$	-0.0700	(2.71)
lnL_f	0.0827	(6.43)
$lnL_f \times DF$	0.0330	(1.06)
$lnVC$	0.3365	(29.62)
$lnVC \times DF$	-0.0562	(2.44)
$lnVL$	0.0663	(22.76)
$lnVL \times DF$	0.0059	(0.99)
lnK	0.0350	(7.97)
$lnK \times DF$	0.0119	(1.46)
lnT	0.2040	(12.23)
$lnT \times DF$	0.0513	(1.62)
irr_share	0.1370	(5.53)
irr_share×*DF*	0.1114	(2.21)
Parameters in variance function		
Constant	-0.1154	(0.11)
DF	-2.4715	(1.60)
largescale	0.1247	(0.38)
num_hh	-0.3089	(2.24)
num_childlt6	0.7304	(2.33)
num_childge6	0.0446	(0.22)
age_head	0.0437	(1.04)
age_wife	-0.0321	(0.75)
educ_head	-0.0458	(0.82)
educ_wife	-0.0663	(1.20)
nonlabor_inc/1000	0.1318	(2.68)
percap_inc/1000	-1.7600	(5.78)
σ_v	0.4679	(89.56)
log-likelihood	-2905.4	
LR test	16.390	[0.012]

Note: Absolute values of t statistic are shown in parentheses and p-values are shown in brackets. Coefficients of province dummy variables are not shown for brevity.

Compared with these estimates, our output elasticities of L_m, L_f, VC, VL, K, and T are 0.10, 0.08, 0.34, 0.07, 0.04, and 0.20 for type M households, respectively. Our output elasticities of labor seem plausible because LZ and CHR use the sum of male and female labor.[14] Our output elasticity of crop inputs VC seems also plausible because LZ define their capital as the sum of depreciation costs of fixed capital and current costs except for fertilizers, which means that their capital and fertilizers practically correspond to our VC. Our output elasticity of capital is very small as expected because we use value of fixed capital. Finally, our output elasticity of land is much smaller than that of LZ and CHR mainly because nearly 30% of our output comes from livestock products, while output of LZ includes only crops.

Next, we examine the coefficients of interaction terms between the dummy variable DF and logarithm of the six inputs to compare output elasticities between type M and type F households. Coefficients of $lnL_m \times DF$ and $lnVC \times DF$ are found to be statistically significant at the 5% level. Furthermore, a likelihood ratio statistic to test joint significance of the six interaction terms is computed as 16.39 with p-value equal to 0.012, which means they are jointly significant at the 5% level. These results show that the production frontier of type F households actually differs from that of type M households. On the other hand, the dummy variable DF itself does not have a significant coefficient. Our results are quite different from Mayen, Balagtas, and Alexander (2010) who estimate a similar SPF for US dairy farmers adopting organic or conventional technology: their result shows that only the intercepts are statistically different between the two groups.

The significant coefficient of $lnL_m \times DF$ is -0.07, implying that output elasticity of male labor is 0.10 for type M and 0.03 for type F households. Table 4 also shows that output elasticity of female labor is estimated at 0.08 for type M and 0.12 for type F, though the difference is not statistically significant. Therefore, male labor of type F households has the lowest output elasticity as expected in the second section, which gives one of the most significant differences in production technology between the two groups. This result confirms our guess: the male household head tends to have low farm productivity when he engages in full-time wage employment and when he works on farm only at peak seasons. Instead, his wife is obliged to specialize more in farm production, which slightly raises output elasticity of female labor compared with that for type M households. Thus, when the household head works full-time for wages, quality (or effort) of male labor tends to decrease and that of female labor tends to increase.

The other significant difference in production technology between the two groups is given by the coefficient of $lnVC \times DF$. Specifically, type F households have an output elasticity 0.28 of crop inputs, which is lower than the similar elasticity 0.34 for type M households. In these households, wife of the household head plays an active role in farm management. She tends to use traditional inputs (seeds, fertilizers, agricultural chemicals) with lower quality or effectiveness than modern inputs because of her conservative attitude in choosing farm inputs and production technology. One might think that type F households earn more incomes than type M households from wage employment and that the former can purchase better (new) inputs. Actually, however, they do not spend increased incomes on better farm inputs, as shown in Table 1.

In summary, the estimated parameters in Table 4 show that the production frontier of type F households is not statistically different in the intercept from that of type M households, but the former has significantly smaller output elasticities for male labor and costs of crop production. This result suggests a lower production frontier for type F households, which will be verified in the next subsection.

Finally, we briefly examine estimated coefficients of the variance function (2). The number of household members (*num_hh*), the number of children younger than five years old (*num_childlt6*), household nonlabor incomes (*rnonlabor_inc*), and per-capita net income in the village (*rpercap_inc*) have significant coefficients at the 5% level. The direct effect of being type F households on the variance of inefficiency u is not significant at the 5% level, with p-value of the related coefficient being 0.109. Furthermore, as indicated by LR test in Table 4, a likelihood ratio statistic to test joint significance of 11 coefficients of variables W_k in equation (2) is computed as 81.16 with p-value equal to 0.000. Therefore, homoskedasticity of inefficiency u is rejected at any reasonable level of significance. To examine implications of these coefficients, we need to evaluate the related partial effects on technical efficiency in section Ⅳ.3.

2. Estimated Production Frontiers and Their Factor Decomposition

We use the estimated parameters α_j and β_j of SPF (1) to predict the production frontiers (or compute predicted maximum outputs) $\hat{Y}_M$ and $\hat{Y}_F$. Sample means of $\hat{Y}_M$ and $\hat{Y}_F$ for 4,340 households are computed as 7319.5 (4532.1) and 6110.5 (3642.3), respectively, where standard deviations are shown in parentheses. The production frontier of type F households is lower by 17% on the average, with the six inputs and the irrigation share being fixed at the common values. To compare the two outputs in more detail, Figure 1 depicts their kernel density curves, with the horizontal axis measuring $\hat{Y}_M$ and $\hat{Y}_F$ and the vertical axis measuring the density. The dotted and solid lines respectively represent the kernel density curves for $\hat{Y}_M$ and $\hat{Y}_F$. The curve for $\hat{Y}_F$ has the mode at around 5,000, which is slightly smaller than the mode of $\hat{Y}_M$. The figure again confirms lower production frontier for type F households.

To find relevant factors to explain the lower production frontier for type F households, we decompose the geometric means of $\hat{Y}_M$ and $\hat{Y}_F$ and find important factors to explain the lower production frontier of type F households. By definition of $\hat{Y}_M$ and $\hat{Y}_F$, we can write these values for household $i\,(=1, \cdots, 4340)$ as

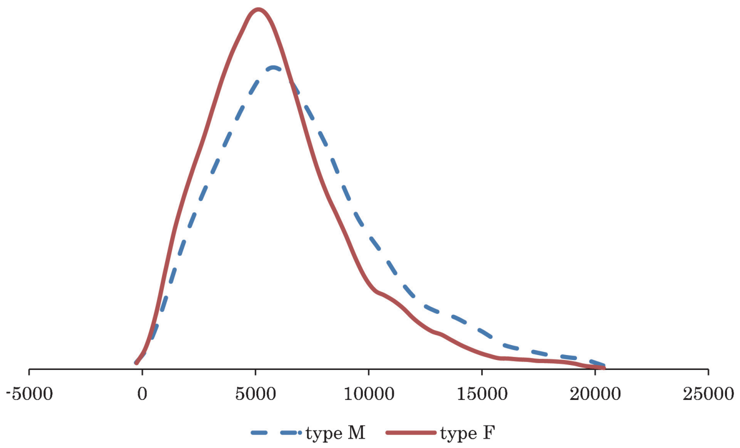
$$\hat{Y}_{M,i} = \exp(\hat{\alpha}_0)\Pi_{k=1}^{7} X_{k,i}^{\hat{\alpha}_k}, \tag{5}$$

$$\hat{Y}_{F,i} = \exp(\hat{\alpha}_0+\hat{\beta}_0)\Pi_{k=1}^{7} X_{k,i}^{\hat{\alpha}_k+\hat{\beta}_k} \tag{6}$$

where $X_{k,i}\,(k=1, \cdots, 6)$ denote L_m, L_f, VC, VL, K, and T for household *t*, $X_{7,i} = \exp(irr\_share_i)$, and $\hat{\alpha}_k$ and $\hat{\beta}_k$ are maximum likelihood estimates of α_k and β_k.

Using equations (5) and (6), we take geometric means $\tilde{Y}_M$ and $\tilde{Y}_F$ of $\hat{Y}_{M,i}$ and $\hat{Y}_{F,i}\,(i=1, \cdots, 4340)$ and obtain

Figure 1. Distribution of Predicted Maximum Outputs $\hat{Y}_M$ (type M) and $\hat{Y}_f$ (type F)



$$\tilde{Y}_F / \tilde{Y}_M = \exp(\hat{\beta}_0)\Pi_{k=1}^{7} \tilde{X}_k^{\hat{\beta}_k} \quad (7)$$

where $\tilde{X}_k$ $(k=1,\cdots,7)$ denote the geometric mean of $X_{k,i}$ over 4,340 households. Equation (7) shows that the ratio $\tilde{Y}_F/\tilde{Y}_M$ is decomposed into the difference in the intercept of the production frontier, $\exp(\hat{\beta}_0)$, and the difference in the contribution of factor k $(=1,\cdots,7)$ to the production frontier, $\tilde{X}_k^{\hat{\beta}_k}$. The contribution $\tilde{X}_k^{\hat{\beta}_k}$ of production factor k to the ratio $\tilde{Y}_F/\tilde{Y}_M$ varies depending on the difference $\hat{\beta}_k$ in output elasticity between the two groups. It is greater than 1 if $\hat{\beta}_k > 0$, lower than 1 if $\hat{\beta}_k < 0$, and equal to 1 if $\hat{\beta}_k = 0$.

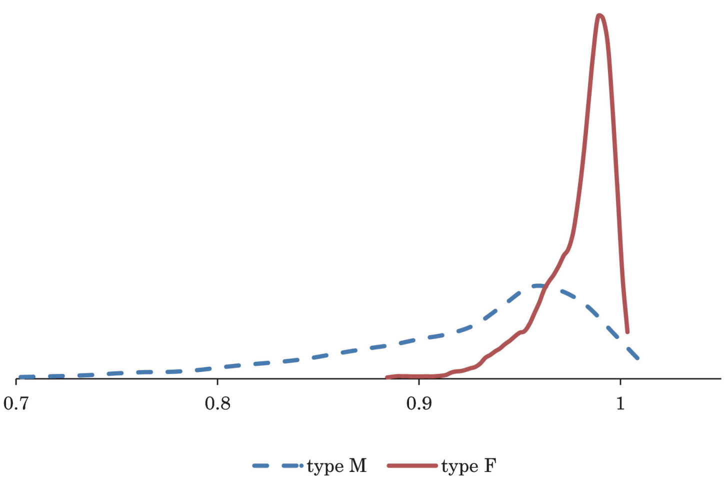
Table 5 presents decomposition of the ratio $\tilde{Y}_F/\tilde{Y}_M$ into the intercept difference ("Constant") and the contributions of production factors. It shows that the production frontier of type F households is 16% lower

Table 5. Contributions of Production Factors to the Ratio $\tilde{Y}_F/\tilde{Y}_M$ of Predicted Maximum Outputs

	Contribution of each production factor to $\tilde{Y}_F/\tilde{Y}_M$
Constant	1.2115
Male labor	0.6223
Female labor	1.2559
Costs of crop production	0.6820
Costs of livestock production	1.0330
Capital	1.0878
Land	1.0900
Irrigation	1.0645
$\tilde{Y}_M$	6117.0
$\tilde{Y}_F$	5150.6
$\tilde{Y}_F/\tilde{Y}_M$	0.8420

Note: $\tilde{Y}_S$ (S = M, F) denotes the geometric mean of output which is predicted using the production technology of type S households. The product of all the contributions is equal to $\tilde{Y}_F/\tilde{Y}_M$.

Figure 2. Distributions of Technical Efficiency for Type M and Type F Households



when we compare geometric means of $\hat{Y}_M$ and $\hat{Y}_F$. Contributions substantially greater than 1 come from the intercept difference (1.21) and female labor (1.26), whereas those substantially smaller than 1 come from male labor (0.62) and costs of crop production (0.68). Furthermore, all the other contributions exceed 1 and their product is 1.30. As we have already examined, the output elasticities of male labor and costs of crop production are significantly lower for type F households, whose effects dominate the others to eventually produce their lower production frontier. We have also examined that these households have higher quality of female labor because wife of the household head has to specialize more in farm production, which explains the relatively large contribution of female labor. The relatively large contribution of intercept difference implies, for example, that the head's wife for type F households might gain higher managerial ability after specializing more in farming or they have land with better (unobserved) quality. Although each of the other contributions is not large and is not statistically significant, they are combined to make as much contribution as female labor do. Therefore, type F households use inputs with somewhat better quality excluding inputs for crop production.

3. Estimated Technical Efficiency and Its Determinants

The sample mean of technical efficiency TE in equation (3) is computed as 0.921 (0.066) for type M households and 0.979 (0.018) for type F households, where standard deviations are shown in parentheses. The average type F household has 6% higher technical efficiency. For Chinese farm households, LZ and CHR estimate TE between 0.73 and 0.77 for the eastern region and between 0.55 and 0.69 for the (south) western regions. Our higher estimates might be plausible because our inputs and outputs cover livestock production, for which Latruffe et al. (2004) find a 15% higher *TE* than that for crop production in Poland. For detailed comparison, Figure 2 depicts the kernel density curves of TE index for the two groups, with the horizontal axis measuring TE and the vertical axis measuring the density. The dotted and solid lines respectively represent the kernel density curves for type M and type F households. The curve for type F has a narrower distribution with a mode between 0.98 and 0.99, whereas the curve for type M has a wider distribution with a mode between 0.95 and 0.96. Therefore, the figure again confirms higher technical efficiency for type F households.

To find relevant factors to explain the higher TE for type F households, we recall the discussion near equation (4) and compute partial effects on TE of a

Table 6. Partial Effects of Relevant Variables on Technical Efficiency (unit: %)

Variable W_k	(a) Partial effect of a unit change in W_k on TE	(b) Difference in Mean of W_k between type M and type F	(a)×(b)
DF	3.253	1.000	3.253
largescale	-0.283	-0.151	0.043
num_hh	2.433	-0.084	0.204
num_childlt6	-1.897	-0.009	0.017
num_childge6	-0.099	0.253	-0.025
age_head	-0.064	-4.577	0.293
age_wife	0.047	-4.272	-0.201
educ_head	0.067	0.925	0.062
educ_wife	0.097	1.014	0.098
nonlabor_inc/1000	-0.192	0.007	-0.001
percap_inc/1000	2.568	0.049	0.125

Note: Partial effects of continuous variables are computed using equation (4), while those of discrete variables are computed by the difference between TE indexes in equation (3) evaluated at the base and reference values. Difference in mean of W_k is computed by subtracting its sample mean for type M households from that for type F households.

unit change in variable W_k. Column (a) of Table 6 presents the computed partial effects in percentage.[15] The three variables with statistically significant coefficients in Table 4, *num_hh, num_childlt6*, and *percap_inc*, have relatively large effects on TE, though *nonlabor_inc* does not.

The partial effect of the increased number of household members *(num_hh*) from 4 to 5 raises TE by 2.4%. Note that the number of children is controlled in the variance function (2) and that almost all adults work on farm to some extent. Then, the result means that one more adult allows easier labor mobilization to meet peak demands at the time of planting and harvesting, which raises technical efficiency by 2.4%. The partial effect of the increased number of young children (*num_childlt6*) from 0 to 1 lowers TE by 1.9%. This result is expected because family members (particularly wife of the household head) are obliged to take care of their child and they are likely to lose some of their attention to farm production.

The partial effect of an increase in per-capita village income (*percap_inc*) by 1,000 yuan raises TE by 2.6%. An interpretation of this result is that farm households in less developed villages are more likely to be constrained to have liquidity or credit for purchasing current inputs or farm machinery. To show the importance of this effect, we classify our 22 sample provinces into the most developed region (east), the least developed region (west), and the intermediate region (center).[16] For the eastern, central, and western regions, sample means of *percap_inc* are 3,510, 2,226, and 1,578 yuan, respectively. Combining the difference in these mean incomes with the partial effect, farm households in the central region have 3.3% lower TE and those in the western region have 5.0% lower TE than technical efficiency in the eastern region due to their lower village incomes.

Dummy variable *DF* has a relatively large partial effect despite of its insignificant coefficient in Table 4, which means that type F households have 3.3% higher TE than type M households, with other variables in the variance function being fixed. This result is not surprising if we recall the lower production frontier of type F households: they have kept using a traditional inputs and technology for a long time and hence they can make the most of it. Partial effects of changes in the other variables are negligible.

We found some remarkable partial effects, but they are not enough to explain the difference in TE (6%) between the two groups. Column (b) of Table 6 presents the difference in sample means of variable W_k between the two groups, which are computed from the result in Table 3. Column (a)×(b) of this table presents partial effects of variable W_k when it changes by the difference shown in column (b). Nearly half of the difference (3.3%) is explained by the dummy variable *DF*, which seems to be related to their different production technology. However, variables *num_hh*, *num_childlt6*, and *percap_inc*, unit change of which have large partial effects, do not show large difference in the sample mean between the two groups. As a result, all the variables (including *DF*) can explain 3.5% of the TE difference 6% between them. Future research should improve the model so as to explain this remaining difference.

4. Implications of the Empirical Results

Finally, we examine implications of the empirical results, assuming that the share of type F households will rise along with further economic development of China. A direct implication of the empirical results is decrease in farm outputs. Specifically, if a type M household turns into type F, its farm output will be reduced by 17% due to lower quality or effort regarding its inputs (male labor and crop inputs). Although higher technical efficiency is expected to raise output of this household by 6%, it is much weaker than the opposite effect of lower quality inputs. Furthermore, the change of a type M into a type F household decreases all the inputs, which causes reduction in output by 22%. Consequently, change from a type M to type F household causes 33% output reduction in total.

On the other hand, increased share of type F households is expected to improve farm income and the related income inequality.[17] Specifically, the total income from agricultural production and wage work is 7,343 yuan for type M and 8,488 yuan for type F households. The Gini coefficient is computed as 0.38 for type M and 0.28 for type F households. Furthermore, Theil index is computed as 0.225 using total income of all households, which is decomposed into within type M inequality, 0.191, within type F inequality, 0.032, and between the groups inequality, 0.002. All these results suggest that both total income and income inequality improve as the share of type F households increase.

Considering the share of type F households is still 22% in our sample, it is expected to rise because further economic development is likely to increase wage work hours of the household head and hence increase farm work hours of females in comparison with those of males. The raised share is likely to have a negative effect of reducing farm outputs and a positive effect of increasing farm incomes and reducing income inequality. Increase in type F households reflects reallocation of labor from agricultural sector to more profitable sectors, which is inevitable and necessary change along with economic development. Therefore, plausible policies might be to avoid substantial reduction in farm outputs without interrupting the reallocation of rural labor.

Our empirical results show that farm outputs can be reduced substantially along with further economic development because the household head works full-time for wages and his wife mainly manages how and when to use crop inputs in type F households. The lower effort of male labor in these households might be difficult to avoid. On the other hand, the lower quality and reduced amount of crop inputs can be mitigated by helping these households use newer or more effective crop inputs. As suggested in de Brauw et al. (2008), type F households are likely to have fair access to production factors and financing. Therefore, it is helpful for them to have instructions and assistance for introducing newer crop inputs and technology.

V. Conclusions

By defining type F households as those in which females work on farm longer than males and the male household head works for wages longer than for farming, this study examines productivity difference between type F and type M (non-type F) households using data on 4,340 Chinese farm households in 2002. For this purpose, we estimate a stochastic production frontier which allows for different production technology between the two groups and which has a heteroskedastic error term (inefficiency). Using the estimation results, we compare predicted maximum outputs (production frontiers) and technical efficiency between the two groups. Furthermore, we examine determinants of the productivity difference by decomposing the ratio of the predicted maximum outputs and by computing partial effects of relevant variables on technical efficiency.

Main results are summarized as follows. The two types of households have different production technology and type F households have 17% lower production frontier, with the inputs being controlled between the two groups. In a farm household where the male household head works full-time for wages, he works on farm only at peak seasons and his wife mainly takes care of farm production. Consequently, its maximum output is lower because of lower quality or skill of his farm labor and use of traditional or older inputs in crop production, although his wife is likely to gain her skill and managerial ability in farm production. On the other hand, type F households have 6% higher technical efficiency. Since we cannot find other important factors for this efficiency difference than a dummy variable for type F households, it is likely to come mainly from their strong dependence on traditional production technology.

Combining the estimated difference in production frontiers and technical efficiency, we conclude that type F households have 11% lower productivity than type M households and that the lower productivity is mainly attributed to the lower production frontier of type F households. Our result is consistent with Mayen, Balagtas and Alexander (2010) in the sense that the difference in production frontiers is more important than the difference in technical efficiency between the two groups.

Notes

1) de Brauw et al. (2008) consider the following work status for males and females: (a) work full time off the farm, (b) work mainly off farm and work on the farm only in the busy season, (c) work part time on the farm, and (d) work full time on the farm. Then, they define female-managed households as those for which males do not play an active role on the farm, that is, either case (a) or (b) for males. We follow them to use the term female-managed households hereafter.

2) Gustafsson, Li, and Sicular (2008) and Knight, Deng, and Li (2011) provide a detailed description of the survey.

3) Jacoby (1993) adds 20% of the livestock value in computing the value of outputs.

4) Of 9,200 households originally included in the survey, the shares of households which miss data for production value of grains, economic crops, and livestock products are 6%, 8%, and 15%, respectively.

5) Among 4,340 households, farm work hours of hired workers are positive only for 953 households and the average hours for these households are 120.0, which is only 4% of farm work hours of their family members (2677.8). For this reason, we do not include hired work hours in male and female farm labor.

6) Most households in our sample do not rent land from other households. The average share of rented land in total land T is about 4%.

7) We ignore non-agricultural self-employment partly because the household head is likely to work more on his farm when participating in self-employment work near his home than when participating in wage work outside his home. Furthermore, we do not separate households whose heads migrate from those whose heads do local wage work because the number of the former is only 310. Most household heads in rural China do not migrate partly because they are not so young (see Table 1 for the average age) and because they have relatively good access to local wage work.

8) Migrants are defined as those who work out of their home county at least 90 days in the survey year.

9) Of the 4,340 sample households, only 40, 219, and 560 of them do not produce grains, economic crops, and livestock products, respectively.

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

11) Although a more popular assumption might be a truncated normal distribution of technical inefficiency u, Liu and Myers (2009), for example, show that SPF with heteroskedastic and half-normal inefficiency u can predict similar results for responses of technical efficiency index to changes in its explanatory variables.

12) A more popular way is just to regress estimated technical efficiency on variables W_k , but this procedure can yield a biased result, as pointed out by Wang and Schmidt (2002).

13) Discrete variables include *DF*, largescale, *num_hh, num_childlt6*, and *num_childge6*. Their base values are

0 for the variables except for *num_hh,* whose base value is set at 4. Their reference values are obtained by adding one to their base values. It should be noted that *DF* is also included in the production frontier, which is accounted for when computing the effect of *DF* on *TE*.

14) CHR use almost the same definition of inputs and output as LZ.

15) In computing partial effects of a change in W_k, other variables are fixed at their sample means (or their base values for discrete variables). Sample means are evaluated in three ways (for total sample, type F households only, and type M households only), but the results are similar. Table 6 presents the result based on total sample means.

16) 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.

17) Agricultural income is computed by subtracting production costs from value of farm products for grains, economic crops, and livestock. The inequality indexes are computed using only positive household incomes.

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