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The Outsourcing Choice of Agricultural Production Tasks: Implications for Food Security

– A Multiple-task Based Approach *

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Abstract

Outsourcing of agricultural operating tasks has become an important part of agricultural production in China, which has aroused concerns about food security considering the moral hazard problems that commonly existed in outsourcing. To address the endogeneity of outsourcing decisions in estimating its effect on crop yields, and account the simultaneous decisions of outsourcing choices in the first stage, we adopt an Garden Variety 2SLS with multiple variate probit (MVP) model in the first stage. This method has great application values in settings like estimating causal effect of multiple binary choices. Based on a rural household survey in 12 counties in China, we find that: (i) outsourcing of agricultural production tasks does not influence crop yields negatively, but generally has a positive effect instead after addressing the endogeneity and joint decision of outsourcing choices, this implies that the positive effects of specialization brought by outsourcing exceed the negative effects of moral hazard. (ii) outsourcing choices are proved to be highly correlated, which highlights the necessity of modeling outsourcing choices as a system by relaxing unit variance matrix of conventional binary choice models. (iii) (Un)conditional probabilities using simulation based on estimated MVP parameters reveals that the general outsourcing order is from harvesting, ploughing, transplanting to pesticide spraying.

Short title: Outsourcing of Agricultural Production Tasks
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1 Introduction

With an aging agricultural labor force, large-scale industrialization in China over the past decades has caused significant outflow of agricultural labor (Rozelle, Taylor and DeBrauw 1999; Li and Sicular 2013*a*; Xie and Lu 2017). Meanwhile, the potential great value of arable land hinders farmers' compensated withdrawal of rural contracted land (Jin and Deininger 2009). These two trends have raised great concerns about how to maintain farmland operation. Outsourcing of agricultural production tasks has emerged as a new solution to this problem in China (China Ministry of Agriculture and Rural Affairs, 2019) [1]. For instance, the proportion of outsourcing costs out of total production costs of maize has increased from 27.4% in 2004 to 47.2% in 2018 in China.

Measuring the effect of agricultural production outsourcing on land productivity is of great significance and has important policy implications. If outsourcing cannot increase, or oven decrease, land productivity, this will have a great impact on local food security and global grain market considering that China has nearly one fifths of the global population. Moral hazard problem is commonly existed in all types of outsourcing in second and third industries (Elitzur, Gavious and Wensley 2012; Sedatole, Vrettos and Widener 2012), so we cannot suppose it is not existed in agricultural production outsourcing. This problem may have a negative impact on the land productivity, further influence the food security considering the rigid land constraint in China.

However, specialization with the outsourcing can have a positive effect on land productivity (Yi 2003; Sako 2006; Zhang, Yang and Thomas 2017; Cortes and Salvatori 2019). The principal farm operators generally have lower human capital compared with off-farm operators in rural China at the current stage (Li and Sicular 2013*b*) , while the outsourcing service providers are generally more educated, informative, proficient, and with more skills compared to farm household operators. Agricultural service providers also have more agricultural machines and tools than household operators. Therefore, the specialization of outsourcing service providers can improve the inputs in all tasks of agricultural production, thus increasing the land productivity. The overall effect of agricultural production outsourcing on land production requires empirical evidence.

One problem existed in estimating the effect of outsourcing on land productivity is the endogeneity of outsourcing choices (Sheng et al. 2017). Omitted variable bias (OVB) can be exist resulting from unobserved factors that influence both crop yields and farm households' outsourcing choices. For instance, the land plot location can both influence the outsourcing

[1]Strengthen agriculture outsourcing service, and promote the connection between small landholders and modern Agriculture Development `http://www.moa.gov.cn/xw/zwdt/201903/t20190305_6173265.htm`.

choice and crop yields in this plot, but most of the data sets do not have an accurate and measurable definition for land location. Even though some research take reverse causality as another source of endogeneity of outsourcing choices, we do not agree with this point. Since the outsourcing choices are made before the yields realized, the crop yields can not have an influence on this season's outsourcing choice.

Another problem is that the outsourcing choices of farmers are made jointly, but conventional approaches model them separately (Wu and Babcock 1998). For example, (Sun, Rickaille and Xu 2018) modeled the outsourcing decision of a single task, and (Ji et al. 2017) modeled several tasks, but did not consider the correlation among different tasks. However, unobserved factors such as farmers' personal preference for leisure can simultaneously influence the outsourcing choices of four tasks, which result in high correlation among the outsourcing choices. Conventional binary choice models such as probit or logit model ignores the correlation between different tasks, thus losing the useful information among the four tasks. Without considering the correlation, the predicted outsourcing probabilities can be biased or inaccurate, thus resulting the estimation biasedness of the second stage.

This article potentially contributes to the literature in the following three aspects. First, after addressing the endogeneity problem of outsourcing choices via a garden variety 2SLS approach (Angrist and Pischke 2008), this paper provides solid empirical evidence that outsourcing of agricultural production tasks does not decrease yields significantly, but generally increase the land productivity instead, thus not hurting local or even global food security. Second, this paper shows that the outsourcing choices of agricultural production tasks are highly correlated, and an employment of MVP models allows that the outsourcing choices are jointly decided as a system by relaxing unit variance matrix and gives a more precise prediction for fitted values of outsourcing in the first stage. A garden variety 2SLS with MVP in the first stage can be applied to many settings such as evaluating the causal effects of multiple agricultural technology adoptions. Third, we estimate the un(conditional) probabilities using simulation based on the parameter estimation of MVP models though it involves computation complexity, this predicted probabilities show the general outsourcing order of agricultural production, which is meaningful for designing policies to promote the development of agricultural production outsourcing. Therefore, this method provides us opportunities to indirectly observe the dynamic outsourcing order of a representative farm household even without a panel data tracing the same households across years.

2 The Model

In this section, first, we use a multivariate probit model (MVP) to analyze farmers' outsourcing choices of four rice production tasks (i.e., Transplanting, Ploughing, Pesticide Spraying, and Harvesting). Except for the common explanatory variables such as household characteristics, land characteristics and farmers' social capital, we mainly focus on the effect of wage-rent ratio on outsourcing choices for two reasons: (i) wage-rent ratios can account for the remarkable differences of outsourcing percentage in the four tasks; (ii) wage-rent ratios can be a valid instrumental variable (IV) for farmers' outsourcing choice in estimating the effect of outsourcing on rice yields. Second, a garden variety 2SLS method is applied to estimate the effect of each outsourcing choice on rice yields using wage-rent ratio as an IV for outsourcing in each task.

2.1 The Outsourcing Choice of Agricultural Production Tasks

Farmer household faces a binary choice in every task of rice production. Assume that $OS_j^*, j \in \{T, P, S, H\}$ is an unobserved latent variable that is proportional to the level of demand for each of the four tasks. The latent variable OS_j^* equals to:

$$OS_j^* = X_j'\gamma + \varepsilon_j = \alpha Ratio_j + Z'\beta + \varepsilon_j \quad (j = T, P, S, H) \tag{1}$$

where $Ratio_j$ represents the wage-rent ratio of task j, Z' is a vector of control variables, including farm household characteristics, land characteristics, and social capital of farm households, and ε_j is the residual term. X' is a combination of $Ratio$ and Z', i.e., $X' = (Ratio_j, Z')$, and γ is a combination of α and β, i.e., $\gamma = (\alpha, \beta')$. Depending on the sign of OS_j^*, we map Equation (1) to an observed binary choice variable OS_j^*:

$$OS_j = \begin{cases} 1 & \text{if } OS_j^* > 0 \\ 0 & \text{if } OS_j^* \leq 0 \end{cases} \quad (j = T, P, S, H) \tag{2}$$

If we assume that $\varepsilon_j \quad (j = T, P, S, H)$ are mutually independent and identically distributed (i.i.d.) with a standard normal distribution, then Equation (2) represents four independent univariate probit models (UVP). However, the above-mentioned i.i.d. assumption is very strong, which means that all the unobserved factors that influence the outsourcing choice of farmer households in one task are not correlated with the unobserved factors in the other three tasks. For example, the correlation can be caused by the farm households' unobserved characteristics such as preference for leisure and social connections that have similar effects on farm households' outsourcing decision of these four tasks.

To relax this strong assumption, we allow for the correlation across the residuals of these four tasks by utilizing a multivariate probit model (MVP) (Cappellari and Jenkins 2003; Bel, Fok and Paap 2018). Multivariate Probit model assumes that the residual terms, ε_j, in Equation (1) jointly conform to a multivariate normal distribution, that is

$$\begin{pmatrix} \varepsilon_T \\ \varepsilon_P \\ \varepsilon_S \\ \varepsilon_H \end{pmatrix} \sim N \left\{ \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}, \begin{bmatrix} 1 & \rho_{TP} & \rho_{TS} & \rho_{TH} \\ \rho_{PT} & 1 & \rho_{PS} & \rho_{PH} \\ \rho_{ST} & \rho_{SP} & 1 & \rho_{SH} \\ \rho_{HT} & \rho_{HP} & \rho_{HS} & 1 \end{bmatrix} \right\} \tag{3}$$

where $\rho_{jk}, j, k \in \{T, P, S, H\}$ and $j \neq k$ is the correlation coefficient of ε_j and ε_k, and $\rho_{jk} = \rho_{kj}$. With this assumption (Equation (3)), Equation (1) and Equation (2) define a multivariate probit model (MVP), which considers the unobserved factors for the same farm households. UVP is a special case of MVP when the correlation coefficient $rho_{jk} = 0$ for $j, k \in \{T, P, S, H\}$.

The marginal probability of outsourcing for univariate probit model in each task of rice production is:

$$\Pr(OS_j|X_j) = \Phi_1(X_j'\beta_j) \quad (j \in \{T, P, S, H\}) \tag{4}$$

There are $16(= 2^4)$ kind of joint probabilities for these four binary choices of farm households in MVP model. Below are some joint probabilities of our interest:

$$\begin{aligned}
\Pr(OS_H = 0, &OS_P = 0, OS_T = 0, OS_S = 0|X_H, X_P, X_T, X_S) \\
=&\Phi_4(-X_H'\beta_H, -X_P'\beta_P, -X_T'\beta_T, -X_S'\beta_S; \rho_{HP}, \rho_{HT}, \rho_{HS}, \rho_{PT}, \rho_{PS}, \rho_{TS}) \\
\Pr(OS_j = 1, &OS_k = 0, OS_m = 0, OS_n = 0|X_j, X_k, X_m, X_n) \quad j, k, m, n \in \{H, P, T, S\} \\
=&\Phi_4(X_j'\beta_j, -X_k'\beta_k, -X_m'\beta_m, -X_n'\beta_n; -\rho_{jk}, -\rho_{jm}, -\rho_{jn}, \rho_{km}, \rho_{kn}, \rho_{mn}) \\
\Pr(OS_H = 1, &OS_P = 1, OS_T = 0, OS_S = 0|X_H, X_P, X_T, X_S) \\
=&\Phi_4(X_H'\beta_H, X_P'\beta_P, -X_T'\beta_T, -X_S'\beta_S; \rho_{HP}, -\rho_{HT}, -\rho_{HS}, -\rho_{PT}, -\rho_{PS}, \rho_{TS}) \\
\Pr(OS_H = 1, &OS_P = 1, OS_T = 1, OS_S = 0|X_H, X_P, X_T, X_S) \\
=&\Phi_4(X_H'\beta_H, X_P'\beta_P, X_T'\beta_T, -X_S'\beta_S; \rho_{HP}, \rho_{HT}, -\rho_{HS}, \rho_{PT}, -\rho_{PS}, -\rho_{TS}) \\
\Pr(OS_H = 1, &OS_P = 1, OS_T = 1, OS_S = 1|X_H, X_P, X_T, X_S) \\
=&\Phi_4(X_H'\beta_H, X_P'\beta_P, X_T'\beta_T, X_S'\beta_S; \rho_{HP}, \rho_{HT}, \rho_{HS}, \rho_{PT}, \rho_{PS}, \rho_{TS})
\end{aligned} \tag{5}$$

where $\Phi_4(\cdot)$ represents the cumulative distribution function (CDF) of standard normal distribution with four dimensions [2]. Different conditional probabilities are available in this setting, we still give some conditional probabilities of our interest:

$$\Pr(OS_j = 1|Y_H = 1; X_H, X_j) = \frac{\Phi(X_j'\beta_j, X_H'\beta_H; \rho_{jH})}{\Phi(X_H'\beta_H)}, j \in \{P, T, S\}$$
$$\Pr(OS_k = 1|Y_H = 1, Y_P = 1; X_H, X_P, X_k) = \frac{\Phi(X_k'\beta_k, X_H'\beta_H, X_P'\beta_P; \rho_{kH}, \rho_{kP}, \rho_{HP})}{\Phi(X_H'\beta_H, X_P'\beta_P; \rho_{HP})}, k \in \{T, S\} \tag{6}$$

The log-likelihood function multivariate probit model (MVP) for an i.i.d. sample of N farm households is given by:

$$\begin{aligned}\ln(L) = &\sum_{i=1}^{N}\sum_{j=0}^{1}\sum_{k=0}^{1}\sum_{m=0}^{1}\sum_{n=0}^{1} \boldsymbol{1}_i(OS_{Hi} = j, OS_{Pi} = k, OS_{Ti} = m, OS_{Si} = n)\times \\ &\ln(\Pr(OS_{Hi} = j, OS_{Pi} = k, OS_{Ti} = m, OS_{Si} = n|X_{Hi}, X_{Pi}, X_{Si}, X_{Ti}))\end{aligned} \tag{7}$$

2.2 Estimating the Effects of Outsourcing Decisions on yields

To evaluate the effects of outsourcing on crop yields, we employ a 2SLS method. The first stage is:

$$OS_{ij} = \alpha_j Ratio_{ij} + Z_{ij}'\beta + \varepsilon_{ij} \tag{8}$$

The second stage is:

$$Y_i = \gamma_j OS_{ij} + Z_{ij}'\alpha + e_{ij} \tag{9}$$

where i and j denote i^{th} household and j^{th} task; Y_i is the rice yield for farm household i; wage-rent ratio ($Ratio_{ij}$) acts as the instrument variable for farmers' outsourcing choice (OS_{id}); the other notations are same as in Equation (1). In this 2SLS model, parameter γ_j is of our interest.

Since the endogenous variable (OS_{ij}) is a dummy variable, the underlying conditional expectation function (CEF) for Equation (8) may be nonlinear. But the first stage of usual 2SLS is a linear approximation of $E(OS_{ij}|Ration_{ij}, Z_{ij}')$. This problem accounts for one of the reasons for which we use multivariate probit model (MVP) in the first stage, and obtain the fitted values of $O\hat{S}_{ij,p}$. However, if we substitute $O\hat{S}_{ij,p}$ for OS_{ij} directly in Equation (9), then another problem arise: only the OLS estimation of Equation (8) guarantees that the first stage residuals (ε_{ij}) are uncorrelated with predicted values $O\hat{S}_{ij}$ and covariates Z_{ij}'. Jerry Hausman (1975) terms this problem as *Forbidden Regression*, and Angrist and Pischke (2009) proposed an approach called *Garden Variety 2SLS* to solve this problem. That is,

[2] $\Phi_j(\cdot)$ means CDF of standard normal distribution with j dimensions in the following for all such notations in the below.

use the predicted probability $O\hat{S}_{ij,p}$ as the instrument variable for actual outsourcing status OS_{ij} in Equation (8) [3]. Therefore, the actual first stage is:

$$OS_{ij} = \alpha_j O\hat{S}_{ij,p} + Z'_{ij}\beta + \varepsilon_{ij} \tag{10}$$

Two assumptions guarantee the wage-rent ratios to be valid instruments. The first one is $\text{Cov}(Ratio_{ij}, OS_{ij}) \neq 0$, which ensures that $Ratio_{ij}$ actually captures some variation in OS_{ij}. This assumption can be tested by the significance of $Ratio_{ij}$s' coefficients in MVP model. The second assumption is "exclusion restriction" , i.e., $\text{Cov}(Ratio_{ij}, e_{ij}) = 0$, which ensures that $Ratio_{ij}$ is uncorrelated with e_{ij}. Since wage-rent ratio is constructed by farm household head's off-farm wage and local outsourcing price, we have no reasons to believe that these two variables are correlated with the unobservable or uncontrolled factors that influence a specific farmer's rice yield. Therefore, although the "exclusion restriction" is not testable, we take it as a valid IV.

3 Data

3.1 Sampling

We mainly use a dataset of rice production to estimate the effect of wage-rent ratios on farmer's outsourcing decisions. The dataset is sourced from a rice production survey conducted by School of Agricultural Economics and Rural Development (SARD), Renmin University of China (RUC) in the summer of 2018. This survey collected detailed information of rice production at both the agricultural household level and village level.

The survey utilized a stratified random sampling method to select farm households in China. This approach can be summarized into three steps: First, we respectively chose Heilongjiang, Zhejiang, and Sichuan Provinces from the three rice production regions in China: Northeast China, East China, and Southeast China; Second, we randomly chose 4 counties in every province, and 2 towns in every county, so there are 24 towns in our sample; Third, within every town, we randomly select about 18 farm households. After eliminating observations that suffer from incomplete information, there are 404 farm households in our final sample.

Although our sample size is not very large, we believe that this dataset is representative for rice production in China. Figure 1 shows the geographical distribution of rice based

[3] As mentioned in page 193 of Angrist and Pischke (2009), "If the nonlinear model gives a better approximation to the first-stage conditional expectation function (CEF) than the linear model, the resulting 2SLS estimates will be more efficient than those using a linear first stage (Newey, 1990)."

on rice output[4]. We can see that Northeast, East and Southwest China are three major regions of rice production, our 12 studied counties are exactly distribute in these regions respectively. Furthermore, more than 90% of farmers' lands in the 3 studied provinces (Heilongjiang, Zhejiang, and Sichuan) are used to plant rice in at least one growing season. Based on the facts above, the sample can well represent the regions of rice production in China.

3.2 Variable definitions and choices

Two important variables in this research are wage-rent ratio and outsourcing decision of different tasks in rice production. We define wage-rent ratio as $Ratio = \frac{W}{R}$, where W is off-farm wage, measured by the hourly off-farm wage of farm household head (Yuan/Hour), and R is the hourly value of farmers' self operation of some task in the outsourcing market (Yuan/Hour). For example, if the outsourcing price of harvesting is 80 Yuan/Mu, and the farmer needs to spend 8 hours on 1-Mu harvest work by himself and his hourly off-farm wage is 30 Yuan/Hour, then the outsourcing rent is 10 Yuan/Hour and the wage-rent ratio is 3. This definition implies that the higher the ratio, the higher opportunity cost for the farmer to operate this task. Another important variable is the outsourcing choice of farmers. We define the outsourcing choice (OS_i) as dummy variable, which equals to 1 if the farmer household chooses not to operate the task i by themselves, but to buy the outsourcing service from the market, and 0 otherwise.

Control variables can mainly be categorized into three groups. First, the farm household head characteristics, including gender, age, education, and risk preference. Second, land characteristics, including planting area, number of plots, whether the plot has good fertility, whether this plot is a plain. Third, the social capital of the farm household, including whether the farm household is a member of some cooperative, whether a family member is a member of China Communist Party (CPC), whether a family member is village committee member, whether a family member is a villager representative, and whether a family member has religion belief. Besides control variables of these three categories, we also add county level dummies to control county-level unobserved characteristics.

3.3 Descriptive statistics

The summary statistics for all the variables are presented in Table 1. What is the relationship between wage-rent ratio and farmers' outsourcing decisions? Before going to the regression

[4]Data source: National Bureau of Statistics of China 2018.

analysis, We first plot the densities of wage-rent ratios of two different groups (outsourcing and non-outsourcing farm households) in four tasks. As shown in Figure 2, the blue line represents the densities of wage-rent ratios for non-outsourcing group, while the red line for outsourcing group. All the four panels in Figure 2 indicates that the wage-rent ratios of both groups are skewed to the right, which means that the mean of wage-rent ratio is higher than the median of wage-rent ratio. Considering the densities of 4 different tasks are closer to normal distribution (we can see the means and medians are close for the outsourcing price of 4 tasks in Table 1), positive skewness of wage-rent ratio implies positive skewness of hourly off-farm wage of farmers, this is consistent with the survey results of Chinese National Survey Data (CGSS) [5].

Table (2) presents the observed joint and marginal probabilities of outsourcing choice of these four tasks. The results in Table (2) show a remarkable difference among these four tasks. Specifically, outsourcing probability of Harvesting is the highest (81.50%) among these four tasks, while Pesticide Spraying is the lowest (9.25%), and Transplanting and Ploughing are 26.5 % and 48.5 % respectively. We can also find that some joint probabilities are trivial or even zero, such as Case 3, 6, and 8. Therefore, we only care the cases with relatively high joint probabilities.

Table (3) further illustrates how these four tasks are highly correlated. For example, among farm households whose choose to outsourcing Harvesting, Ploughing, transplanting, 33.33% of them choose to outsource pesticide spraying, while the unconditional probability is 9.25 % for the general population. Among those farm households who outsource harvesting, 57.67% of them are those who outsource transplanting. Hence, if we know a farm household has outsourced one task, such as harvesting, then its probability of outsourcing another particular task is higher, such as Ploughing. The summary statistics in Table (2) and Table (3) imply that strong correlations among these four tasks of rice production. We will revisit the conditional probabilities after using multivariate probit (MVP) model to control other explanatory variables.

4 Empirical Results

To compare with the MVP model, we first estimate the four task equations using univariate probit model (UVP), the results are presented in Table (4). After accounting for the cross-tasks correlation, we use our preferred multivariate probit (MVP) model, by which the outsourcing decisions are jointly estimated by relaxing the variance-covariance matrix of

[5] Data Source: http://www.cnsda.org/index.php.

four task equation residuals. The estimated parameters using MVP model for the four rice production tasks are presented in Table (5). Comparing the results in Table (4) with Table (5), we find that there are significant differences in estimates and their standard errors. For instance, the standard errors of the coefficients for wage-rent ratios decrease. In the following, we will focus on analyzing the results of MVP model.

In Table (5), the last three rows are the estimated correlation coefficients $\rho_{i,j}(i, j = T, P, S, H; i \neq j)$. These six correlation coefficients are jointly statistically significant at 1% level, and four of them are significantly different from zero. This result shows a strong correlation among these four outsourcing tasks for the same farm household. Many unobserved factors can result in this correlation. For instance, farmers' preference of leisure can influence their outsourcing choices of all the four tasks. Therefore, the results show that MVP models perform better than UVP models in this setting.

The marginal effects (MEs) of explanatory variables on unconditional outsourcing probabilities in MVP models are reported in Table (6) , and all MEs are evaluated at the sample means of the other explanatory variables. Wage-rent ratios all have significant positive effects on the outsourcing choices of these four tasks, one-unit increase in the wage-rent ratio results in 13.50%, 4.5%, 27.37% and 16.87% rise of outsourcing probability in transplanting, ploughing, pesticide spraying, and harvesting respectively. Considering the sample means of the wage-rent ratios in these four tasks are 1.09, 2.27, 0.78, and 4.23 respectively, one unit increase of wage-rent ratio means a 91.74%, 44.05%, 128%, and 23.63% rise in transplanting, ploughing, pesticide spraying, and harvesting respectively at the sample means of wage-rent ratios.

Some control variables also give us some insights of the outsourcing choice of rice production tasks. Age has a significant positive effect on the outsourcing choice in ploughing and harvesting, but does not influence the outsourcing choice of transplanting and spraying significantly. This result is probably because harvesting and ploughing are highly demanding for physical strength relatively to tasks like pesticide spraying. One-year older of farmers increase about 6.7% and 2.9% of outsourcing probability in task harvesting and ploughing respectively. Similarly, whether the plot is plain has significant effects on the outsourcing choice in ploughing and Harvesting, but does not influence the outsourcing choice of transplanting and spraying significantly. This maybe because agricultural machines that used in harvesting and ploughing are much larger than the ones used in the other two tasks, and large machines operate better in the plain.

Based on the estimation results of MVP model, we calculate the conditional and unconditional probabilities. For comparison, we also calculate the conditional and unconditional probabilities using an UVP approach proposed by (Angrist and Pischke 2008). Specifically, we estimate four separate univariate probit models for each of the tasks with the other three dummies of tasks on the right-hand side, which is termed as "UVP-Exogenous" model. In Table (7), we report the predicted (un)conditional probabilities using MVP models and UVP-Exogenous models[6]. There are remarkable differences between the results using two different methods, for instance, the outsourcing probability of transplanting conditional on harvesting at means using MVP model (0.2320 with SE 0.0308) is much higher than that probability (0.1474 with SE 0.0190) predicted by UVP-Exogenous model [7].

Although we can not observe the outsourcing order of one farm household without long panel household survey data, un(conditional) probabilities in Table (7) provide us opportunity to infer the outsourcing order. Predicted unconditional probabilities in Table (7) show that harvesting achieves the highest probability, which means that harvesting is the task that will be outsourced with highest probability (93.36%) among the general population. Conditional on outsourcing the harvesting task, the second most likely to be outsourced is plouging, with conditional probability (47.73%). As the same logic, the transplanting and pesticide spraying will be outsourced in order.

Based on the predicted value of $\hat{OS}_{ij,p}$, we use a Garden Variety 2SLS approach to estimate the causal effect of the outsourcing choices on crop yields (Equation (9) and (10)), and results are summarized in Table (8). The outsourcing choice of four tasks all have positive effects on rice yields. Existing literature about outsourcing both in agriculture and other industries also have found evidence for an increase of productivity (Picazo-Tadeo and Reig-Martínez 2006; Paul and Yasar 2009; Sheng et al. 2017). In our research, a 10% rise of outsourcing probability in transplanting increases about 52.7 Jin (26.35 Kg) [8], 51.0 Jin in ploughing, 44.4 Jin in pesticide spraying, and 14.3 Jin in harvesting respectively. This result implies that shows that the outsourcing choices generally improve the crop yields though the potential existence of moral hazard problem. This positive effect may result from the specialization of agricultural outsourcing service providers, who generally are proficient in operating tasks of agricultural production. This positive results relieve the concerns about food security issues caused by outsourcing, and proved that the outsourcing of operating

[6] (Ramful and Zhao 2009) calculates (un)conditional probabilities for MVP model too. But to the best of our knowledge, there are no existing commands in Stata or R to calculate the conditional probabilities for MVP model. Such calculations involve computational complexity, but it provides useful information of the outsourcing choice of farmers. We will release the codes that are used to calculate these predicted probabilities for reference.

[7] Standard errors for the predicted (un)conditional probabilities in Table (7) are calculated using simulation. First, we simulate coefficients 3000 times based on the estimated coefficients, standard errors, and correlation coefficients; Second, matrix multiply the vector of sample means of all covariates, and finally obtain 3000 sets of simulated probabilites. Sample SEs are calculated based on the simulated results.

[8] 1 Jin =0.5 Kg.

tasks is a realistic, feasible, and efficient way to agricultural production considering the rural arable land system and outflow of agricultural labor in rural China.

5 Conclusion

The outsourcing of agricultural production tasks has been a new trend in the past two decades. Measuring the effect of agricultural production outsourcing is of great implications. If outsourcing cannot increase, or even decrease, land productivity, this will have a great impact on local food security and global grain market considering that China has nearly one fifth of the global population. Existing econometric evaluations focus on the effect of a single task outsourcing on the crop yields, and take the outsourcing of other tasks as exogenous. However, the outsourcing decisions may be made jointly due to some unobserved factors such as farmers' preference for leisure. Another problem in existing literature is no suitable instrumental variables for outsourcing in evaluating its effect on yields.

Based on a rural household survey of 12 counties in China, we use a garden variety 2SLS approach with MVP model in the stage as our identification strategy. First, we adopt wage-rent ratios for outsourcing in four tasks of rice production; Second, we use multivariate probit (MVP) model to account for the correlations among the outsourcing choices of these four tasks, and get a more precise prediction of outsourcing probability in the first stage; Third, we use the predicted outsourcing probability (instrumented by wage-rent ratio) as instruments for actual outsourcing status in a conventional 2SLS procedure.

This study provides valuable information on the outsourcing choice of farmers and empirical evidence of the positive effect of outsourcing on land productivity. First, the results show that the outsourcing choices of tasks are highly correlated, which highlight the advantage of MVP model in the first stage over the UVP model, by which the information of cross-task outsourcing is missing. Second, wage-rent ratios have significant effects on the outsourcing on all four tasks, which implies that an increase of off-farm wage, a decrease of outsourcing price, an increase(decrease) of farmers' productivity in off-farm (farm) work can promote the outsourcing probabilities of all four tasks. Third, although lacking long panel data tracing the outsourcing order of these four tasks for the same household, the (un)conditional probabilities provided by MVP model show that the general outsourcing order in population is: Harvesting $\Rightarrow$ Ploughing $\Rightarrow$ Transplanting $\Rightarrow$ Pestcide Spraying. Last, the outsourcing of rice production tasks does not decrease the land productivity, but increases the yields after addressing the endogeneity of all four outsourcing dummies, which implies that the positive effect of agricultural outsourcing specialization is larger than the potential negative effect of moral hazard problem commonly existing in outsourcing. This result reduces concerns about the food security and provides some inspiring empirical evidence for the existence of specialization in agriculture.

Limited by the data availability, a cross-sectional data can not trace the outsourcing characteristics that change with time, and may miss some unobserved factors in our control variables though we have added county dummies to control for unobserved county-level characteristics. With the development of outsourcing of agricultural productions in China and the accumulation of data, researchers should be in a position to use panel data to analyze farmers' outsourcing behavior dynamically and provide more solid empirical evidence of the effect of outsourcing on land productivity.

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Table 1. Summary statistics

	Mean	Std.Dev	Min	Median	Max
Transplanting	0.27	0.44	0.00	0.00	1.00
Ploughing	0.48	0.50	0.00	0.00	1.00
Spraying	0.09	0.29	0.00	0.00	1.00
Harvesting	0.81	0.39	0.00	1.00	1.00
Off-farm wage (Yuan/day)	222.02	347.31	0.05	90.00	2495.00
Wage-rent ratio (T)	1.09	2.03	0.00	0.40	21.32
Wage-rent ratio (P)	2.27	3.72	0.00	1.00	31.19
Wage-rent ratio (S)	0.78	1.36	0.00	0.28	15.59
Wage-rent ratio (H)	4.23	7.47	0.00	1.50	71.29
Transplanting price (Yuan/Mu)	82.72	26.45	25.00	85.00	140.00
Ploughing rent (Yuan/Mu)	109.22	48.26	30.00	100.00	200.00
Pesticide spraying price (Yuan/Mu)	21.88	13.23	5.00	21.00	100.00
Harvesting price (Yuan/Mu)	115.55	35.84	60.00	100.00	300.00
Gender	0.97	0.16	0.00	1.00	1.00
Age	58.64	8.91	36.00	60.00	85.00
Years of education	6.42	2.90	0.00	6.00	16.00
Off-farm occupation	0.41	0.49	0.00	0.00	1.00
Risk preference	0.45	0.40	0.00	0.40	1.00
Planting area (mu)	52.76	165.07	0.00	14.00	2901.20
Number of plots	33.55	132.35	0.00	8.00	850.00
Good fertility	0.57	0.50	0.00	1.00	1.00
Plain	0.91	0.29	0.00	1.00	1.00
COOP participation	0.08	0.27	0.00	0.00	1.00
CPC member	0.29	0.45	0.00	0.00	1.00
VIL representatives	0.32	0.47	0.00	0.00	1.00
VIL committe member	0.23	0.42	0.00	0.00	1.00
Religion belief	0.08	0.27	0.00	0.00	1.00

Figure 1. The geographical distribution of rice production in 2017 and sample counties

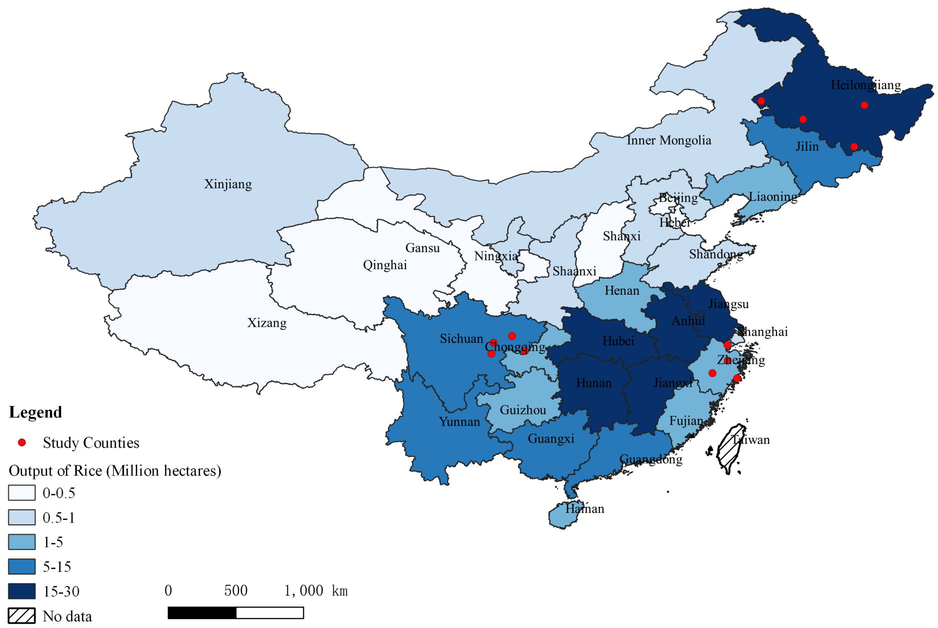

Table 2. Observed joint and marginal outsourcing probabilities

Case	Joint probability		T	P	S	H
1	Transplanting only	0.030	0.030			
2	Ploughing only	0.010		0.010		
3	Spraying only	0.000			0.000	
4	Harvesting only	0.263				0.263
5	Transplanting and ploughing only	0.005	0.005	0.005		
6	Transplanting and spraying only	0.000	0.000		0.000	
7	Transplanting and harvesting only	0.068	0.068			0.068
8	Ploughing and Spraying only	0.000		0.000	0.000	
9	Ploughing and harvesting only	0.288		0.288		0.288
10	Spraying and harvesting only	0.010			0.010	0.010
11	Transplanting, ploughing, and spraying only	0.000	0.000	0.000	0.000	
12	Transplanting, ploughing, and harvesting only	0.105	0.105	0.105		0.105
13	Transplanting, spraying, and harvesting only	0.005	0.005		0.005	0.005
14	Ploughing, spraying, and harvesting only	0.025		0.025	0.025	0.025
15	Transplanting, ploughing, spraying, and harvesting	0.053	0.053	0.053	0.053	0.053
16	None	0.140	0.000	0.000	0.000	0.000
	Marginal	1.000	0.265	0.485	0.093	0.815

Figure 2. Comparison of densities between Non-outsourcing and Outsourcing groups: Rice

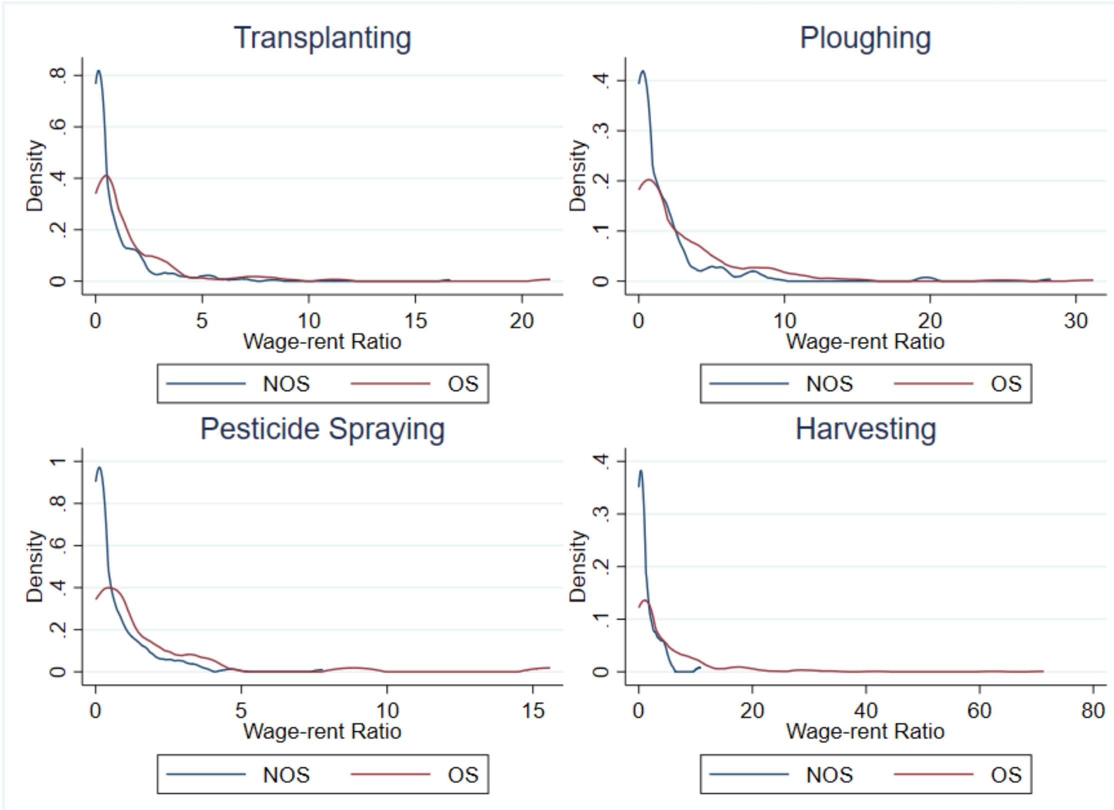

Table 3. Selected observed (un)conditional outsourcing probabilities

	Transplanting	Ploughing	Spraying	Harvesting
$\Pr(\cdot)$	0.265	0.485	0.0925	0.815
$\Pr(\cdot \vert H = 1)$	0.2822	0.5767	0.1135	1
$\Pr(\cdot \vert H = 1, P = 1)$	0.3351	1	0.1649	1
$\Pr(\cdot \vert H = 1, P = 1, T = 1)$	1	1	0.3333	1

Table 4. Parameter estimates for Probit models of rice production outsourcing

	(1)	(2)	(3)	(4)
VARIABLES	Transplanting	Ploughing	Spraying	Harvesting
Wage-rent ratio (T)	0.134999**			
	(0.064717)			
Wage-rent ratio (P)		0.045214*		
		(0.023367)		
Wage-rent ratio (S)			0.273724***	
			(0.069268)	
Wage-rent ratio (H)				0.168674***
				(0.045978)
Gender	-0.044356	-0.367567	0.029973	-0.243994
	(0.491043)	(0.458891)	(0.498936)	(0.427220)
Age	0.006092	0.028891***	0.006610	0.066735***
	(0.011052)	(0.009667)	(0.011672)	(0.013959)
Years of education	0.026642	0.039555	0.041909	0.025546
	(0.033878)	(0.027348)	(0.037679)	(0.033820)
Off-farm occupation	-0.096265	0.108889	0.001314	-0.021739
	(0.192261)	(0.156984)	(0.196041)	(0.201154)
Risk preference	-0.013320	-0.188529	-0.021731	0.112193
	(0.219908)	(0.188782)	(0.244098)	(0.236293)
Planting area (mu)	0.000946***	0.000128	0.002019*	-0.000763*
	(0.000366)	(0.000366)	(0.001101)	(0.000417)
Number of plots	0.000536	-0.000276	0.000226	0.001384*
	(0.000586)	(0.000575)	(0.000612)	(0.000840)
Good fertility	-0.128412	0.123397	-0.187489	0.295733
	(0.176218)	(0.151100)	(0.205027)	(0.181610)
Plain	-0.054575	1.073071***	0.198263	0.665855**
	(0.265153)	(0.370316)	(0.341018)	(0.275349)
COOP participation	-0.116163	-0.649148**	0.239827	-0.395764
	(0.300848)	(0.296846)	(0.345907)	(0.321600)
CPC member	-0.507005**	0.015162	-0.328631	0.156991
	(0.210534)	(0.180348)	(0.233567)	(0.222366)
VIL representatives	-0.282042	-0.069049	-0.128949	0.031156
	(0.190141)	(0.165950)	(0.236098)	(0.197910)
VIL committe member	0.505795**	-0.089988	0.168010	-0.277764
	(0.216722)	(0.202444)	(0.268383)	(0.245256)
Religion belief	-0.288601	-0.113161	-0.158888	0.647911**
	(0.316938)	(0.268661)	(0.329050)	(0.315727)
Constant	-1.6e+00*	-3.2e+00***	-2.2e+00***	-4.3e+00***
	(0.835708)	(0.850130)	(0.828516)	(0.993424)
County dummies	Yes	Yes	Yes	Yes
Observations	362	398	398	398

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5. Parameter estimates for MVProbit models of rice production outsourcing

	(1)	(2)	(3)	(4)
VARIABLES	Transplanting	Ploughing	Spraying	Harvesting
Wage-rent ratio (T)	0.135**			
	(0.0536)			
Wage-rent ratio (P)		0.0436**		
		(0.0220)		
Wage-rent ratio (S)			0.230***	
			(0.0770)	
Wage-rent ratio (H)				0.136***
				(0.0457)
Gender	0.00426	-0.389	0.122	-0.0813
	(0.479)	(0.412)	(0.612)	(0.560)
Age	0.00508	0.0300***	0.0129	0.0689***
	(0.0114)	(0.00971)	(0.0129)	(0.0120)
Years of education	0.0197	0.0377	0.0483	0.0274
	(0.0340)	(0.0284)	(0.0370)	(0.0357)
Off-farm occupation	-0.0465	0.108	0.0217	0.0680
	(0.190)	(0.168)	(0.205)	(0.208)
Risk preference	0.0281	-0.134	0.00857	0.110
	(0.227)	(0.195)	(0.255)	(0.236)
Planting area (mu)	0.000983*	0.000181	0.00226*	-0.000573
	(0.000549)	(0.000547)	(0.00118)	(0.000565)
Number of plots	0.000470	-0.000433	0.000215	0.00109
	(0.000550)	(0.000552)	(0.000657)	(0.000852)
Good fertility	-0.0929	0.115	-0.319*	0.218
	(0.172)	(0.153)	(0.190)	(0.185)
Plain	-0.0792	1.157***	0.398	0.645**
	(0.274)	(0.387)	(0.393)	(0.273)
COOP participation	0.0452	-0.599**	0.0901	-0.461
	(0.317)	(0.301)	(0.334)	(0.311)
CPC member	-0.504**	0.00392	-0.335	0.107
	(0.237)	(0.183)	(0.256)	(0.245)
VIL representatives	-0.200	-0.0405	0.0650	0.0364
	(0.210)	(0.179)	(0.232)	(0.213)
VIL committe member	0.384	-0.0910	0.243	-0.180
	(0.248)	(0.207)	(0.262)	(0.247)
Religion belief	-0.271	-0.142	-0.197	0.558
	(0.345)	(0.303)	(0.418)	(0.406)
Constant	-1.359	-3.238***	-2.907**	-4.582***
	(0.913)	(0.824)	(1.139)	(0.958)
Counties Dummies	Yes	Yes	Yes	Yes
Observations	399	399	399	399

Standard errors in parentheses
*** < 0.01, ** $p < 0.05$, * $p < 0.1$

Table 6. Marginal effects for MVProbit models of rice production outsourcing

	(1) Transplanting	(2) Ploughing	(3) Spraying	(4) Harvesting
main				
Wage-rent ratio (T)	0.134999**			
	(0.064717)			
Wage-rent ratio (P)		0.045214*		
		(0.023367)		
Wage-rent ratio (S)			0.273724***	
			(0.069268)	
Wage-rent ratio (H)				0.168674***
				(0.045978)
Gender	-0.044356	-0.367567	0.029973	-0.243994
	(0.491043)	(0.458891)	(0.498936)	(0.427220)
Age	0.006092	0.028891***	0.006610	0.066735***
	(0.011052)	(0.009667)	(0.011672)	(0.013959)
Years of education	0.026642	0.039555	0.041909	0.025546
	(0.033878)	(0.027348)	(0.037679)	(0.033820)
Off-farm occupation	-0.096265	0.108889	0.001314	-0.021739
	(0.192261)	(0.156984)	(0.196041)	(0.201154)
Risk preference	-0.013320	-0.188529	-0.021731	0.112193
	(0.219908)	(0.188782)	(0.244098)	(0.236293)
Planting area (mu)	0.000946***	0.000128	0.002019*	-0.000763*
	(0.000366)	(0.000366)	(0.001101)	(0.000417)
Number of plots	0.000536	-0.000276	0.000226	0.001384*
	(0.000586)	(0.000575)	(0.000612)	(0.000840)
Good fertility	-0.128412	0.123397	-0.187489	0.295733
	(0.176218)	(0.151100)	(0.205027)	(0.181610)
Plain	-0.054575	1.073071***	0.198263	0.665855**
	(0.265153)	(0.370316)	(0.341018)	(0.275349)
COOP participation	-0.116163	-0.649148**	0.239827	-0.395764
	(0.300848)	(0.296846)	(0.345907)	(0.321600)
CPC member	-0.507005**	0.015162	-0.328631	0.156991
	(0.210534)	(0.180348)	(0.233567)	(0.222366)
VIL representatives	-0.282042	-0.069049	-0.128949	0.031156
	(0.190141)	(0.165950)	(0.236098)	(0.197910)
VIL committe member	0.505795**	-0.089988	0.168010	-0.277764
	(0.216722)	(0.202444)	(0.268383)	(0.245256)
Religion belief	-0.288601	-0.113161	-0.158888	0.647911**
	(0.316938)	(0.268661)	(0.329050)	(0.315727)
Constant	-1.6e+00*	-3.2e+00***	-2.2e+00***	-4.3e+00***
	(0.835708)	(0.850130)	(0.828516)	(0.993424)
County dummies	Yes	Yes	Yes	Yes
Observations	362	398	398	398

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7. Predicted (un)conditional probabilities: MVP vs UVP-Reduced

	MVP		UVP-Exogenous	
$Pr(T=1\|\bar{X})$	0.1503	(0.0185)	0.2402	(0.0276)
$Pr(P=1\|\bar{X})$	0.4515	(0.0297)	0.4195	(0.0327)
$Pr(S=1\|\bar{X})$	0.0740	(0.0146)	0.0535	(0.0170)
$Pr(H=1\|\bar{X})$	0.9336	(0.0180)	0.9393	(0.0194)
$Pr(T=1\|H=1,\bar{X})$	0.1474	(0.0190)	0.2320	(0.0308)
$Pr(P=1\|H=1,\bar{X})$	0.4773	(0.0311)	0.4917	(0.0330)
$Pr(S=1\|H=1,\bar{X})$	0.0782	(0.0153)	0.0535	(0.0170)
$Pr(T=1\|H=1,P=1,\bar{X})$	0.1484	(0.0282)	0.2074	(0.0442)
$Pr(S=1\|H=1,P=1,\bar{X})$	0.1445	(0.0264)	0.1628	(0.0349)

Table 8. Effect of outsourcing choice on rice yields: Garden Variety 2SLS

	(1) Yield	(2) Yield	(3) Yield	(4) Yield
Transplanting choice (T)	527.44**			
	(268.93)			
Ploughing choice (P)		510.03***		
		(197.11)		
Pesticide spraying choice (S)			443.53***	
			(144.80)	
Harvesting choice (H)				143.81***
				(46.43)
HH Head characteristics	Yes	Yes	Yes	Yes
Land characteristics	Yes	Yes	Yes	Yes
Social capital	Yes	Yes	Yes	Yes
County dummies	Yes	Yes	Yes	Yes
Observations	399	399	399	399

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$