Agricultural Cooperatives and Investment in Organic Soil Amendments and Chemical Fertilizer in China

Wanglin Ma, Awudu Abdulai, and Renan Goetz

In this article, we develop a dynamic model to show how membership in agricultural cooperatives influences smallholder farmers' decisions to invest in organic soil amendments and chemical fertilizer. The model considers management decisions of heterogonous producers within an intertemporal framework, with the decision to join the cooperative assumed to be endogenous. Farm-level data of apple farmers from three provinces in China are used to estimate the impact of cooperative membership on investment in organic soil amendments and chemical fertilizer. A recursive bivariate probit model that accounts for potential endogeneity of cooperative membership and selection bias is employed in the empirical analysis. The empirical results show that cooperative membership exerts a positive and statistically significant impact on the likelihood of investing in organic soil amendments. The findings also reveal that tenure security, human capital, farm size, and access to credit positively and significantly influence the probability of a farmer joining a cooperative and the likelihood of investing in soil quality measures.

Key words: Agricultural cooperative, Investment, Soil quality, Dynamic optimization, Impact assessment.

JEL codes: C83, F61, J54, P52, Q01.

In many developing countries, agricultural cooperatives constitute a major vehicle that can be used to improve smallholder agricultural performance, particularly through services that enhance the adoption of new agricultural technologies, sustainable farm practices, and output marketing. A number of studies have highlighted the positive and significant impacts of cooperative membership on outcomes such as farm income and profits, producer prices and output market participation (e.g., Hellin et al. 2009; Ito et al. 2012; Vandeplas et al. 2013; Chagwiza et al. 2016; Mojo et al. 2017; Wossen et al. 2017). However, little effort has gone into investigating how cooperative organizations influence the adoption of agricultural technologies by smallholder farmers. Although land degradation due to soil erosion and loss of soil quality has been identified as one of the most serious ecological and economic problems facing farmers in developing countries (Rozelle et al. 1997; Pender et al. 2001; Antle and Diagana 2003), the role of agricultural cooperative in facilitating investment in sustainable land management practices has been overlooked.

Land degradation does not only contribute to a reduction in crop yields, but also increases crop production costs in the long run (Rozelle et al. 1997; Barbier 2000). Thus, from a sustainable agriculture perspective, investment in soil-improving measures is an inevitable choice for smallholder farmers facing land degradation problems. Empirical evidence using microlevel data indicates that investment in soil-improving measures helps increase farm productivity (Ersado et al. 2004; Holden et al. 2009).

Few studies have analyzed the impact of cooperative membership on investment in

Wanglin Ma is a post-doctoral fellow at the Department of Global Value Chains and Trade, Lincoln University, Christchurch, New Zealand. Awudu Abdulai is a professor at Department of Food Economics and Consumption Studies, University of Kiel, Germany. Renan Goetz is a professor at the Department of Economics, University of Girona, Spain. The authors are grateful to Editor Travis Lybbert and three reviewers for comments and suggestions that helped to improve the article. Wanglin Ma acknowledges the support of the University of Kiel, Germany, for his doctoral thesis. Awudu Abdulai acknowledges the support of the German Research Foundation (DFG). Renan Goetz gratefully acknowledges the support of the Ministerio de Economía y Competitividad Spain grant ECO2016-75927-R. Correspondence to be sent to: aabdula@food-econ.uni-kiel.de

static inputs such as pesticides and chemical fertilizers (Abebaw and Haile 2013; Verhofstadt and Maertens 2014). In their investigation of the impact of cooperative membership on adoption of agricultural technologies in Ethiopia, Abebaw and Haile (2013) found that agricultural cooperatives have a positive and significant impact on application of chemical fertilizers. The study by Verhofstadt and Maertens (2014) on Rwanda also found a positive and significant relationship between agricultural cooperatives and adoption of chemical fertilizer. Although crop yields normally increase with higher rates of application of chemical fertilizer, yields may decline over time due to soil degradation, if no organic material is added to the soil. It is generally known that organic material adds to the soil quality, while chemical fertilizer does not (Gaur 1992).[1] Given the importance of investing in organic inputs that build up the soil structure and naturally replenish nutrients in the soil, examining the impact of cooperative membership on investment in organic soil amendments would provide significant information for agricultural policy design.[2]

To the extent that cooperative membership is not randomly distributed, the studies mentioned above have employed propensity score matching (PSM) model to address the issue of selection bias (Abebaw and Haile 2013; Verhofstadt and Maertens 2014). A well-known shortcoming of the PSM approach is that it addresses the issue of selection bias by controlling for only observable factors, without accounting for unobservable factors like innate abilities and motivations to improve soil quality. Further, the studies mentioned above did not attempt to develop a coherent conceptual framework that links cooperative membership to investment in soil quality and yield-enhancing measures.

This study contributes to the literature by developing a dynamic model that relates farmers' cooperative membership to their decisions to invest in organic soil amendments and chemical fertilizer. In particular, the study develops a theoretical framework that considers management decisions of heterogonous producers within an intertemporal framework, with the decision to join the cooperative assumed to be endogenous. Specifically, we identify conditions under which cooperative membership helps in reducing costs and enhancing investments in organic soil amendments and chemical fertilizer. The existing theoretical literature on cooperatives and heterogeneity tends to focus on the analysis of market power, vertical coordination or organizational structure (e.g., Fulton and Giannakas 2013; Saitone and Sexton 2010). The present study focuses on heterogeneity of producers, input choice, and management of the soil.

To the extent that farmers self-select into joining or not joining a cooperative, we use a recursive bivariate probit model to account for potential endogeneity and selectivity bias. To complement the theoretical analysis, we employ farm-level data of 481 households from three major apple-producing provinces in China to examine the factors that influence farmers' decisions to join cooperatives, and the impact of membership on investment in organic soil amendments and chemical fertilizer.

Soil erosion and desertification are considered to be two of the most serious environmental degradation problems in China, which impact adversely on environmental sustainability and yields in apple production. In particular, soil erosion is cited as the source of severe land degradation in the China's Loess Plateau region, which includes Gansu and Shaanxi, two popular apple producing regions (Rozelle et al. 1997; Hou et al. 2014). Although China is the largest apple producing country in the world, it is still struggling to produce high-value apples that meet the phytosanitary requirements of international markets. For example, only 0.25% of apples produced in China were exported to the US markets in 2016, which is less than 2% of the US apple imports (Wheat 2017). Hence, it is quite significant to enhance investments in soil quality measures among smallholder apple farmers, in order to achieve the multiple goals of high productivity, high value apples, and environmental sustainability, which would allow Chinese farmers to reap the benefits from exporting to international markets like Europe, Canada, and the United States.

[1] Besides anthropogenic activities, soil evolution generally depends on climate, topography, organisms, parent material, and aging (Gaur 1992).

[2] Organic soil amendments refer to organic fertilizer that farmers can purchase in the market and/or farmyard manure that is produced either from the family yard or bought from livestock farms.

Theoretical Framework

The theoretical framework presented in this article analyzes the link between the decision to join an existing agricultural, open-membership cooperative and to invest in organic soil amendments and chemical fertilizer. In line with previous studies, we consider that the choice of joining a cooperative is endogenous and producers are heterogeneous (Karantininis and Zago 2001; Fulton and Giannakas 2013; Mérel et al. 2015).

Let ξ denote the outcome of the decision to join a cooperative or not, where $\xi = 1$ indicates the farmer joining, and $\xi = 0$ not joining. Given that current investment decisions tend to affect the evolution of soil quality over time, we analyze the decision problem of an individual farmer within a dynamic context. In the empirical literature, household and farm-level characteristics are normally assumed to be specific for each farmer and tend to include variables like age, education, household size, farm size, asset ownership, and soil types. Following the concept of the so-called location or address models (Fulton and Giannakas 2013), we consider that household and farm-level characteristics, which form the basis of an index, denoted by θ, are specific for each farmer. Let the index be scaled such that it is distributed over the interval $[0, 1]$, with $\theta = 0$ indicating the characteristics with the lowest, and $\theta = 1$ having the highest effect on the net returns from production.[3]

We assume that the farmer cultivates a unit of land and combines investment in measures such as organic soil amendments $O(t)$, and chemical fertilizer $M(t)$, where t indicates calendar time. To simplify the analysis, we also assume that farmers do not change their membership status from the initial period to the end of the planning horizon T.

The quality of the agricultural product is a distinctive characteristic and influences the price P that farmers can obtain for their products. However, the production of high quality is more costly, as it requires employing more inputs and following a more stringent production protocol. To focus on the fundamental characteristics of the driving forces, we consider only high and low qualities as characteristics of the products. Let the high-quality product be indicated by H and the low quality by L, with the associated prices by P^H and P^L, respectively. The agricultural production function per unit of land, $Y^j(\cdot), j = L, H$ can be specified as a function of organic soil amendments $O(t)$, chemical fertilizer $M(t)$, soil quality $S(t)$, and the household and farm-level characteristics θ . This is given as $Y^j(O(t),\ M(t),\ S(t);\ \theta), j = L, H$. To simplify notation, we suppress the information $j = L, H$ for the remaining part of the text. We assume that the function $Y^j(\cdot)$ is strictly concave in the arguments O, M, S and additive separable in O and M, because these two inputs are in the short-run nearly perfect substitutes with respect to production. Consequently, the cross derivative with respect to these variables is equal to zero. The cost of production for nonmembers is denoted by the function $C^j(O(t),\ M(t);\ \theta)$. Given a higher productivity index, the same amount of output can be produced with less organic soil amendments. Thus, we assume that the production costs and net-returns index are negatively related, that is, $C^j_\theta(\cdot;\theta) < 0$ and $C^j_{\theta\theta}(\cdot;\theta) > 0$.[4] The evolution of the returns and costs as a function of θ is presented in figure 1 for high- and low-quality producing nonmembers. We base our graphical analysis on the cost function given by

$$(1) \quad C^j = (\alpha^j - \beta^j\theta)(O(t) + M(t)) \text{ with } \alpha, \beta > 0 \text{ and } \alpha^j - \beta^j\theta > 0.^5$$

The specification shows that the cost functions are linear in $O(t)$ and $M(t)$, so that C^j_O, and C^j_M depend exclusively on θ. In figure 1, we show the level of household and farm-level characteristics required for a nonmember to break even. It shows that low-quality farmers with characteristics $\theta < \underline{\theta}^L$ do not break even, and thus production of low quality is only profitable for nonmembers if $\theta \geq \underline{\theta}^L$. Similarly, figure 1 shows that

[3] Let the lowest and the highest values of the unscaled index be denoted by l and h, respectively. Hence, the lowest and highest values of the scaled index θ are given by $(l-l)/(h-l) = 0$ and $(h-l)/(h-l) = 1$, respectively. Any in between value i of the unscaled index is transformed by the equation $(i-l)/(h-l) \in (0, 1)$to the scaled index.

[4] Throughout the text, the subindex of a function by a variable indicates the partial derivative of the function with respect to the variable.

[5] The choice of nonlinear functions would complicate the analysis but does not offer any additional insights, because the intersection between the return and cost function is relevant and not the curvature of the cost function.

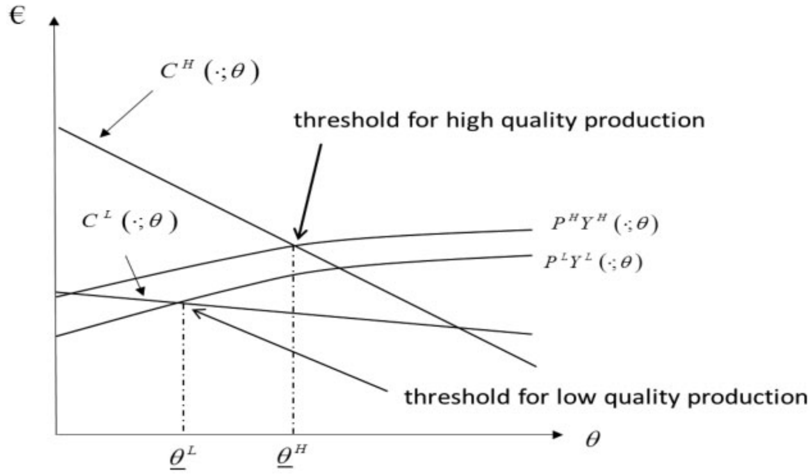

Figure 1. Returns and cost for nonmembers of type *θ*

high-quality producing nonmembers only make profits if their individual characteristics are at least as high as $\underline{\theta}^H$.

Widespread empirical evidence shows that members of agricultural cooperatives may have a relative advantage over nonmembers with respect to production efficiency, as well as input and output market operations (Hendrikse and Bijman 2002; Abebaw and Haile 2013; Vandeplas et al. 2013). These benefits may include lower search costs for input and output markets, a better bargaining position for lower input and higher output prices, screening of market partners in the presence of asymmetric information with respect to quality of the inputs, and better access to credit and management information. In particular, a number of studies have shown that agricultural cooperatives play a significant role in supplying markets with high quality products (e.g., Moustier et al. 2010; Naziri et al. 2014). We therefore assume that farmers with cooperative membership have lower productions costs over a wide range of θ. Let us denote the cost function of members of the cooperative by $CO^j(\cdot;\theta)$. The difference between the cost functions, $C^j(\cdot;\theta) - CO^j(\cdot;\theta)$, represents the individual share of the cooperative benefits that members of the cooperative with characteristics θ can realize exclusively as members. Without loss of generality, we only consider cooperative benefits resulting from cost savings, and not from premium sale prices. It is significant to note that a different formulation of the theoretical model would not alter the results of the analysis, since the magnitude of the cooperative benefits is the determining factor for the farmer's participation decision, and not the source of the cooperative benefits.

As indicated previously, being a member of a cooperative does not only bring along advantages but also a number of obligations. These may include paying an annual fixed fee, following a stricter and more expensive production protocol, as well as being subject to frequent contacts/controls in order to ensure that members meet the quality standards laid down by the cooperative.[6] The population of farmers is heterogeneous and the farmer's household and farm-level characteristics, θ, follow a distribution function $\Gamma(\theta)$. We consider that farmers whose value of θ is below a threshold $\bar{\theta}^j$ incur lower production costs, if they are members of the cooperative. Beyond this limit value, we assume that the potential of the farmer's net returns is so high that being a member of a cooperative does not lead to any reduction in the production costs, that is, for $\theta < \bar{\theta}^j$ we have $CO^j(\cdot;\theta) < C^j(\cdot;\theta)$, and for $\theta > \bar{\theta}^j$ we have $CO^j(\cdot;\theta) > C^j(\cdot;\theta)$. Based on the introduced notation, the net returns function for low- and

[6] The obligations of cooperative members in developing countries including China may be different from that in Western countries. For instance, in the United States, cooperative members are expected to contribute equity or risk capital in proportion to their patronage and are recipients of the surplus, or residual claims in proportion to their patronage, and they must meet specific qualifications that are stated in the cooperatives' bylaws (Gijselincks et al. 2014).

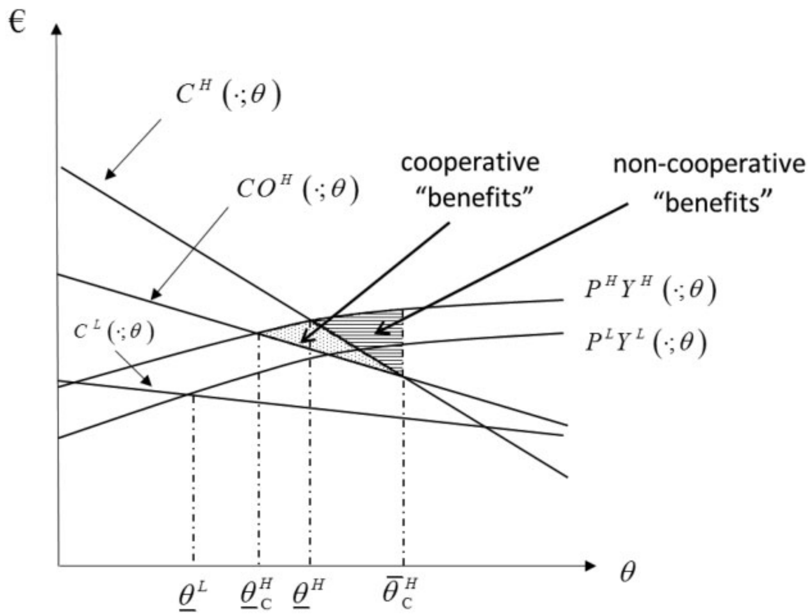

Figure 2. Returns and cost for nonmembers and members of type θ

high-quality production for members and nonmembers is given by:

$$(2) \quad P^jY^j(\cdot;\ \theta) - \xi CO^j(\cdot;\theta) - (1-\xi)C^j(\cdot;\theta)$$

As an extension of the analysis in figure 1, we present in figure 2 the evolution of the returns and cost functions, $P^jY^j(\cdot;\ \theta)$, $C^j(\cdot;\theta)$ and $CO^H(\cdot;\theta)$ as a function of θ. Without loss of generality, we focus our analysis on the production of high-quality products. It is assumed that the qualitative properties of the cost functions of the members, CO^j, are identical to those of nonmembers, C^j, such that C^j_O, CO^j_O and C^j_M, CO^j_M depend exclusively on θ. Although the cost functions have the same mathematical structure, the value $CO^j(\cdot)$ may be greater or lower than $C^j(\cdot)$ as specified above. Consequently, figure 2 reflects the cost function of high-quality producing cooperative members, $CO^H(\cdot;\theta)$ and the cost functions of low- and high-quality producing nonmembers, $C^L(\cdot;\theta)$ and $C^H(\cdot;\theta)$, respectively. The analysis of the cases of low-quality producing cooperative members, or of qualities in between low and high, is identical to the discussed case of high quality.

For cooperative members, figure 2 demonstrates that they make profits, if their characteristics are at least as high as $\underline{\theta}^H_C$. However, if their characteristics are higher than $\bar{\theta}^H_C$, they will still be making profits but less than nonmembers. It would therefore be optimal for farmers producing high quality to join the cooperative if their characteristics fall within the range of $[\underline{\theta}^H_C, \bar{\theta}^H_C]$. Within this range, the net returns of members are higher than those of nonmembers. The dotted area in figure 2 indicates the share of the cooperative net returns that accrue to its members with characteristics $\theta \in [\underline{\theta}^H_C, \bar{\theta}^H_C]$, while the striped area shows the net returns that are realized by all farmers, irrespective of cooperative membership. Without the specification of the density function, $\Gamma'(\theta)$, the number of farmers with $\theta \in [\underline{\theta}^H_C, \bar{\theta}^H_C]$ is not known, and therefore, the dotted area in figure 2 can only be interpreted as the individual share but not as aggregate cooperative benefits.[7]

Drawing the returns and cost functions differently would yield distinct results. Depending on the location of the values $\underline{\theta}^L, \underline{\theta}^H, \underline{\theta}^H_C, \bar{\theta}^H_C$, situations could emerge where it is beneficial for none of the farmers, or for

[7] If the total number of farmers was given by N, every farmer had a different θ, and if the density function was given by $1/N$, the dotted area in figure 1 would correspond approximately to the total aggregate cooperative benefits. However, since the specification of the distribution function does not provide any additional insights we do not pursue this issue any further.

all the farmers to join a cooperative. Thus, figure 2 presents an intermediate case and is consistent with our empirical analysis, where we observe segmentation with respect to the decision to join or not to join.

After analyzing the decision to join or not to join an existing cooperative, we now examine how cooperative membership impacts on investment in organic soil amendments and chemical fertilizer. For this purpose, it is significant to note that the continuous application of organic soil amendments improves the soil quality over time, while the application of chemical fertilizer, considered as a static input, does not influence soil quality directly but indirectly through the withdrawal of nutrients through crop harvest. Thus, we assume that the application of organic soil amendments improves soil quality by the factor α_O, while harvesting reduces soil quality by the factor α_Y, with $\alpha_O,\ \alpha_Y > 0$. Hence, the evolution of the soil quality over time can be represented by

$$(3)\quad \dot{S} = \alpha_O O(t) - \alpha_Y Y(O(t), M(t), S(t);\ \theta), \text{with } S(0) = S_0,$$

where a dot over a variable denotes the operator d/dt and S_0 is the given soil quality at time 0. To avoid additional notation, we assume that the soil quality is initially identical for all farmers. The parameter α_Y represents the decrease in soil quality in proportion to the harvested output resulting from soil degradation in the absence of any investment in organic soil amendments.

We assume that farmers maximize their farm net returns over the planning horizon T, and that the present value of the soil quality at the end of the planning horizon is given by $S(T;\theta)e^{-\delta(T)}$, where δ represents the value of the intertemporal discount rate. The farmer's decision problem with characteristics θ is then given by:

$$(4)\ J^* = \max_{O,\ M,\ \xi} \int_0^T \left\{ \begin{array}{c} P^H Y(O(t),\ M(t),\ S(t);\ \theta) - \xi CO^H(O(t),\ M(t);\theta) \\ -(1-\xi)C^H(O(t),\ M(t);\theta) + \xi\mu_0 - \xi\mu_1 \end{array} \right\} e^{-\delta t} dt + S(T;\theta)e^{-\delta T}$$

subject to

$$(5)\quad O, M > 0,\ \xi \in [0,\ 1], \text{ and } \dot{S} = \alpha_O O - \alpha_Y Y(\cdot;\theta), \text{ with } S(0,\ \theta) = S_0,$$

where the Lagrange multipliers μ_0 and μ_1 are associated with the lower and upper limits of the decision variable ξ, while α_O and α_Y are as defined earlier. To simplify notation, we suppress the argument t of the variables O, M, S, unless necessary for an unambiguous notation. Equation (4) indicates that farmers maximize the discounted farm net returns over the planning horizon.

The definition of the current value Hamiltonian (H) of the farmer's decision problem yields:

$$(6)\quad H = P^H Y(O, M, S;\ \theta) - \xi CO^H(O, M;\theta) - (1-\xi)C^H(O, M;\theta) + \xi\mu_0 - \xi\mu_1 + \lambda(\alpha_O O - \alpha_Y Y(O, M, S;\ \theta)).$$

The first-order conditions for an interior solution with respect to O, M and an interior and boundary solution with respect to ξ are given by:

$$(7)\quad H_O = P^H Y_O - \xi CO^H_O - (1-\xi)C^H_O + \lambda(\alpha_O - \alpha_Y Y_O) = 0$$

$$(8)\quad H_M = P^H Y_M - \xi CO^H_M - (1-\xi)C^H_M - \lambda\alpha_Y Y_M = 0$$

$$(9)\quad H_\xi = -CO^H + C^H + \mu_0 - \mu_1 = 0\ .$$

The first-order conditions related to the dynamics of the soil and their respective analysis can be found in the supplementary online appendix.

The variable ξ is defined as a continuous variable in the interval $[0,\ 1]$, but since the Hamiltonian is linear in ξ, the optimal value is given at the boundary of the domain of ξ. If the farm net returns are strictly positive, the maximization of H requires choosing $\xi = 1$, otherwise $\xi = 0$. Hence, the possible solution is either to join or not to join a cooperative.

As mentioned above, the initial soil quality $S(0) = S_0$ is identical for all farmers. Let the steady state value of the soil quality be

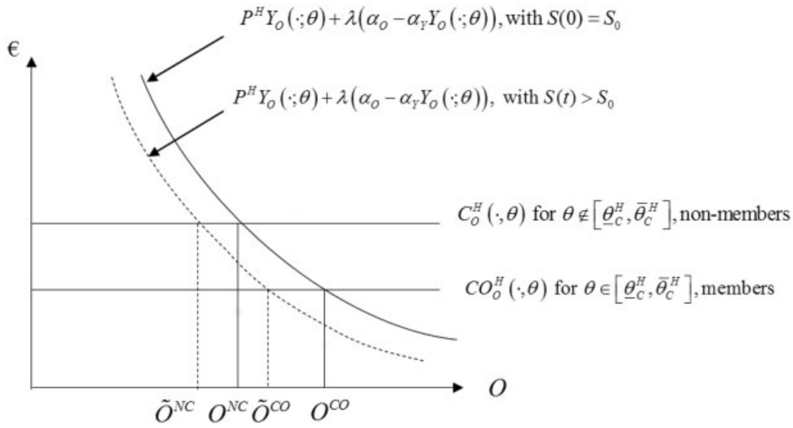

Figure 3. The optimal level of organic soil amendments applied by farmers with and without cooperative membership, given the farm and household characteristics θ and different level of soil quality

denoted by S^{∞}. Given that soil quality is likely to evolve over time, we further assume that the soil quality $S(t)$ at a specific time t is not identical for the two groups of farmers, due to different optimal investment behaviors in the long run. We assume that the organic soil amendment O and chemical fertilizer M are substitutes with respect to S, that is, $Y_{MS}<0$, $Y_{OS}<0$. Thus, an increase in S decreases the marginal productivity of O and M. Given these assumptions, we illustrate in figure 3 the farmers' short-run and long-run investment behavior, which is determined by the first-order condition in equation (7).

As shown in figure 3 (continuous lines), the solution to equation (7) demonstrates that the efficient level of organic soil amendments O^{CO} applied by cooperative members will be higher than the efficient level by nonmembers, O^{NC}. With respect to the optimal investment behavior of farmers in the long-run, we analyze it for the cases where $S_0<S^{\infty}$ and $S_0>S^{\infty}$, where S^{∞} denotes the value of the steady state equilibrium of soil quality. For the case of $S_0<S^{\infty}$, it is optimal for farmers to build up soil quality over time, so that $S(t)>S_0$. However, for $S_0>S^{\infty}$, it would be optimal to reduce soil quality so that $S(t)<S_0$ holds. Given the situation that farmers build up soil quality, $S(t)>S_0$, an increase in $S(t)$ decreases the marginal productivity $Y_O(t)$. Thus, the curve $P^H Y_O+\lambda(\alpha_O-\alpha_Y Y_O)$ shifts to the left as indicated by the discontinuous line in figure 3. Therefore, it is optimal for farmers to reduce the level of organic soil amendments over time, so that $O^{CO}\rightarrow\tilde{O}^{CO}$ and $O^{NC}\rightarrow\tilde{O}^{NC}$. For the case where it is optimal to reduce $S(t)$, that is, $S(t)<S_0$, a decrease in $S(t)$ will decrease the marginal productivity, $Y_O(t)$. In this case, it would be optimal for both cooperative members and nonmembers to increase the level of organic soil amendments.[8]

Similar to equation (7) and figure 3, the solution to equation (8) can be analyzed graphically. The analysis of equation (8) and the corresponding graphical illustration can be found in the supplementary online appendix. It shows that members apply more chemical fertilizer than nonmembers. The economic intuition for the different behavior of members and nonmembers resides in the fact that cooperatives help their members adopt cost reducing strategies, which then enable them increase the level of investments in organic soil amendments and chemical fertilizer.

Thus, farmers whose household and farm-level characteristics fall within the range of [$\underline{\theta}_C^H$, $\bar{\theta}_C^H$] are better off joining the cooperative and investing in organic soil amendments than those, whose characteristics do not fall within this specified range. In other words, farmers may self-select into cooperatives, depending on their characteristics.

Our analytical results are consistent with the empirical results reported by Verhofstadt and Maertens (2014) who found a positive impact of cooperative membership on the use

[8] This case is not shown in figure 2 in order to make the figure more tractable.

of chemical fertilizer. However, the extent to which this positive impact is due to changes in the household and farm-level characteristics θ, and the extent to which this is explained by cooperative membership, has received little attention in the previous literature. A change in the household and farm-level characteristics can be interpreted in different ways. One way would be to interpret them as invariable, so that an analysis of a change in θ explains behavioral changes between farmers with different θs. However, we do not follow this line of argument but rather consider the household and farm-level characteristics to be variable and interdependent to a certain degree. Obviously, some characteristics like level of education or farm size will not vary with the outcome of the farmer's decision to join a cooperative, while other characteristics like access to expertise or networking skills are likely to improve through cooperative membership. Thus, it is possible to interpret changes in the farmer's characteristics with changes in the farmer's input and investment decisions.

Figures 3 and A1 in the supplementary online appendix have shown the impact of cooperative membership on the production intensity. We now show how changes in the household and farm-level characteristics influence cooperative membership. In order to disentangle the effects of the two underlying forces on the farmer's investment behavior, we conduct a comparative static analysis. We consider the soil quality as given, in order to focus on the effect of an increase in θ on the optimal amounts of organic soil amendments $O^*(\theta)$ and chemical fertilizer $M^*(\theta)$ of the members of a cooperative. As detailed in the supplementary online appendix, the analysis reveals that an improvement in the household and farm-level characteristics may increase, moderate or even reverse the intensification of the production intensity resulting from joining the cooperative. The precise results depend on the signs and magnitude of the changes in the marginal productivity and marginal costs in relation to the cooperative benefits. The signs of $Y_{M\theta}$ and $Y_{O\theta}$ and their magnitudes cannot be determined on theoretical grounds. The index θ encompasses a wide range of factors, and depending on the particular situation of each farmer, different factors may be most influential for the determination of the value of θ. Thus, if for some farmers, education or the farm size is most influential for the determination of θ, one can imagine that $Y_{I\theta}$, $I = M, O$ is strictly positive, that is, M and O are complements with respect to θ. On the other hand, if the soil quality is the most important factor for the calculation of the index, it seems reasonable to assume that M and O are substitutes with respect to θ, that is, $Y_{I\theta} < 0, I = M, O$.

Despite the indeterminacy with respect to the magnitudes of $Y_{I\theta}$ and $C_{I\theta}$, as well as the sign of $Y_{I\theta}$, the analysis in the supplementary online appendix allows the identification of three situations that govern the farmer's behavior with respect to the production intensity, and relate them to the cooperative membership effect. However, the relative significance of each of these three situations is important for policy analysis and can only be evaluated empirically, given a specific population of farmers located in a given region. The empirical part of the study addresses this issue.

Empirical Specification

We demonstrated in the theoretical model how farmers' characteristics influence their choice of cooperative membership, and how these choices tend to influence their investment decisions in organic soil amendments and chemical fertilizer. We assumed in equation (4) that the decision problem of the farmer with characteristics θ is to maximize the expected farm net returns J^* , subject to some restrictions. However, the expected farm net returns is unobservable, since it is subjective. What is observed in the data is the cooperative membership status and investment decision of the farmer. To operationalize the decision problem, let R_{ik}^* represent the unobserved or latent variable. In this case, the observed variable R_{ik} can be used to represent a farmer's decision to invest in organic soil amendments ($R_{ik} = 1$), or not to invest ($R_{ik} = 0$). Following the maximization problem outlined in equation (4), the unobserved variable would be positive, if the conditions $\partial J^*/\partial O$ and $\partial J^*/\partial M$ are both positive. Moreover, equations (7) and (8) imply that the farmer's decision to invest in organic soil amendments and chemical fertilizer is influenced by the choice of cooperative membership, as well as household and farm-level characteristics.

Given that the primary goal of the empirical analysis is to examine how household and farm-level characteristics θ_i influence a farmer's decision to join a cooperative ξ_i, as well as to analyze the impact of the characteristics and cooperative membership on the investment decision, we express the farmer's investment decision as a latent variable function[9]:

$$(10) \quad R_{ik}^* = \omega\xi_i + \gamma\theta_i + \mu_{ik}, \quad R_{ik} = 1 \text{ if } R_{ik}^* > 0,$$

where R_{ik} is a binary indicator variable which equals 1 if the household i chooses to invest in organic soil amendments $(k = 1)$ and chemical fertilizer $(k = 2)$, if the expected farm net returns (R_{ik}^*) from investment is positive, and 0 otherwise; ξ_i is a dummy variable for the choice of cooperative membership; ω and γ are parameters to be estimated; and μ_{ik} is an error term assumed to be normally distributed.

In line with our theoretical model, a household chooses to belong to a cooperative, if the expected farm net returns derived from cooperative membership (ξ_{i1}^*) is greater than that from non-membership (ξ_{i0}^*). Households are then assumed to choose to join cooperatives if the difference in farm net returns is positive, that is, $\xi_i^* = \xi_{i1}^* - \xi_{i0}^* > 0$. However, ξ_i^* cannot be directly observed but can be expressed as a function of observed elements in the following latent variable function:

$$(11) \quad \xi_i^* = \beta Z_i + \varepsilon_i, \xi_i = 1 \quad \text{if} \quad \xi_i^* > 0,$$

where ξ_i equals 1, if a household is a member of a cooperative, and 0 otherwise; Z_i represents a vector of factors that influence a farmer's decision to belong to a cooperative; β is a vector of parameters to be estimated, and ε_i is the error term assumed to be normally distributed.

If the same unobservable factors (e.g., farmers' innate ability and motivation to improve soil quality by virtue of cooperative organization) influence both the error term (ε_i) in the cooperative membership choice equation and the one (μ_{ik}) in the investment equation, selection bias occurs, resulting in a correlation of the two error terms in the two specifications, such that $corr(\varepsilon_i, \mu_i) = \rho_{\varepsilon\mu}$. In this case, any standard regression technique such as probit or logit model applied to estimate equation (10) produces biased results when $\rho_{\varepsilon\mu} \neq 0$. Thus, rigorous assessment of the effect of cooperative membership on investment decisions of farmers should take into account the endogeneity of the cooperative membership variable.

The endogenous switching probit (ESP) model suggested by Lokshin and Sajaia (2011) could be used to estimate the average treatment effects of cooperative membership on the probabilities of investing in organic soil amendments and chemical fertilizer, accounting for both observable and unobservable heterogeneities. However, this approach does not estimate the marginal effects of cooperative membership and the other explanatory variables. Given our interest in estimating both the marginal effects and average treatment effects of cooperative membership on investment in soil-improving and productivity-enhancing measures, this study employs a recursive bivariate probit (RBP) model in the empirical analysis (Vall Castello 2012; Lanfranchi and Pekovic 2014; Thuo et al. 2014). The RBP model estimates the cooperative membership choice equation and the investment equation simultaneously, using full information maximum likelihood (FIML) approach.

In estimating the RBP model, the variables in the vector θ_i in equation (10) and Z_i in equation (11) are allowed to overlap. However, identification of the bivariate probit model requires a valid instrument that explains the probability of choosing to belong to a cooperative, but that is not correlated with the outcome variable. In this study, the presence of a cooperative in a farmer's village of residence is used as an identifying instrument.[10] As noted by Deng et al. (2010), one of the primary reasons for low cooperative membership rate in China is due to the absence of agricultural cooperatives in many villages. Thus, the presence of a cooperative in a village is related to the choice of cooperative membership but should not influence the farmer's decision to invest in soil quality measures.

[9] It is significant to note that θ_i, which is used to denote household and farm-level characteristics, is an index in the theoretical section, but a vector in the empirical specification.

[10] In China, a farmer can choose to either join a cooperative in the village of residence, or join a cooperative in a different village, town or county. In this study, the randomly selected members either have the membership in village cooperatives or cooperatives in other towns or counties. We expect that farmers living in villages with cooperative will be more likely to join cooperatives.

We also estimate the average treatment effects on the treated (ATT), using the method proposed by Chiburis et al. (2011) to provide a better understanding of the causal effects of cooperative membership on the likelihood of investing in organic soil amendments and chemical fertilizer. The ATT is calculated using the following expression:

$$(12)\quad ATT = \frac{1}{N_\xi}\sum_{i=1}^{N_\xi}\{\Pr(Y_{ik}=1)|\xi_i=1) - \Pr(Y_{ik}=0|\xi_i=1)\}$$

where N_ξ denotes the total sample for the treated; $\Pr(Y_{ik}=1)|\xi_i=1)$ represents the predicted investment probability for cooperative members in an observed context, while $\Pr(Y_{ik}=0)|\xi_i=1)$ represents the predicted probability that a farmer belonging to a cooperative (in a counterfactual context) will not invest.

Data and Descriptive Statistics

The data used in the analysis are from a household survey of apple farmers conducted in Gansu, Shaanxi and Shandong provinces in China between September and December 2013. In China, the majority of apple orchards are primarily in the Bohai Gulf region (Shandong, Liaoning, and Hubei provinces) and Northwest Loess Plateau region (Shaanxi, Shanxi, Henan, and Gansu provinces). In particular, more than half of the country's apple orchards are located in Gansu (12.72%), Shaanxi (28.92%) and Shandong (12.53%) (CRSY 2013). Apple production plays an important role in determining smallholder farmers' livelihoods in the surveyed regions.

Considering our interests in analyzing the impact of cooperative membership on apple farmers' investment decisions, we focus on cooperatives specialized in apple production and marketing in this study. These cooperatives are located either in the farmers' villages of residence or in other towns or counties, but they share similar attributes in helping members across different provinces. The cooperatives' behaviors are regulated by the national law on Farmers' Professional Cooperatives. In the surveyed regions, farmers are intensively producing apples on their cultivated land. Among other things, the cooperatives assist members in orchard management approaches (e.g., pruning, branch drawing), efficient use of both organic and chemical fertilizers for sustainable soil management, efficient use of pesticides for pest management and apple quality control and collectively purchasing inputs at reasonable prices. They also provide members with marketing information (e.g., prices, channels), with the aim of enhancing members' participation in output markets.[11]

A multistage sampling procedure was used to select 208 cooperative members and 273 nonmembers. First, Gansu, Shaanxi, and Shandong provinces were purposively selected due to the intensive apple production in these provinces. Second, we selected representative districts with significant apple output in each province. In particular, Jingning county in Gansu, Luochuan county in Shaanxi, and Qixia and Laiyang cities in Shandong were selected. Third, six agricultural cooperatives were randomly selected from these districts. Fourth, three villages affiliated to each cooperative in the selected district were randomly selected. Finally, around 25–30 households including both cooperative members and nonmembers in each village were randomly selected. A structured questionnaire was used to collect information from households with and without cooperative membership. The questionnaire covered a range of topics including socioeconomic and farm-level factors (e.g., age, education, household size, and farm size), soil characteristics, access to credit, as well as asset ownership (e.g., manual sprayer and rotary cultivator).

The dependent variable used in the analysis refers to the farmer's choice of cooperative membership, which takes the value of one for cooperative members and zero for nonmembers. The questionnaire also includes

[11] Agricultural cooperatives in China usually provide members with both production and marketing services, although they do not fully supply inputs to members, or purchase members' farm produce due to loose management structures. Moreover, they provide very little help with respect to credit facilities to its members (Deng et al. 2010). In comparison, cooperatives in the United States have various responsibilities and functions such as marketing, supply, processing, bargaining and service (Gijselincks et al. 2014). For instance, US agricultural service cooperatives provide farmers with a wide variety of services including credit, utilities, insurance, irrigation and others, while agricultural marketing cooperatives emphasize the marketing of farm products supplied by their members. With respect to food production and marketing, members in the US transact with a cooperative by buying materials and inputs, or selling raw materials (Gijselincks et al. 2014).

dichotomous dummy variables that indicate whether farmers apply any of the soil-improving and yield-enhancing measures such as organic soil amendments and chemical fertilizer. We draw on the existing literature on cooperative membership to identify explanatory variables (e.g., Bernard and Spielman 2009; Marenya and Barrett 2009; Ito et al. 2012; Abebaw and Haile 2013; Chagwiza et al. 2016; Mojo et al. 2017). Table 1 presents descriptive statistics for the selected variables.

Age and education are two important proxies for human capital. As noted by Schultz (1982), human capital increases people's abilities to perceive, interpret, and respond to new events. Previous studies have reported positive impacts of age and education on farmers' decisions to choose cooperative membership (Bernard and Spielman 2009; Chagwiza et al. 2016). Moreover, our theoretical analysis reveals that farmers with specific characteristics tend to be more likely to join agricultural cooperatives. We include age and age squared terms, as well as education and education squared terms in the specification to examine potential nonlinearities between these variables and cooperative membership, as well as investment decisions. Consistent with previous studies, household size and farm size are expected to have positive impacts on cooperative membership (Abebaw and Haile 2013; Mojo et al. 2017).

With regards to physical assets, transportation costs and household wealth, previous studies have shown that ownership of radio, ox, cattle, and farm equipment exerts positive impacts on the probability of joining a cooperative (Bernard et al. 2008; Abebaw and Haile 2013). In this study, we use ownership of manual sprayer and rotary cultivator, ownership of livestock as proxy variables for ownership of physical assets, and we expect positive impacts of these variables on choice of cooperative membership.

To the extent that farmers may channel higher investments into more fertile soils, we include soil quality dummies in the analysis to account for soil conditions. A number of studies have shown that land tenure security influences farmers' decisions to invest in soil-improving measures (e.g., Ma et al. 2013; Abdulai and Goetz 2014; Rao et al. 2016). Ma et al. (2013) indicate that although different land laws introduced since 1998 have contributed to an improvement in the land tenure security, household perceptions of tenure security has not changed in many parts of China. Wang et al. (2011) have argued that land reallocation may occur in the future due to changes in the population and emerging land inequality. We therefore include a variable representing farmers' perceived land tenure security in the analysis. As indicated by Abdulai and Goetz (2014), land tenure security may be influenced by investment decisions, resulting in potential endogeneity of land tenure security variable in the investment specification. We therefore employ a two-stage control function approach suggested by Wooldridge (2015) to address the potential endogeneity of the tenure security variable.[12] Finally, a set of location dummies are included to account for unobserved agro-climatic and socioeconomic heterogeneities among the sample districts.

It can be observed from table 1 that 43% of farmers had cooperative membership. Mean use rate for organic soil amendments is 87%, while the mean use rate for chemical fertilizer variable is 93%. The average age of household head is almost 48.63 years, whereas the mean number of years of schooling is about 7.6 years. Farmers in the sample are smallholders with an average farm size of 5.07 mu. We also present a comparison of the mean characteristics between cooperative members and nonmembers in the supplementary online appendix. The figures suggest that cooperative members are more likely to invest in organic soil amendments but less likely to invest in chemical fertilizer than nonmembers. Members obtain higher farm net returns than their counterparts without membership. However, since cooperative membership was not randomly assigned to farmers, a rigorous assessment of the impact of cooperative membership on investment in organic soil amendments and chemical fertilizer needs to account for possible selection bias that may arise from unobserved factors (e.g., Vall Castello 2012; Thuo et al. 2014).

Results and Discussion

Before presenting the results for the recursive bivariate probit (RBP) model, we first

[12] In the first stage, tenure security variable is specified as a function of all other explanatory variables and an instrumental variable (distance to orchards in the present study). In the second stage, the residual predicted from the first-stage estimation is included as an additional regressor in the soil investment equation.

Table 1. Definition of Variables and Descriptive Statistics

Variable	Definition	Mean (SD)
Dependent variables		
Membership	1 if farmer is a cooperative member, 0 otherwise	0.43 (0.50)
Organic soil amendments	1 if farmer applies organic fertilizer and/or farmyard manure, 0 otherwise	0.87 (0.34)
Chemical fertilizer	1 if farmer applies chemical fertilizer, 0 otherwise	0.93 (0.26)
Organic fertilizer	1 if farmer applies organic fertilizer, 0 otherwise	0.84 (0.37)
Farmyard manure	1 if farmer applies farmyard manure, 0 otherwise	0.28 (0.45)
Organic soil amendment expenditure	Expenditure on organic soil amendments (100 yuan/mu)[a]	5.62 (4.70)
Chemical fertilizer expenditure	Expenditure on chemical fertilizer (100 yuan/mu)	9.36 (5.81)
Net returns	Apple gross revenue minus variable costs (1,000 yuan/mu)	7.54 (3.91)
Independent variables		
Age	Age of farmer (years)	48.63 (10.25)
Education	Years of formal education of farmer	7.60 (2.87)
Household size	Total number of household members	4.33 (1.44)
Farm size	Total farm size of apple orchard (mu)	5.07 (3.24)
Manual sprayer	1 farmer owns manual sprayer, 0 otherwise	0.72 (0.45)
Rotary cultivator	1 if farmer owns rotary cultivator, 0 otherwise	0.53 (0.50)
Access to credit	1 If farmer is not liquidity constrained, 0 otherwise	0.53 (0.50)
Sandy soil	1 if land has sandy soil, 0 otherwise	0.38 (0.49)
Clay soil	1 if land has clay soil, 0 otherwise	0.45 (0.50)
Loam soil	1 if land has loam soil, 0 otherwise	0.17 (0.37)
Irrigation	1 if farmer has access to irrigation facilities, 0 otherwise	0.61 (0.49)
Road condition	1 if farmer reports that road condition from orchards to village/market is good, 0 otherwise	0.60 (0.49)
Livestock	1 if farmer owns livestock, 0 otherwise	0.23 (0.42)
Tenure security	1 if farmer perceives that land will not be readjusted within five years, 0 otherwise	0.48 (0.50)
Shandong	1 if farmer resides in Shandong province, 0 otherwise	0.43 (0.50)
Gansu	1 if farmer resides in Gansu province, 0 otherwise	0.17 (0.37)
Shaanxi	1 if farmer resides in Shaanxi province, 0 otherwise	0.40 (0.49)
Distance to orchards	Farmers' self-reported distance between orchards and home (1 = far; 2 = fair; 3 = close)	2.32 (0.66)
Village cooperative	1 if there is a cooperative in farmer's residing village, 0 otherwise	0.09 (0.28)

Note: [a] 1 mu = 1/15 hectare; 1$=6.14 yuan.

present estimates from a seemingly unrelated bivariate probit (SUBP) model and the goodness-of-fit test to justify the use of the RBP model.

Results for SUBP Estimates and Goodness-of-fit Test

The main reason for estimating the SUBP model is to ascertain whether the decision to choose cooperative membership is correlated with the outcome variables through unobserved heterogeneities, and whether these two decisions are substitutes or complements (Thuo et al. 2014). The SUBP model estimation requires that cooperative membership variable is dropped from the investment equation. The estimates for the two model specifications can be found in the supplementary online appendix. The *P*-values for the null hypothesis that $\rho'_{\varepsilon\mu}$ in the two specifications are both significantly different from zero, indicating that the unobserved heterogeneities of both decisions are correlated. These findings suggest that the probability that a farmer chooses to belong to a cooperative is related to the probability of investing in organic soil amendments and chemical fertilizer through unobserved effects captured in the model's error terms. Moreover, the sign for $\rho'_{\varepsilon\mu}$ is positive in model 1, suggesting that cooperative membership and investment in organic soil amendments are complementary decisions

(Huth and Allee 2002; Thuo et al. 2014). By contrast, the negative sign for $\rho'_{\varepsilon\mu}$ in model 2 indicates that cooperative membership and investment in chemical fertilizer are substitutes in terms of decisions (Thuo et al. 2014).

Note that maximizing the joint density of the observed dependent variables in RBP model does not guarantee a good fit (Chiburis et al. 2012). We therefore run both Murphy's (2007) score test and Hosmer-Lemeshow's (1980) test, using the methods proposed by Chiburis et al. (2011) to check misspecification of the RBP model. In particular, the null hypothesis of the Murphy's score test is that the error terms in equations (10) and (11) are bivariate standard joint normal, and the null hypothesis of the Hosmer-Lemeshow test is that the sample frequencies of the dependent variables and the fitted probabilities of the observation subgroup are identical. The results can be found in the supplementary online appendix. The *P*-values are all not significantly different from zero at the 10% level in the three model specifications, indicating that the null hypothesis of normality cannot be rejected, confirming the validity of the RBP model.

Results for RBP Estimates

The estimates of the determinants of cooperative membership and its impacts on organic soil amendments and chemical fertilizer, using the RBP model are presented in table 2. As indicated previously, the FIML approach jointly estimates the cooperative membership choice equation and two soil investment equations.[13] The results presented in the lower part of table 2 show that all estimated correlation coefficients $\rho_{\varepsilon\mu}$ in models 1–2 are significantly different from zero, indicating the presence of selection bias arising from unobserved factors. In particular, the negative correlation coefficients $\rho_{\varepsilon\mu}$ indicate negative selection bias, suggesting that farmers having lower probabilities of investing in organic soil amendments and chemical fertilizer are more likely to choose to belong to cooperatives. Moreover, the results of the Wald tests for $\rho_{\varepsilon\mu} = 0$ in models 1–2 are significantly different from zero, indicating that the null hypothesis that the cooperative membership variable is exogenous can be rejected. That is, farmers' decisions to belong to a cooperative and to invest in organic soil amendments and chemical fertilizer are made jointly. The coefficients of the tenure residual variable are not statistically significant in all specifications, suggesting that the coefficients of the tenure security variable have been consistently estimated (Wooldridge 2015).

Determinants of Cooperative Membership and Investment Decisions

The results from the first-stage estimates of the RBP model, which show the determinants of farmers' decisions to choose cooperative membership, are presented in the second and fourth columns in table 2. Given that the variables having the same names show similar signs and significance levels in the two model specifications, we have chosen to discuss the results from the cooperative membership choice equations in models 1–2 together. In the two specifications, the coefficients of the education variable are positive and significant, while the coefficients for the squared terms are negative and significant, suggesting that an increase in education increases the probability of choosing cooperative membership, with the maximum effect occurring at appropriately nine years of schooling. The low probability of the membership choice for farmers with more than nine years' education is probably due to the fact that these farmers have better skills that enable them to diversify their income sources from farming to off-farm activities.

The household size variable is positively and significantly associated with the choice of cooperative membership in the two specifications, indicating that larger households with more labor endowments are more likely to choose to belong to a cooperative. Consistent with the findings from Ito et al. (2012) and Mojo et al. (2017), farm size tends to increase the probability of being a cooperative member. Ownership of manual sprayer and access to convenient roads appear to increase the probability of joining cooperatives. The results also show that farmers' decisions to choose cooperative membership are related to soil quality.

[13] We estimated a SUBP model to test whether farmers' decisions to investment in organic soil amendments and chemical fertilizer are correlated through unobserved factors. The results, which are presented in the supplementary online appendix show that the correction coefficients (ρ_{OC}) of the error terms in the two model specifications and the Wald test for $\rho_{OC} = 0$ are not statistically significant. The findings confirm that it is more efficient to estimate the impact of cooperative membership on investment in organic soil amendments and chemical fertilizer separately, using the RBP model.

Table 2. The RBP Model Estimates for the Impact of Cooperative Membership on Investment in Organic Soil Amendments and Chemical Fertilizer

	Model 1		Model 2	
	Membership	Organic soil amendments	Membership	Chemical fertilizer
Membership		1.672 (0.328)***		0.514 (0.458)
Age	0.047 (0.048)	−0.041 (0.046)	0.045 (0.050)	0.056 (0.056)
Age squared	−0.000 (0.001)	0.000 (0.000)	−0.000 (0.001)	−0.001 (0.001)
Education	0.166 (0.079)**	−0.003 (0.077)	0.189 (0.085)**	−0.228 (0.096)**
Education squared	−0.009 (0.005)*	0.004 (0.006)	−0.010 (0.006)*	0.014 (0.007)*
Household size	0.117 (0.049)**	−0.157 (0.061)**	0.125 (0.052)**	−0.001 (0.079)
Farm size	0.096 (0.027)***	−0.041 (0.030)	0.091 (0.027)***	0.088 (0.047)*
Manual sprayer	0.730 (0.161)***	−0.304 (0.201)	0.768 (0.164)***	−0.339 (0.218)
Rotary cultivator	0.197 (0.134)	0.378 (0.196)*	0.219 (0.134)	0.054 (0.205)
Access to credit	0.128 (0.128)	0.411 (0.169)**	0.161 (0.131)	−0.014 (0.186)
Sandy soil	1.459 (0.357)***	−0.103 (0.472)	1.739 (0.406)***	0.209 (0.491)
Loam soil	0.421 (0.188)**	0.384 (0.289)	0.466 (0.191)**	0.307 (0.320)
Irrigation	0.261 (0.144)*	0.416 (0.218)*	0.233 (0.144)	0.422 (0.208)**
Road condition	0.455 (0.159)***	−0.057 (0.189)	0.452 (0.163)***	0.169 (0.268)
Livestock	−0.011 (0.216)	0.008 (0.249)	0.122 (0.195)	−0.606 (0.223)***
Tenure security	−0.444 (0.143)***	0.917 (0.354)***	−0.483 (0.143)***	0.681 (0.400)*
Shandong	0.057 (0.395)	−0.238 (0.434)	−0.235 (0.438)	−0.423 (0.503)
Gansu	0.389 (0.279)	0.362 (0.335)	0.333 (0.272)	−0.234 (0.351)
Tenure residual		−0.178 (0.168)		−0.150 (0.180)
Village cooperative	1.033 (0.232)***		0.988 (0.247)***	
Constant	−4.767 (1.156)***	1.187 (1.167)	−5.048 (1.217)***	0.831 (1.342)
$\rho_{\varepsilon\mu}$	−0.839 (0.158)***		−0.784 (0.171)***	
Log−likelihood	−395.592		−349.571	
Wald test of $\rho_{\varepsilon\mu}$=0	5.181**, with Prob = 0.023		5.632**, Prob = 0.018	
ATT	0.510 (0.227)**		0.120 (0.141)	
Sample size	481		481	

Note: *, **, and *** denote significance at 10%, 5%, and 1% levels, respectively. Robust standard errors are in parentheses. The reference region is Shaanxi and the reference soil type is clay soil. ATT refers to average treatment effects on the treated.

The results regarding the impacts of cooperative membership on investment in organic soil amendments are presented in the third column in table 2. The estimates show that cooperative membership exerts a positive and statistically significant impact on the probability of investing in organic soil amendments.[14] The other coefficient estimates in the third column in the table reveal that investment in organic soil amendments tends to be influenced by other factors. In particular, the coefficient of the household size variable is negative and significantly different from zero, suggesting that larger households are less likely to invest in organic soil amendments. Although larger household size normally have higher labor endowments, the increased financial burden sometimes put financial constraints on such households, resulting in reduced financial resources for investment in agricultural technology.

The coefficient of the variable for access to credit is positive and significantly different from zero, suggesting that farmers who do not face liquidity constraints are more likely to invest in organic soil amendments. Sufficient liquidity enables farmers to purchase organic soil amendments such as organic fertilizer from the markets and farmyard manure from livestock farms. Ownership of rotary cultivator and access to irrigation facilities tend to have significant and positive effects on investment in organic soil amendments, indicating wealth effects. The positive and significant coefficient of tenure security variable suggests that farmers

[14] Given that organic soil amendments variable is merged by organic fertilizer and farmyard manure variables, we also estimate the impact of cooperative membership on investment in organic fertilizer and farmyard manure to provide a better understanding. The results, which can be found in the supplementary online appendix, show that cooperative membership has a positive and significant impact on the probability of investing in organic fertilizer and farmyard manure.

with tenure security are more likely to invest in organic soil amendments. This finding is in line with Jacoby et al. (2002) for China, who found that farmers living in villages where expropriation risk is higher tend to invest less in organic fertilizer.

The estimates of the impact of cooperative membership on investment in chemical fertilizer are presented in the last column of table 2. The results show that cooperative membership has a positive but statistically insignificant impact on the probability of investing in chemical fertilizer. Among other factors that influence chemical fertilizer investment, the coefficient of education is negative and significant, while that of education squared is positive and statistically significant, suggesting a nonlinear relationship between education and the probability of investing in chemical fertilizer. The coefficients of the variables for farm size and irrigation facilities are positive and statistically significant, suggesting that farmers having larger farms and access to irrigation are more likely to invest in chemical fertilizer. The negative coefficient of livestock variable suggests that farmers raising livestock are less likely to invest in chemical fertilizer. Tenure security also appears to increase the probability of farmers investing in chemical fertilizer, again supporting the notion that farmers cultivating land with more secured land rights are more likely to invest in yield-enhancing measures.

Given the high application rates of both organic soil amendments and chemical fertilizer, we also analyzed the impact of cooperative membership on expenditures on organic soil amendments and chemical fertilizer using a Tobit model. The potential endogeneity of cooperative membership variable is addressed using the two-stage control function approach (Wooldridge 2015). The results, which can be found in the supplementary online appendix, show that cooperative membership does not significantly influence expenditures on organic soil amendments and chemical fertilizer. This finding clearly indicates that cooperatives could be important in influencing farmers' decisions to use soil-improving inputs but not the extent to which they use it, since this probably depends more on other factors such as liquidity constraints.

Marginal Effects and Average Treatment Effects

Given that the estimated coefficients of the explanatory variables in table 2 cannot be directly interpreted, we also compute the marginal effects to provide a better understanding about the impacts of the variables on investment. We are particularly interested in the marginal effects of variables that influence farmers' soil investment decisions, so the marginal effects from the first-stage estimation of the RBP model are not presented in the article for the sake of brevity. The results presented in table 3 reveal that cooperative membership increases the probabilities of investing in organic soil amendments and chemical fertilizer by 30.7% and 5.9%, respectively. Among other variables, farmers with larger farms tend to be 0.8% less likely to invest in organic soil amendments but 1.1% more likely to invest in chemical fertilizer. Farmers who have access to credit are 8.3% more likely to invest in organic soil amendments, compared to their counterparts facing liquidity constraints.

With respect to soil quality variables, the results show that farmers cultivating land with sandy soils are 2.1% less likely to invest in organic soil amendments, while 2.4% are more likely to invest in chemical fertilizer, relative to farmers cultivating clayey soils. Farmers cultivating land with loamy soils are 6.5% and 3.1% more likely to invest in organic soil amendments and chemical fertilizer, respectively. Thus, more fertile lands tend to attract higher investments for organic amendments, probably due to the expected higher returns from fertile land (Jacoby and Mansuri 2008). Access to irrigation increases the probabilities of investing in organic soil amendments and chemical fertilizer by 8.7% and 5.4%, respectively. It is significant to note that the marginal effects discussed above represent average values of the θ discussed in the theoretical section. Thus, the empirical results are consistent with the theoretical findings that cooperative membership tends to favor investment in organic soil amendments and chemical fertilizer.

To the extent that marginal effects only estimate the partial effects of cooperative membership on investment in organic soil amendments and chemical fertilizer in the case of changing cooperative membership variable from zero to one, we also employed the approach suggested by Chiburis et al. (2011) to estimate the average treatment effects (ATT) to provide a better and more comprehensive understanding of the effects of cooperative membership on investment decisions of smallholder farmers. We used

Table 3. Marginal Effects of RBP Model Estimation on the Marginal Probability of Investing in Organic Soil Amendments and Chemical Fertilizer (in %)

Variables	Organic Soil Amendments	Chemical Fertilizer
Membership	0.307	0.059
Age	−0.008	0.007
Age squared	0.000	−0.000
Education	−0.001	−0.027
Education squared	0.001	0.002
Household size	−0.031	−0.000
Farm size	−0.008	0.011
Manual sprayer	−0.056	−0.036
Rotary cultivator	0.077	0.006
Access to credit	0.083	−0.002
Sandy soil	−0.021	0.024
Loam soil	0.065	0.031
Irrigation	0.087	0.054
Road condition	−0.011	0.021
Livestock	0.002	−0.093
Tenure security	0.182	0.082
Shandong	−0.048	−0.053
Gansu	0.062	−0.031
Tenure residual	−0.035	−0.018
Sample size	481	481

bootstrap replications to reduce sampling noise (Chiburis et al. 2011). Unlike the mean differences presented in the supplementary online appendix, these ATT estimates account for selection bias arising from the fact that members and nonmembers are systematically different in terms of both observed and unobserved characteristics. The results are presented in the lower part of table 2. Our findings show that cooperative membership significantly increases the probability of investing in organic soil amendments by 51%. However, no statistically significant impact was found for the impact of cooperative membership on investment in chemical fertilizer. Although the RBP model estimation reveals some differences in the magnitude of the marginal effects and average treatment effects of cooperative membership, both reveal highly positive and statistically significant impacts. As pointed out by Lanfranchi and Pekovic (2014), these differences are expected, since they are calculated based on two different evaluation parameters. In particular, the marginal effect shows how the probability of investing in a particular soil quality measure changes as the cooperative membership variable changes from zero to one, while the ATT measures the causal effect of cooperative membership on the probability of investing in soil quality measures.

Conclusion

This article examined the impact of cooperative membership on investment in organic soil amendments and chemical fertilizer in rural China. Specifically, we developed a dynamic model to show how cooperative membership and household and farm-level characteristics influence farmers' decisions to invest in organic soil amendments and chemical fertilizer. We used the model to analyze the decisions of heterogeneous producers to join agricultural cooperatives and the intensity of production. To complement the theoretical analysis, we used survey data from apple producing households in Gansu, Shaanxi, and Shandong provinces in China to examine the impact of cooperative membership and household and farm-level characteristics on investment in organic soil amendments and chemical fertilizer. A recursive bivariate probit model was employed to address potential selectivity bias that arises from both observed and unobserved heterogeneities.

The theoretical analysis showed that there is a limited range of household- and farm level characteristics where farmers find it optimal to join a cooperative. It also identified two situations where farmers with cooperative membership are more likely to invest in organic soil amendments and chemical fertilizers than those without membership. The econometric estimates revealed that a number of factors tend to drive farmers' decisions to join agricultural cooperatives, including education, household size, farm size, and asset ownership. With respect to the investment decisions, our findings showed that cooperative membership tends to positively influence investment in organic soil amendments and chemical fertilizers, although the positive influence on chemical fertilizer was not statistically significant. Furthermore, farmers' access to credit and irrigation facilities, as well as perceived tenure security were found to increase the propensity to invest in organic soil amendments. The findings also revealed that cooperative membership does not have any statistically significant impact on expenditures on organic soil amendments and chemical fertilizer.

Our findings generally confirm the significant role of agricultural cooperatives in facilitating the adoption of soil quality measures among smallholder farmers, which actually enhance environmental sustainability and agricultural productivity. This suggests that the government should intensify its efforts to encourage smallholder farmers to join cooperatives. A crucial finding of the study is that agricultural cooperatives significantly influence farmers' decisions to invest in organic soil amendments but not the extent to which they use it. Thus, it is of significance to enhance cooperatives' ability to supply their members with production inputs at reasonable prices, which in turn could help increase the level of investments in organic soil amendments. The finding of a positive and significant impact of tenure security suggests that improving land tenure security, or land rights would help enhance investment in organic soil amendments and sustainable agriculture.

Moreover, given the roles of access to credit and irrigation facilities in facilitating investment in soil quality measures, it is apparent that policies that enhance farmers' access to credit and accelerate the development of rural infrastructure such as irrigation facilities would help in increasing investment in soil quality measures that could contribute to sustainable agriculture. Despite the interesting theoretical and empirical findings, the study still has some limitations that could be considered in future research in the area. While we found that agricultural cooperatives increase the probabilities of investing in organic soil amendments, little appears to be known about the cost and profit efficiency of cooperative members compared to nonmembers in the adoption of agricultural technologies.

Supplementary Material

Supplementary material are available at *American Journal of Agricultural Economics* online.

References

Abdulai, A. and R. Goetz. 2014. Time-related Characteristics of Tenancy Contracts and Investment in Soil Conservation Practices. *Environmental and Resource Economics* 59 (1): 87–109.

Abebaw, D. and M. G. Haile. 2013. The Impact of Cooperatives on Agricultural Technology Adoption: Empirical Evidence from Ethiopia. *Food Policy* 38: 82–91.

Amare, M., S. Asfaw, and B. Shiferaw. 2012. Welfare Impacts of Maize-Pigeonpea Intensification in Tanzania. *Agricultural Economics* 43 (1): 27–43.

Antle, J. M., and B. Diagana. 2003. Creating Incentives for the Adoption of Sustainable Agricultural Practices in Developing Countries: The Role of Soil Carbon Sequestration. *American Journal of Agricultural Economics* 85 (5): 1178–84.

Barbier, E. B. 2000. The Economic Linkages between Rural Poverty and Land Degradation: Some Evidence from Africa. *Agriculture, Ecosystems and Environment* 82 (1–3): 355–70.

Bernard, T., and D. J. Spielman. 2009. Reaching the Rural Poor through Rural Producer Organizations? A Study of Agricultural Marketing Cooperatives in Ethiopia. *Food Policy* 34 (1): 60–69.

Bernard, T., A. S. Taffesse, and E. Gabre-Madhin. 2008. Impact of Cooperatives on Smallholders' Commercialization Behavior: Evidence from Ethiopia. *Agricultural Economics* 39: 147–61.

Byiringiro, F., and T. Reardon. 1996. Farm Productivity in Rwanda: Effects of Farm Size, Erosion, and Soil Conservation Investments. *Agricultural Economics* 15 (2): 127–36.

Chagwiza, C., R. Muradian, and R. Ruben. 2016. Cooperative Membership and Dairy Performance among Smallholders in Ethiopia. *Food Policy* 59: 165–73.

Chiburis, R., C. J. Das, and M. Lokshin. 2011. *A Practical Comparison of the Bivariate Probit and Linear IV Estimators*. World Bank Policy Research Working Paper no. WPS 5601.

CRSY. 2013. *China Rural Statistical Yearbook*. Beijing: China Statistics Press.

Deng, H., J. Huang, Z. Xu, and S. Rozelle. 2010. Policy Support and Emerging Farmer Professional Cooperatives in Rural China. *China Economic Review* 21 (4): 495–507.

Ersado, L., G. Amacher, and J. Alwang. 2004. Productivity and Land Enhancing Technologies in Northern Ethiopia:

Health, Public Investments, and Sequential Adoption. *American Journal of Agricultural Economics* 86 (2): 321–31.
Fulton, M., and K. Giannakas. 2013. The Future of Agricultural Cooperatives. *Annual Review of Resource Economics* 5 (1): 61–91.
Gao, L., J. Huang and S. Rozelle. 2012. Rental Markets for Cultivated Land and Agricultural Investments in China. *Agricultural Economics* 43 (4): 391–403.
Gaur, A. C. (1992). Bulky Organic Manures and Crop Residues. In *Fertilisers, Organic Manures, Recyclable Wastes and Biofertilisers: Components of Integrated Plant Nutrition*, ed. H. L. S. Tandon, 36–43. New Dehli: Fertiliser Development and Consultation Organisation.
Gijselincks, C., L. Zhao, and S. Novkovic. 2014. *Co-operative Innovations in China and the West*. London: Palgrave Macmillan.
Hellin, J., M. Lundy, and M. Meijer. 2009. Farmer Organization, Collective Action and Market Access in Meso-America. *Food Policy* 34 (1): 16–22.
Hendrikse, G. and J. Bijman. 2002. Ownership Structure in Agrifood Chains: The Marketing Cooperative. *American Journal of Agricultural Economics* 84 (1): 104–19.
Holden, S. T., K. Deininger, and H. Ghebru. 2009. Impacts of Low-Cost Land Certification on Investment and Productivity. *American Journal of Agricultural Economics* 91 (2): 359–73.
Hosmer, D. W., and S. Lemeshow. 1980. Goodness of Fit Tests for the Multiple Logistic Regression Model. *Communications in Statistics - Theory and Methods* 9 (10): 1043–69.
Hou, L., D. Hoag, C. M. H. Keske, and C. Lu. 2014. Sustainable Value of Degraded Soils in China's Loess Plateau: An Updated Approach. *Ecological Economics* 97: 20–27.
Huth, P. K., and T. L. Allee. 2002. *The Democratic Peace and Territorial Conflict in the Twentieth Century*. New York: Cambridge University Press.
Ito, J., Z. Bao, and Q. Su. 2012. Distributional Effects of Agricultural Cooperatives in China: Exclusion of Smallholders and Potential Gains on Participation. *Food Policy* 37 (6): 700–709.
Jacoby, H. G., G. Li, and S. Rozelle. 2002. Hazards of Expropriation: Tenure Insecurity and Investment in Rural China. *American Economic Review* 92 (5): 1420–47.
Jacoby, H. G. and G. Mansuri. 2008. Land Tenancy and Non-contractible Investment in Rural Pakistan. *Review of Economic Studies* 75 (3): 763–88.
Karantininis, K. and A. Zago. 2001. Endogenous Membership in Mixed Duopsonies. *American Journal of Agricultural Economics* 83 (5): 1266–72.
Lanfranchi, J. and S. Pekovic. 2014. How Green Is My Firm? Workers' Attitudes and Behaviors towards Job in Environmentally Related Firms. *Ecological Economics* 100: 16–29.
Lokshin, M., and Z. Sajaia. 2011. Impact of Interventions on Discrete Outcomes: Maximum Likelihood Estimation of the Binary Choice Models with Binary Endogenous Regressors. *Stata Journal* 11 (3): 368–85.
Ma, X., N. Heerink, E. van Ierland, M. van den Berg, and X. Shi. 2013. Land Tenure Security and Land Investments in Northwet China. *China Agricultural Economic Review* 5 (2): 281–307.
Marenya, P. P., and C. B. Barrett. 2009. Soil Quality and Fertilizer Use Rates among Smallholder Farmers in Western Kenya. *Agricultural Economics* 40 (5): 561–72.
Mérel, P., T. L. Saitone, and R. J. Sexton. 2015. Cooperative Stability under Stochastic Quality and Farmer Heterogeneity. *European Review of Agricultural Economics* 42 (5): 765–95.
Mojo, D., C. Fischer, and T. Degefa. 2017. The Determinants and Economic Impacts of Coffee Farmer Cooperatives: Recent Evidence from Rural Ethiopia. *Journal of Rural Studies* 50: 84–94.
Moustier, P. P., T. G. Tam, D. T. Anh, V. T. Binh, and N. T. T. Loc. 2010. The Role of Farmer Organizations in Supplying Supermarkets with Quality Food in Vietnam. *Food Policy* 35 (1): 69–78.
Murphy, A. 2007. Score Tests of Normality in Bivariate Probit Models. *Economics Letters* 95 (3): 374–79.
Naziri, D., M. Aubert, J.-M. Codron, N. T. T. Loc, and P. Moustier. 2014. Estimating the Impact of Small-Scale Farmer Collective Action on Food Safety: The Ccase of Vegetables in Vietnam. *Journal*

of Development Studies 50 (January): 715–30.
Pender, J., B. Gebremedhin, S. Benin, and S. Ehui. 2001. Strategies for Sustainable Agricultural Development in the Ethiopian Highlands. *American Journal of Agricultural Economics* 83 (5): 1231–40.
Rao, F., M. Spoor, X. Ma, and X. Shi. 2016. Land Tenure (In)Security and Crop-Tree Intercropping in Rural Xinjiang, China. *Land Use Policy* 50: 102–14.
Rozelle, S., J. Huang, and L. Zhang. 1997. Poverty, Population and Environmental Degradation in China. *Food Policy* 22 (3): 229–51.
Saitone, T. L., and R. J. Sexton. 2010. Product Differentiation and Quality in Food Markets: Industrial Organization Implications. *Annual Review of Resource Economics* 2: 341–68.
Schultz, T. W. 1982. *Wolfram Schultz. Investing in People: The Economics of Population Quality*. Berkeley: University of California Press.
Thuo, M., A. A. Bell, B. E. Bravo-Ureta, M. A. Lachaud, D. K. Okello, E. N. Okoko, and N. Puppala. 2014. Effects of Social Network Factors on Information Acquisition and Adoption of Improved Groundnut Varieties: The Case of Uganda and Kenya. *Agriculture and Human Values* 31 (3): 339–53.
Vall Castello, J. 2012. Promoting Employment of Disabled Women in Spain: Evaluating a Policy. *Labour Economics* 19 (1): 82–91.
Vandeplas, A., B. Minten, and J. Swinnen. 2013. Multinationals vs. Cooperatives: The Income and Efficiency Effects of Supply Chain Governance in India. *Journal of Agricultural Economics* 64 (1): 217–44.
Verhofstadt, E., and M. Maertens. 2014. Smallholder Cooperatives and Agricultural Performance in Rwanda: Do Organizational Differences Matter? *Agricultural Economics* 45 (S1): 39–52.
Wang, H., J. Tong, F. Su, G. Wei, and R. Tao. 2011. To Reallocate or Not: Reconsidering the Dilemma in China's Agricultural *Land Ttenure Policy. Land Use Policy* 28 (4): 805–14.
Wheat, D. 2017. China Boosts Apple Exports to U.S. *The Capital Press (March 23)*. Retrieved from http://www.capitalpress.com/Orchards/20170323/china-boosts-apple-exports-to-us.
Wooldridge, J. M. 2015. Control Function Methods in Applied Econometrics. *Journal of Human Resources* 50 (2): 420–45.
Wossen, T., T. Abdoulaye, A. Alene, M. G. Haile, S. Feleke, A. Olanrewaju, and V. Manyong. 2017. Impacts of Extension Access and Cooperative Membership on Technology Adoption and Household Welfare. *Journal of Rural Studies* 54: 223–33.