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Do economic preferences and personality traits influence fertilizer use? Evidence from rice farmers in eastern China

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ABSTRACT

Environmental problems associated with the inappropriate use of fertilizers by rural smallholders are a growing concern in many countries. This paper contributes to the literature by examining whether risk preferences, time preferences, and personality traits are related to farmers' use of synthetic and organic fertilizers. We rely on survey data collected from 815 farm households in three rice-producing provinces in eastern China in the empirical analyses. Results of OLS and rare events logistic regressions indicate that risk-seeking and patience are positively associated with the application of organic fertilizer in rice production but not with the intensity of synthetic fertilizer use. There is also no significant association between personality traits and (synthetic or organic) fertilizer use. In addition, personality traits do not mediate nor moderate the associations between economic preferences and fertilizer use. Robustness analysis using the two-stage probit least squares (2SPLS) model not only supports these findings, but also suggests that organic fertilizers complement the use of synthetic fertilizers and are only sporadically used in Chinese rice production. The insights gained in this study can provide important inputs for designing policies aimed at promoting sustainable agricultural intensification in China and elsewhere.

1. Introduction

Agricultural production in Asian countries has grown dramatically in the last few decades to fulfil rising domestic and global demand (Huang & Yang, 2017). This development, however, has also brought obstacles to countries, such as China, in pursuing a transition towards a more sustainable agricultural system. For example, data from the Food and Agriculture Organization of the United Nations (FAO) show that China ranks among the countries with the highest rate of nitrogen fertilizer application per hectare of cropland globally (see Fig. A1 in the Supplementary Material), but its nitrogen use efficiency is relatively low (Guo et al., 2020; Menegat et al., 2022). A substantial portion of the applied chemicals, i.e., nitrogen and phosphate, is not absorbed by the crops but instead leaches into the water system from the soil, leading to significant adverse environmental externalities (Wang et al., 2018; Wu, 2011). An additional cause of the environmental pollution in China is the inadequate management of organic waste from farms (Chadwick et al., 2015). While manure and other organic fertilizers, such as crop straw or compost, have the potential to preserve soil quality in the mid- or long-term, organic waste from livestock farms in China is often underutilized, with more than half of the manure nutrients being lost (Jin et al., 2021). These circumstances give rise to two intriguing questions: Why do Chinese farmers heavily rely on synthetic fertilizers, and why is the use of organic fertilizers infrequent?

The extant literature suggests that farm characteristics (Zhou et al., 2010), household and farmer characteristics (Smith and Siciliano, 2015), and markets and policies (Li et al., 2012) can explain farmers' fertilizer use decisions to a large extent. Recent research also suggests that individual-specific characteristics, such as economic risk and time preferences, may explain the adoption or use of fertilizers (Khor et al.,

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2018; Le Cotty et al., 2018). For example, Le Cotty et al. (2018) found significant associations between maize farmers' fertilizer-use decisions and time preferences but no associations with risk preferences in Burkina Faso. However, the results of studies on the associations between fertilizer use and economic preferences are inconclusive, and most research has been conducted in countries where the uptake of synthetic fertilizer is relatively low (e.g., Sub-Saharan Africa). Moreover, institutional settings relevant to risk and time preferences differ internationally. For example, in most countries, farmers bear the risks related to volatile output prices. But since 2004, stable output prices for grain products in China have been maintained through the implementation of a "minimum procurement price" policy. Little is known about the associations between fertilizer use and economic preferences in countries such as China, where synthetic fertilizers are widely and excessively used (Van Wesenbeeck et al., 2021), and where the government mitigates farmers' market risks through output-price support.

A growing number of behavioural economists suggests that personality traits can complement economic preferences to explain why different people behave differently (Almlund et al., 2011; Becker et al., 2012; Borghans et al., 2008). A recent study showed that personal characteristics (e.g., polychronicity, passion, and optimism) may affect farmers' technology adoption decisions and efficiency of input use in Ghana (Ali et al., 2019). This implies that considering personality traits in addition to economic preferences can enrich the analysis of farmers' fertilizer use. To our knowledge, there is no empirical evidence to date on the role played by personality traits for the associations between economic preferences and fertilizer use.

This study addresses the identified research gaps and contributes to the existing literature in at least three ways. First, the paper tests for associations between economic preferences and farmers' fertilizer-use decisions within a unique context in China where synthetic fertilizers are commonly used and market risks of grain products are substantially mitigated. Secondly, our study empirically examines the potential mediating or moderating role of personality traits in the relationship between economic preferences and fertilizer use. This contributes to a more comprehensive understanding of the intricate interplay between economic preferences and personality traits when explaining the economic decisions farmers make. Lastly, unlike existing literature that often scrutinizes the use of synthetic or organic fertilizers in isolation, our study provides a more holistic perspective on farmers' fertilizer-use choices by empirically considering the possible joint nature of these decisions.

The remainder of this paper is organized as follows. Section 2 presents a conceptual framework of the relationships between risk preferences, time preferences, personality traits and farmers' fertilizer-use behaviour. Section 3 describes the dataset and empirical methods. Section 4 presents the results, and Section 5 presents the discussion and conclusions.

2. Conceptual framework

2.1. Economic preferences and fertilizer use

Farmers often face decisions imbued with inherent risks. The profitability of an investment, for instance, hinges on unpredictable factors such as weather conditions, potential disease outbreaks, and future market dynamics (Binswanger, 1980; Wuepper et al., 2023). Additionally, many agricultural decisions involve a temporal dimension, where substantial investments may yield benefits only in the future. Individual disparities arise in the willingness to embrace risk and defer outcomes, characterized as "risk preferences" and "time preferences" by economists, respectively (Becker et al., 2012).

To facilitate predictions of economic decisions under risk and with delayed outcomes, economists rely on formal mathematical utility maximisation models. The premise of these models is that behaviour is best proxied by the assumptions that people know how much utility they will obtain from any decision and then choose whatever option maximizes their utility subject to a budget constraint. In these models, risk preferences are captured by the curvature of people's utility functions. People averse to risk exhibit concave utility functions so that the additional utility they receive from consuming another unit of a good declines the more they have already consumed this good. Risk aversion implies that people strictly prefer a certain reward over a risky reward with the same expected value. Time preferences are represented by a discount rate, where individuals with higher impatience levels discount the future more than those with higher patience levels.

To conceptualize the role of economic preferences in farmers' fertilizer-use decisions, we consider an intertemporal farm household model in which a farmer maximizes the sum of discounted utilities over two periods within a single season of crop production. Period 1 is the planting period in which the farmer allocates all initial wealth W_0 to either fertilizer investment F or composite consumption c_1. Although fertilizer investments in period 1 precede the benefits in harvest period 2, credit access and savings are not considered for simplicity (Le Cotty et al., 2018). The farmer is assumed to consume all agricultural production c_2 in period 2, and maximizes the following isoelastic utility function:

$$MaxU = \frac{c_1^{1-\gamma}}{1-\gamma} + \frac{1}{1+r}\,\frac{c_2^{1-\gamma}}{1-\gamma} \tag{2.1}$$

where U is the expected discounted utility of the farmer, which is assumed to be time-separable with a constant relative risk aversion (CRRA) parameter γ ($\gamma \neq 1$). This γ parameter determines the curvature of the utility function. The higher γ is, the more risk averse people are. Discounting is represented by the discount rate r. People with a high r value the utility obtained in period 1 much more than in period 2. Utility is maximized subject to the following constraints:

$$c_1 + p_f F = W_0 \tag{2.2}$$

$$c_2 = AF^{\alpha} \tag{2.3}$$

where p_f is the price of fertilizer, A is the total factor productivity, and α is the output elasticity of fertilizer use ($\alpha < 1$). We assume that agricultural produce is a numéraire good with a price of 1 and that the production function satisfies a Cobb-Douglas specification with decreasing returns to scale.

Substituting c_1 and c_2 into equation (2.1) and taking the first derivative of the utility function with respect to F yields the following first-order condition:

$$\frac{\partial U}{\partial F} = \left(-p_f\right)\left(W_0 - p_f F\right)^{-\gamma} + \frac{1}{1+r}\left(AF^{\alpha}\right)^{-\gamma}\left(\alpha A F^{\alpha-1}\right) = 0. \tag{2.4}$$

By rearranging equation (2.4), we obtain the following equation:

$$\frac{p_f(1+r)}{\alpha A^{1-\gamma}} = \frac{\left(W_0 - p_f F\right)^{\gamma}}{F^{1+\alpha\gamma-\alpha}} \tag{2.5}$$

In equation (2.5), fertilizer use (F) on the right-hand side decreases when the discount rate r on the left-hand side increases, while other parameters are held constant. Equation (2.5) thus implies that patient farmers use more fertilizer, or that fertilizer input F monotonically decreases with respect to discount rate r:

$$\frac{\partial F}{\partial r} < 0. \tag{2.6}$$

The available literature provides some empirical evidence for the negative link between impatience and fertilizer use described in Equation (2.6). Duflo et al. (2011) found that the lack of synthetic fertilizer application in Kenya may be partly driven by farmers' time-inconsistency and procrastination. Le Cotty et al. (2018) found that farmers with higher patience in Burkina Faso tended to use more fertilizer during the planting period. Time preferences may affect the use of organic fertilizer specifically because organic fertilizers generally require 3–5 years to produce positive effects on crop yields and soil quality (Jacoby et al., 2002). Therefore, more patient farmers tend to apply more fertilizers, particularly organic fertilizers.

The relationship between risk preferences and fertilizer use in equation (2.5) is nontrivial, and the empirical literature produces mixed findings on this relationship. Some studies found that a higher level of risk-seeking is positively associated with farmers' intensity of synthetic fertilizer use when the quality of fertilizers is uncertain (Khor et al., 2018; Roosen and Hennessy, 2003). However, other studies suggest that risk-averse farmers tend to use more synthetic fertilizers to secure yields (Stuart et al., 2014). Risk preferences may be particularly relevant in the decision to use organic fertilizers. Applying organic fertilizers may introduce weeds and pests (Zhang et al., 2021) which may result in a volatile yield (Moe et al., 2019). The benefits of combining synthetic and organic fertilizers, such as increased soil organic carbon content that increases crop yields in the long run (Dick and Gregorich, 2004), may be unclear and considered uncertain by farmers. In addition, organic fertilizers may face the risk of loss during transportation and storage (Zhang et al., 2019). This suggests that risk-averse farmers are less likely to use organic fertilizers.

2.2. *Personality traits and fertilizer use*

There is a growing literature that investigates the role of personality traits for economic behaviour. Personality traits typically refer to the underlying patterns of individual thinking, feelings, and behaving, which are partly biologically determined and relatively stable in adulthood (Roberts, 2009). Personality traits can help explain the heterogeneity in behaviour across individuals and groups in many circumstances. The most prominent model of personality traits is the *Big Five Model*, which distinguishes five broad dimensions: openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism (Costa Jr & McCrae, 1992) [1]. Differences in personality traits have been observed to explain variations in rural-urban migration and smallholders' land rental decisions (Ayhan et al., 2020; Qian et al., 2020). Similarly, it may be argued that farmers with low levels of openness to experience may prefer conventional to innovative agricultural practices, conscientious farmers may be more likely to apply organic fertilizer in combination with synthetic fertilizer to improve the growth conditions of crops, and farmers with higher levels of agreeableness may apply less synthetic fertilizer or be more likely to use organic fertilizer as they tend to care more about the environment (Westjohn et al., 2012).

While both concepts of economic preferences and personality traits are frequently used to explain individual differences in behaviour, they are mostly studied separately in the literature. An exception is the study by Dohmen et al. (2010) who found that risk preferences relate to openness to experience and agreeableness of the Big Five model. Similarly, Daly et al. (2009) found that time preferences are associated with conscientiousness and extraversion. These associations suggest that economic preferences and personality traits might measure similar underlying factors. In contrast, other studies found no evidence for a relationship between the two concepts, suggesting that personality traits may complement economic preferences in explaining behaviour (Becker et al., 2012; Rustichini et al., 2016). Schröder and Gilboa Freedman (2020) suggested that this inconclusive relationship may be attributed to different elicitation methods for economic preferences. They found that economic preferences measured by incentivized choice tasks capture distinct characteristics compared to personality traits, while those measured using non-incentivized self-reports are associated with personality traits.

2.3. *An integrated framework*

Fig. 1 presents the conceptual framework used for the empirical analysis. Farmers' fertilizer-use decisions and the key outcome variables are presented at the centre of the framework. Economic preferences and personality traits, which are the central focus of our study, are shown on the left-hand side. The solid arrows indicate the potential relationships between each box. The dashed arrows indicate the potential mediation and moderation effects.

As shown in the box on the right-hand side of Fig. 1, various external factors can influence farmers' fertilizer decisions. First, natural, physical, financial, human, and social assets can determine how rural households operate farms (Ellis, 2000). These assets are viewed as exogenous as they are likely to remain virtually unchanged over time. Second, in rural areas where major market imperfections exist, household characteristics can influence both agricultural production decisions and consumption decisions made by farming households (De Janvry & Sadoulet, 2006). Third, production theory suggests that higher prices of outputs and (non-complementary) variable inputs have positive effects on fertilizer use, whereas a higher price of fertilizer itself has a negative impact. Finally, agro-ecological conditions, rural institutions and policies, and other relevant external factors should also be controlled for (Hong et al., 2020). We choose not to include household decisions that are interrelated with fertilizer-use decisions, such as land rentals, labour hiring, use of machinery services, off-farm employment, or food consumption, in the conceptual framework. The rationale behind this choice is to avoid confounding factors and maintain model simplicity, given that the primary focus of this study is to estimate the direct effects of economic preferences on fertilizer use decisions.

3. Materials and method

3.1. *Data set*

This study used data collected through a large farm household survey conducted in three typical rice-producing provinces in eastern China in February 2019. The primary goal of the survey was to gather information on farmland rentals and resource management among the rice farmers. The provinces Liaoning, Jiangsu, and Jiangxi were selected based on their distinct levels of economic development and farmland endowments (see Table A1 in the Supplementary Material for details), as well as their diverse geographical location in the northern, central, and southern parts of eastern China (see Fig. 2). The collected data contain rich information about rural household composition, agricultural production in the 2018 crop season, and a range of other indicators, including economic preferences and personality traits.

A multistage stratified sampling strategy was applied to select households for the survey (see Fig. A2 in the Supplementary Material for a flowchart illustrating the key steps of the sampling process). By consulting local policymakers, two counties differing in geographical location and economic development level were selected within each province. Within each county, all townships were sorted based on their per capita arable land, and five counties were selected using the systematic sampling method. Similarly, four villages were selected for each township. Within each selected village, households were classified into three groups (strata): renting in, renting out, and autarkic households. In each stratum, four households were randomly selected for the interviews. Thus, 1420 rural households living in 120 villages were included [2]. The head of each household was invited for the interview. If the household head was absent, a household member responsible for agricultural decision-making was interviewed [3]. We focus on households primarily producing rice, and therefore exclude 389 households that did not produce agricultural output, 195 households that did not grow rice as their major agricultural output, and 21 observations with missing information. Thus, our analysis was based on 815 rice-producing farm households.

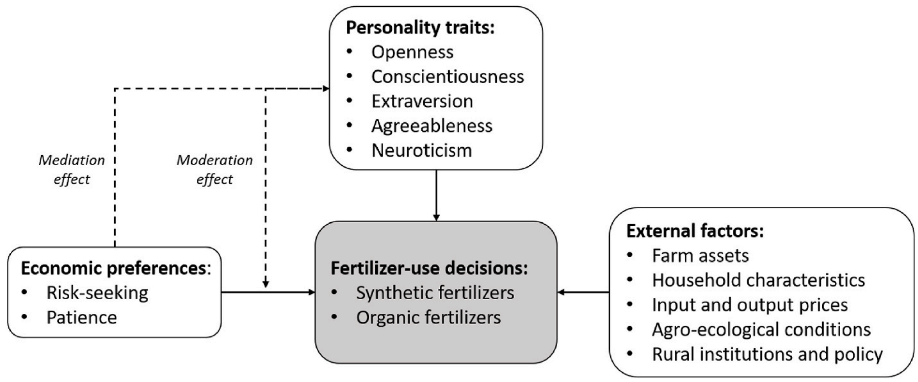

Fig. 1. Graphic presentation of the conceptual framework for fertilizer-use decisions.

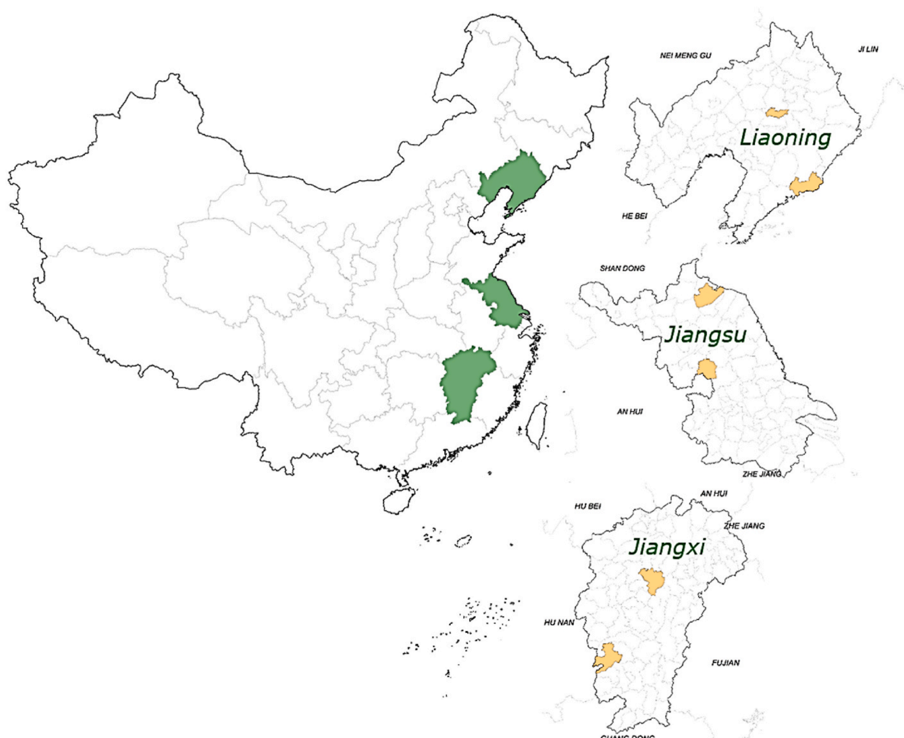

Fig. 2. Location of the study areas.

3.2. Measures

3.2.1. Fertilizer use

The two dependent variables in our analyses are synthetic and organic fertilizer use. The measure for synthetic fertilizer use is based on the aggregated NPK (nitrogen, phosphate, and potassium) nutrient quantity in kg per mu used by the farm households. Different types of synthetic fertilizers, such as compound fertilizer, urea, ammonium bicarbonate, and potassium dihydrogen phosphate, are used for rice production in the study areas. To convert the quantities of the different fertilizer types into the NPK nutrients quantity in kilograms, we followed the national standards outlining the nutrient composition of various fertilizer types. Subsequently, we calculated the synthetic fertilizer use intensity for each household by dividing the aggregated NPK nutrients quantity by the corresponding sown rice area, measured in mu [4]. The survey dataset also includes a dichotomous variable for organic fertilizer use, equalling 1 if a farmer used any type of organic input (purchased organic fertilizer, animal manure, compost, green manure, etc.) and 0 otherwise. The dataset did not differentiate between the different types of organic fertilizers.

3.2.2. Economic preferences

Following Falk et al. (2018), participants' risk preferences and time preferences were elicited using survey measures that combined quantitative and qualitative survey questions that were highly correlated with preferences measured in incentivized and more detailed lab experiments. The main benefit of this approach is that survey measures can be used in the field to robustly measure economic preferences, even when time constraints and other resource constraints do not allow conducting detailed, incentivized experiments (Falk et al., 2016, 2018). The risk-preference measure combines a hypothetical lottery choice task in which participants choose five times between a safe option and a risky gamble with varying expected values and a self-assessment about the willingness to take risks in general (using a 10-point scale). The time-preference measure combines hypothetical choices between receiving an early payment and five different larger delayed payments with a (qualitative) question about the willingness to delay the benefit of consuming something today until someday in the future (again using a

10-point scale). For each preference measure, we first calculated the z-scores of the quantitative and qualitative survey items at the individual level, and then weighted the quantitative and qualitative items based on the weights obtained from an experimental validation procedure presented by Falk et al. (2016). Finally, we standardized this weighted average score to obtain preference variables with zero means and standard deviations equal to one. A higher value for the risk preference variable indicates a greater risk-seeking tendency, and a higher value for the time preference variable indicates a greater level of patience.

3.2.3. Personality traits

Participant's personality traits were measured using the Chinese version of the Big Five Inventory-10 (BFI-10) on a 5-point Likert-type scale. The BFI-10 shows acceptable psychometric properties (measurement validity and reliability) and is thus a suitable instrument to assess respondents' personality traits for economic analysis when the data collection time is limited (Rammstedt and John, 2007). The BFI-10 inventory has been commonly used in other economic studies (*e.g.*, Donato et al., 2017; Qian et al., 2020).

3.2.4. Control variables

We used the farm household's contracted land size and number of contracted land plots as natural assets indicators [5]. Productive assets and livestock endowments were used as indicators of physical assets. Productive assets were obtained by adding the monetary values of various types of machinery, including tractors, harrows, sowers, pesticide sprayers, irrigation pumps, and harvesters. These values were then transformed into logarithms for the regression analyses. Livestock endowment was represented by a binary variable indicating whether a household owned livestock assets or not. These physical assets may also reflect financial assets as they can be a source of self-insurance and liquidity for financially constrained households (Marenya and Barrett, 2009). We also included a binary variable indicating access to credit as an additional measure of financial assets. The total number of labourers in the household, share of female labourers, and age and education of the household head were included as indicators of human assets. Lastly, we proxied social assets with a binary variable indicating whether the household head was a township or village cadre (*e.g.*, an administrative officials).

The household-level dependency ratio, defined as the share of household members aged over 65 or under 16 years, was included as a household characteristic, in addition to the age, gender, and education of the head of the household. We measured the output price of rice by the reported price in the local currency at which rice output was sold per kilogram, and measured the variable input price for synthetic fertilizer (NPK) per kilogram by adjusting the synthetic fertilizer paid by a household for the NPK content of the reported fertilizer types [6]. We also include a dummy variable that indicated whether other households in the village, besides the sampled farmers, used organic fertilizers to control for farmers' access to organic fertilizer from other sources. Furthermore, a dummy variable that indicated whether any double-season rice was grown by the farmer to account for differences in rice production technologies was included.

Regarding policies and institutions, we included a dummy variable indicating whether or not a village was involved in a land consolidation program (LCP) [7]. In addition, two provincial dummy variables were included to account for other unobserved factors such as agro-ecological conditions and other rural institutions and policies that may differ across provinces.

3.3. Descriptive statistics

Table 1 presents the descriptive statistics of the outcome variables and independent variables. All sampled farm households used synthetic fertilizers for their crop production. On average, farm households applied 31.84 kg of synthetic (NPK) fertilizer per mu (*i.e.*, 477.6 kg per ha) of arable land at a mean price of 5.33 yuan per kilogram (*i.e.*, about 0.8 USD per kilogram). Only 8 percent of the households used organic manure. Farm households in the sample were, on average, endowed with 7.99 mu (*i.e.*, 0.53 ha) of arable land spread over 4.43 plots. The average number of labourers within a farm household was 2.92, and 34 percent of them were female. The value of the productive assets owned by the surveyed households varied from zero to as much as two million yuan. Approximately 19 percent of households owned livestock. Interviewed farmers were mainly male, on average 58.4 years old and had on average 6.63 years of schooling.

Table 1
Descriptive statistics.

	N	Mean	SD	Min	Max
Fertilizer use (outcome variables)					
Synthetic fertilizer (NPK) input intensity, kg/mu	815	31.84	12.38	3.97	94.28
Organic manure, 1 = yes	815	0.08	0.28	0	1
Preferences and Personality traits					
Risk preferences (risk-seeking)	815	0	1	−1.02	2.12
Time preferences (patience)	815	0	1	−1.14	1.41
Openness	815	3.02	1.01	1	5
Conscientiousness	815	4.14	0.79	1	5
Extraversion	815	3.92	0.91	1	5
Agreeableness	815	3.93	0.73	1	5
Neuroticism	815	2.33	0.89	1	5
Control variables					
Contracted land size, mu	815	7.99	6.19	0	60
Number of contracted plots	815	4.43	4.05	0	38
Productive asset value, thousand yuan	815	45.02	184.10	0	2065
Zero productive assets, 1 = yes	815	0.45	0.50	0	1
Owning livestock, 1 = yes	815	0.19	0.39	0	1
Manure use by other villagers, 1 = yes	815	0.41	0.49	0	1
Credit access, 1 = yes	815	0.24	0.42	0	1
Agricultural training, 1 = yes	815	0.37	0.48	0	1
Total family labourers	815	2.92	1.36	0	8
Share of female labourers	815	0.34	0.17	0	1
Household head age, years	815	58.40	8.94	27	87
Household head gender, 1 = female	815	0.04	0.19	0	1
Household head education, years	815	6.63	3.21	0	18
Household member as cadre, 1 = yes	815	0.11	0.31	0	1
Household dependency ratio	815	0.28	0.28	0	1
Price of rice, yuan/kg	815	2.52	0.34	1.46	5.00
Price of NPK fertilizer, yuan/kg	815	5.33	0.90	2.40	8.63
Double-season rice, 1 = yes	815	0.24	0.43	0	1
Land consolidation program (LCP), 1 = yes	815	0.51	0.50	0	1

Note: 1 mu = 0.067 ha.

Fig. 3 presents a zero-order correlation matrix heatmap of the key variables in the analysis. The heatmap reflects the strength and direction of the correlations between the variables. Most of the absolute values of the correlation coefficients are below 0.20, indicating that these variables are relatively independent of each other. Notably, a somewhat higher correlation is observed between patience and risk-taking (0.33). The mean variance inflation factor (VIF) of these key variables is 1.20 and the highest VIF is 1.50. As rule of thumb, VIF values larger than either 5 or 10 are generally used to detect multicollinearity. This suggests that multicollinearity is not a major concern in the data set used for the analysis. Fig. 3 also suggests that the correlation between economic preferences and organic fertilizer use is higher than the correlation between economic preferences and synthetic fertilizer use.

3.4. Empirical approach

3.4.1. Multivariate regression analysis

To test whether economic preferences predict Chinese farmers' fertilizer use decisions, we first conducted a multivariate regression

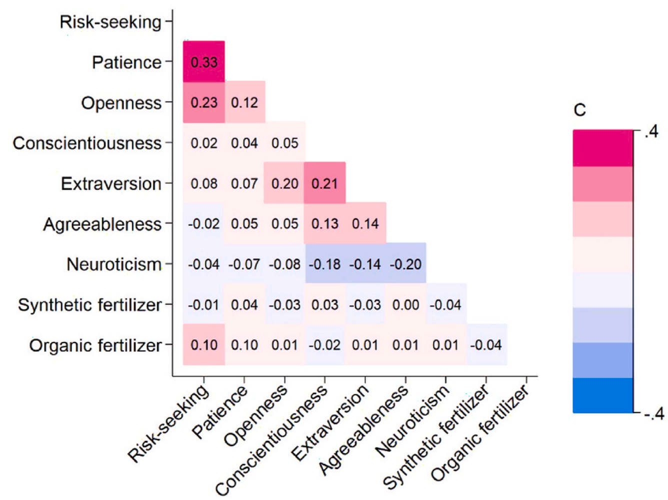

Fig. 3. Correlation matrix heatmap of key variables in the analysis.

analysis using the following models:

$$S_{ij} = \alpha_0 + \alpha_1 R_{ij} + \alpha_2 P_{ij} + \alpha_3^{'} BF_{ij} + \alpha_4^{'} Z_{ij} + \varepsilon_{ij}^{S} \tag{3.1}$$

$$O_{ij} = \beta_0 + \beta_1 R_{ij} + \beta_2 P_{ij} + \beta_3^{'} BF_{ij} + \beta_4^{'} Z_{ij} + \varepsilon_{ij}^{O} \tag{3.2}$$

where S_{ij} and O_{ij} represent the synthetic fertilizer use intensity and the adoption of organic fertilizer by farm household i residing in village j, respectively. R_{ij} and P_{ij} represent the measures of risk-seeking and patience, respectively. BF_{ij} is a vector of the Big Five personality traits. Z_{ij} is a vector of the control variables [9]. α_0, …, $\alpha_4^{'}$, β_0, …, $\beta_4^{'}$ are (vectors of) the coefficients we estimate and ε_{ij}^{S} and ε_{ij}^{O} are village-clustered robust error terms.

Equations (3.1) and (3.2) can be estimated using OLS and probit/logit regressions, respectively, as S_{ij} is a continuous variable and O_{ij} is a binary variable. However, to eliminate potential rare events bias, we estimate equation (3.2) using a rare event logit (or *relogit*) estimator in which the estimated probability of observing a case of organic fertilizer use is corrected upward (King and Zeng, 2001). The *relogit* model provides lower mean square errors and produces more rigorous estimates in cases where the event of interest is rare (Tomz et al., 2003), as is the case with organic fertilizer which is used by only eight percent of farmers in our sample.

3.4.2. Two-stage probit least squares model

Equations (3.1) and (3.2) can be independently estimated without bias if farmers are making separate decisions regarding the use of synthetic and organic fertilizers. However, since the nutrients from synthetic and organic fertilizers can partially substitute each other, farmers might make these decisions jointly, opting to use fewer synthetic fertilizers when utilizing organic fertilizers (Wang et al., 2018). This introduces the possibility of simultaneity biases, where the error terms in Equations (3.1) and (3.2) may be correlated, leading to biased estimates.

To account for this potential interactive relationship between using synthetic and organic fertilizers, we consider estimating two simultaneous equations, where equation (3.1) includes organic fertilizer use, and equation (3.2) includes synthetic fertilizer use as an additional explanatory variable. Considering that the intensity of synthetic fertilizer is a continuous variable and the adoption of organic fertilizer is a binary variable, we employed the two-stage probit least squares (TSPLS) model to obtain unbiased and consistent estimates (Maddala, 1983). In the first stage of the TSPLS model, OLS and probit regressions are used to jointly estimate Equations (3.1) and (3.2), respectively, and to derive the predicted values of the dependent variables. The second stage of the TSPLS model simultaneously estimates the following two equations:

$$S_{ij} = \gamma_0 + \gamma_1 \widehat{O_{ij}} + \gamma_2 R_{ij} + \gamma_3 P_{ij} + \gamma_4^{'} BF_{ij} + \gamma_5^{'} Z_{ij} + \upsilon_{ij}^{S} \tag{3.3}$$

$$O_{ij} = \delta_0 + \delta_1 \widehat{S_{ij}} + \delta_2 R_{ij} + \delta_3 P_{ij} + \delta_4^{'} BF_{ij} + \delta_5^{'} Z_{ij} + \upsilon_{ij}^{O} \tag{3.4}$$

where the predicted values, $\widehat{O_{ij}}$ and $\widehat{S_{ij}}$, estimated from the first stage are included in Equations (3.3) and (3.4). The standard errors of the equations in the second stage were corrected using a recalculation approach, following Keshk (2003).

To identify the simultaneous equation system, at least one independent variable, the so-called excluded instrument(s), must be included in one of the equations but not in the other in both stages. In the equation explaining S_{ij}, we used the synthetic fertilizer (NPK) price for this purpose. It is expected to have a direct effect on the intensity of synthetic fertilizer use but not on the use of organic fertilizers. Livestock ownership and manure use by other villagers serve a similar purpose in the equation for O_{ij}. They are strongly related to the use of organic manure but is not likely to directly affect the amount of synthetic fertilizer used (Place et al., 2003). An F-test on the excluded instruments in the first stage of the estimation was used to test for weak instruments.

4. Results

4.1. The role of preferences and personality traits for fertilizer use

Table 2 presents the estimation results of the multivariate regressions. Columns (1)–(3) report the results for the intensity of synthetic fertilizer use, and columns (4)–(6) report the results for organic fertilizer use. Columns (1) and (4) report the results with only economic preferences and province dummies as independent variables. Neither risk preferences nor time preferences are significantly related to the intensity of synthetic fertilizer use, but time preferences are significantly associated with the use of organic fertilizer ($b = 0.302$; $p = 0.036$). The estimated coefficient is positive, suggesting that more patient farmers are more likely to invest in soil quality by adding organic fertilizer. There is also a non-significant tendency for risk preferences to predict organic fertilizer use ($b = 0.308$; $p = 0.065$).

Columns (2) and (5) show the results from models with additional control variables and columns (3) and (6) present the results of the models that also include personality traits. Two main conclusions emerge. First, the estimated associations between time preferences and organic fertilizer use remain positive and statistically significant [$b = 0.323$; $p = 0.033$, based on column (6)]. Moreover, the associations between risk preferences and organic fertilizer use also become significant in models (5) and (6) [$b = 0.333$; $p = 0.038$, based on column (6)]. These associations suggest that risk-taking farmers are more willing to run the risk of introducing weeds and pests that may come with the use of organic fertilizers, in return for potentially higher yields. The associations between economic preferences and synthetic fertilizer use intensity remain insignificant. In essence, it is not surprising to observe that economic preferences play a more substantial role in determining a farmer's adoption of organic fertilizer rather than influencing the decision on the amount of synthetic fertilizer use. On the one hand, the intensity of synthetic fertilizers use is be more closely tied to socio-economic considerations, given their more immediate effects on crop yields. On the other hand, the adoption of organic fertilizers often involves greater uncertainty and longer time horizons. Farmers applying organic fertilizers may prioritize considerations such as the uncertain quality of organic inputs, the potential for increased risks of pests and diseases, and the longer time required for organic practices to yield results.

Second, contrary to our expectations, we do not find significant associations between personality traits and the use of synthetic fertilizer or organic fertilizer. A possible explanation for this finding is that, when

Table 2
Estimation results, OLS and relogit models.

	Intensity of synthetic fertilizer use, *OLS*			Organic fertilizer use, *relogit*		
	(1)	(2)	(3)	(4)	(5)	(6)
Risk-seeking	−0.524	−0.654	−0.616	0.308[a]	0.326[b]	0.333[b]
	(0.567)	(0.570)	(0.582)	(0.167)	(0.162)	(0.160)
Patience	0.768	0.599	0.575	0.302[b]	0.315[b]	0.323[b]
	(0.592)	(0.573)	(0.584)	(0.144)	(0.150)	(0.151)
Openness			−0.184			−0.038
			(0.360)			(0.162)
Conscientiousness			0.448			−0.121
			(0.470)			(0.144)
Extraversion			−0.363			0.053
			(0.494)			(0.143)
Agreeableness			−0.083			0.097
			(0.598)			(0.195)
Neuroticism			−0.396			0.102
			(0.465)			(0.178)
Contracted land size, mu		0.012	0.013		−0.015	−0.014
		(0.069)	(0.069)		(0.023)	(0.023)
Number of contracted plots		−0.260	−0.250		0.003	0.002
		(0.158)	(0.159)		(0.024)	(0.024)
Log (productive assets value)		−0.387	−0.401		0.129	0.135
		(0.303)	(0.312)		(0.107)	(0.109)
Zero productive assets		−5.336	−5.410		0.708	0.769
		(3.236)	(3.303)		(1.041)	(1.058)
Owning livestock, 1 = yes		0.626	0.675		0.798[c]	0.795[c]
		(1.086)	(1.094)		(0.290)	(0.286)
Manure use by other villagers, 1 = yes		0.174	0.086		0.919[b]	0.925[b]
		(1.237)	(1.242)		(0.394)	(0.393)
Credit access, 1 = yes		1.666[a]	1.636[a]		0.194	0.190
		(0.895)	(0.897)		(0.268)	(0.273)
Agricultural training, 1 = yes		−0.974	−0.849		−0.262	−0.267
		(0.951)	(0.961)		(0.340)	(0.338)
Total family labourers		−0.164	−0.159		−0.007	−0.010
		(0.343)	(0.345)		(0.119)	(0.119)
Share of female labourers		−8.519[b]	−8.240[b]		−0.668	−0.705
		(3.500)	(3.536)		(0.844)	(0.860)
Household head age, years		−0.012	−0.017		0.019	0.018
		(0.062)	(0.063)		(0.015)	(0.015)
Household head gender, 1 = female		5.635[b]	5.624[b]		0.614	0.616
		(2.448)	(2.424)		(0.722)	(0.711)
Household head education, years		−0.097	−0.091		0.011	0.010
		(0.160)	(0.162)		(0.042)	(0.042)
Household member as cadre, 1 = yes		1.587	1.437		−0.277	−0.251
		(1.644)	(1.664)		(0.386)	(0.381)
Household dependency ratio		−4.018[a]	−4.024[a]		−0.112	−0.085
		(2.291)	(2.297)		(0.643)	(0.632)
Price of rice, yuan/kg		−0.755	−0.726		−0.272	−0.264
		(1.199)	(1.244)		(0.498)	(0.508)
Price of NPK fertilizer, yuan/kg		−3.070[c]	−3.105[c]		0.024	0.032
		(0.626)	(0.621)		(0.149)	(0.147)
Double-season rice, 1 = yes		9.924[c]	9.845[c]		−0.054	−0.032
		(2.033)	(2.034)		(0.456)	(0.442)
Land consolidation program (LCP), 1 = yes		−2.307[b]	−2.222[a]		−0.046	−0.053
		(1.137)	(1.149)		(0.262)	(0.266)
Jiangsu Province	1.825	1.417	1.436	0.300	−0.069	−0.037
	(1.374)	(1.403)	(1.437)	(0.449)	(0.380)	(0.392)
Jiangxi Province	1.600	−4.252[b]	−4.032[b]	0.646	0.323	0.275
	(1.543)	(1.853)	(1.824)	(0.439)	(0.410)	(0.395)
Observations	815	815	815	815	815	815
(Pseudo) R-squared	0.006	0.164	0.168	0.037	0.073	0.076

Note: (1) Robust standard errors in parentheses,
(2) Variance Inflation Factors (VIF) of all independent variables (except for the province dummies) are calculated to test for multicollinearity. The mean VIF is 1.28 and the highest VIF value is 2.48, indicating multicollinearity appears not to be an issue in this study.
[a] $p < 0.1$.
[b] $p < 0.05$.
[c] $p < 0.01$. Average marginal effects are reported in columns (4)–(6).

compared to economic preferences, personality traits may be more distal from specific decision-making tasks (Dessart et al., 2019). Consequently, they are more effective in capturing habitual patterns of behaviour rather than narrowly defined economic decisions, such as a farmer's fertilizer use behaviour. As can be seen in Table A2 in the Supplementary Material, personality traits also do not predict fertilizer use when economic preferences and control variables are excluded from the model. As such, we do not find a direct association between personality traits and fertilizer use, and we can rule out that the associations between economic preferences and fertilizer use are mediated by personality traits. However, the strength of the associations between economic preferences and fertilizer use might depend on personality traits. To test for such moderation effects, we ran additional regression models in which we included the interaction between economic preferences and personality traits as predictors. This analysis does not reveal any significant moderation coefficients (see Tables A3-1 and A3-2 in the Supplementary Material).

To assess the reliability and consistency of our findings, we conducted two more robustness checks. First, instead of using the aggregated NPK amount, we use the aggregated amount of the main fertilizer nutrient, i.e., nitrogen (N), as an alternative measure of synthetic fertilizer use intensity. The corresponding results are presented in columns (1)–(2) of Table A4 in the Supplementary Material. Second, we examined whether restricting the sample to households growing only single-season rice would yield different results, considering potential systematic differences in techniques between single-season and double-season rice cultivation. Estimation results are reported in columns (3)–(6) of Table A4. Overall, we observe that the key findings from these robustness analyses align with those from the main models.

4.2. *Using synthetic versus organic fertilizers: are these decisions dependent on each other?*

To check the robustness of our main findings, we estimate the TSPLS model which takes into account that a farmer's synthetic and organic fertilizers use decisions may be interrelated. Table 3 reports the estimated coefficients for the simultaneous equations model using TSPLS. The F-statistics for the first-stage result of synthetic fertilizer use and organic fertilizer use models were 43.00 and 11.55, respectively. Using the "rule of thumb" threshold value of 10, this indicates that the instrumental variables cannot be considered as weak (Staiger and Stock, 1997) [10].

The results presented in Table 3 validate the key findings of the OLS/relogit estimation discussed in Section 4.1. Specifically, farmers' risk-seeking behaviour and patience significantly influenced their decisions regarding organic fertilizer use (joint test of significance p-value = 0.001), but they did not have significant impact on the use of synthetic fertilizer. Personality traits were found to be non-significant in influencing fertilizer use decisions. Additionally, the estimated coefficients of organic fertilizer in the synthetic fertilizer use regression and synthetic fertilizer use in the organic fertilizer use regression were not significantly different from zero. This suggests that farmers' choices regarding synthetic and organic fertilizers in rice production are not interdependent. In other words, organic fertilizers are not yet employed as substitutes by rice farmers to decrease the quantity of synthetic fertilizer used; instead, they are perceived as supplements and only sporadically used in rice production.

Table 3
Estimation results, two-stage probit least squares model.

	Intensity of synthetic fertilizer use	Organic fertilizer use
Organic fertilizer use	0.608	
	(1.387)	
Intensity of synthetic fertilizers use		−0.004
		(0.025)
Risk-seeking	−0.816	0.193[b]
	(0.633)	(0.093)
Patience	0.456	0.185[b]
	(0.598)	(0.089)
Contracted land size, mu	0.098	−0.013
	(0.080)	(0.015)
Number of contracted plots	−0.331[c]	0.001
	(0.116)	(0.020)
Log (productive assets value)	−0.351	0.067
	(0.336)	(0.051)
Zero productive assets	−5.697[a]	0.369
	(3.120)	(0.500)
Owning livestock, 1 = yes		0.428[c]
		(0.152)
Manure use by other villagers, 1 = yes		0.521[c]
		(0.141)
Credit access, 1 = yes	1.746[a]	0.081
	(1.049)	(0.168)
Agricultural training, 1 = yes	0.461	−0.190
	(1.023)	(0.166)
Total family labourers	−0.386	0.008
	(0.356)	(0.057)
Share of female labourers	−7.837[b]	−0.534
	(3.619)	(0.615)
Household head age, years	0.012	0.010
	(0.057)	(0.009)
Household head gender, 1 = female	5.329[b]	0.309
	(2.316)	(0.383)
Household head education, years	−0.033	−0.005
	(0.143)	(0.023)
Household member as cadre, 1 = yes	1.720	−0.159
	(1.425)	(0.244)
Household dependency ratio	−4.759[b]	−0.074
	(2.354)	(0.400)
Price of rice, yuan/kg	−0.771	−0.192
	(1.317)	(0.219)
Price of NPK fertilizer, yuan/kg	−3.036[c]	
	(0.473)	
Double-season rice, 1 = yes	6.714[c]	0.088
	(1.170)	(0.245)
Land consolidation program (LCP), 1 = yes	−1.562[a]	−0.051
	(0.883)	(0.149)
Personality traits (OCEAN)	Yes	Yes
Province dummies	Yes	Yes
Observations	815	815

Note: Corrected standard errors in parentheses
[a] $p < 0.1$.
[b] $p < 0.05$.
[c] $p < 0.01$.

5. Discussion and conclusion

In this study, we investigated whether risk preferences, time preferences, and personality traits are associated with the use of synthetic and organic fertilizers by Chinese rice farmers. We find that risk-seeking and patient farmers are more likely to use organic fertilizers than risk-averse and impatient farmers. However, economic preferences do not significantly affect synthetic fertilizer use. Personality traits do not play a significant, direct, or indirect (through moderating the effects of preferences) role in fertilizer-use decisions. Additionally, we find that organic fertilizers complement rather than substitute the use of synthetic fertilizers in Chinese rice production.

Our study contributes to the literature on behavioural factors that explain farmers' decisions to use synthetic and organic fertilizers in arable farming. Our finding that risk preferences does not affect synthetic fertilizer use by Chinese rice farmers contrasts with the result of Khor et al. (2018), who found a significant relationship between risk preferences and synthetic fertilizer use in Vietnam. These seemingly conflicting findings may be related to the differences in wealth, off-farm employment opportunities, or other options for risk management between the two countries. In addition, the decision to use synthetic fertilizer may be perceived as less risky in China than in other countries because synthetic fertilizer has been used in rice production for many years all over the country, and agricultural support measures have also considerably reduced and stabilized the marginal costs of using synthetic fertilizer (Li et al., 2014). The present study also adds to the existing literature on the relationship between risk and time preferences and pro-environmental behaviour (Fuhrmann-Riebel et al., 2021; Lades et al., 2021) by demonstrating that risk-seeking and patient farmers are more likely to use organic fertilizers. The results on organic fertilizer use imply that investments in sustainable and environmentally friendly practices may not appeal to traditional farmers, as behavioural characteristics such as being risk-averse and myopic may intrinsically prevent them from considering the externalities associated with using synthetic fertilizers.

These findings have several policy implications. First, policies that mitigate farmers' perceived exposure to risks associated with the adoption of organic fertilizers may be an effective means to encourage organic fertilizer use. For instance, crop farmers tend to express concerns about the uncertain quality of organic fertilizers and the potential for increased risks of having pests and diseases resulting from their application (Zhang et al., 2021; 2022). Addressing these concerns necessitates the establishment of a well-functioning system for distributing organic fertilizers. This involves collaborative efforts among stakeholders, including the development of industrial standards and regulatory frameworks, enhancements in storage and application techniques, incentives for the development of machinery for organic fertilization, and the provision of comprehensive information on composition along with scientific advisory services. Second, there may be value in education programs that highlight the long-term benefits of organic fertilizer use and aim to reduce high subjective discount rates among farmers (Bauer and Chytilová, 2010).

A few limitations of our research are noteworthy. First, we lack information on the quantity and specific type of organic fertilizer used by farmers, thereby limiting our analysis to whether organic fertilizer was adopted. Second, the economic preferences and personality traits used in this study were obtained from respondents who were interviewed. In most cases (over 90%), the respondent was the head of the household, who was likely to play a major role in household farming decisions. However, no information was obtained about the preferences and personality traits of other household members who may have affected these decisions.

6. Notes

[1] Openness to experience is a trait that describes a person's degree of creativity, imagination, and originality. Conscientiousness characterizes a person's degree of organization, persistence, and responsibility. Extraversion reflects an individual's tendency to be positive, enthusiastic, or social. Agreeableness is linked to friendliness, altruism, and co-operation. Neuroticism is associated with negative emotions such as anxiety, depression, and negative affect (John and Srivastava, 1999).

[2] The total number of households renting in or renting out land was less than four in some of the selected villages. As a result, 1420 households instead of 1440 were interviewed in total.

[3] For 90.8% of these households, the household head responded to the survey.

[4] 1 mu = 0.067 ha.

[5] In rural China, the village committee allocates arable land to farm households in the village. Farm households do not own this so-called contracted land but are granted long-term use rights to it.

[6] Information about NPK content was written on fertilizer bags purchased by a farm household.

[7] The LCP in rural China is a policy intervention aimed at improving the effectiveness of land cultivation and facilitating environmental management by reducing fragmentation and improving the agricultural infrastructure (Zhang et al., 2014).

[8] One yuan (CNY) corresponded to approximate 0.15 USD in February 2019.

[9] We followed Battese (1997) to deal with households that possess no productive assets. The zero value for households not owning productive assets was replaced by one, and a dummy variable that equals one for those households and zero otherwise was added to the model. Conventional methods to deal with zero values before log transformation (e.g., simply replacing zero observations by one) may result in biased estimators, especially when zero observations take a large proportion of the sample (Battese, 1997).

[10] The first-stage regression results can be found in Table A5 in the Supplementary Material.

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Ethical compliance

All procedures performed in studies involving human participants were in accordance with the ethical standards of Wageningen University and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Chen Qian: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. **Gerrit Antonides:** Conceptualization, Supervision, Writing – review & editing. **Xueqin Zhu:** Methodology, Supervision, Writing – review & editing. **Nico Heerink:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing. **Leonhard K. Lades:** Conceptualization, Methodology, Visualization, Writing – review & editing.

Appendix A. Supplementary data

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References

Ali, D. A., Bowen, D., & Deininger, K. (2019). Personality traits, technology adoption, and technical efficiency: Evidence from smallholder rice farms in Ghana. *Journal of Development Studies, 56*(7), 1330–1348.

Almlund, M., Duckworth, A. L., Heckman, J., & Kautz, T. (2011). *Personality psychology and economics* (Vol. 4, pp. 1–181). Handb. Econ. Edu..

Ayhan, S. H., Gatskova, K., & Lehmann, H. (2020). The impact of non-cognitive skills and risk preferences on rural-to-urban migration in Ukraine. *Journal of Comparative Economics, 48*(1), 144–162.

Battese, G. E. (1997). A note on the estimation of Cobb-Douglas production functions when some explanatory variables have zero values. *Journal of Agricultural Economics, 48*(1-3), 250–252.

Bauer, M., & Chytilová, J. (2010). The impact of education on subjective discount rate in Ugandan villages. *Economic Development and Cultural Change, 58*(4), 643–669.

Becker, A., Deckers, T., Dohmen, T., Falk, A., & Kosse, F. (2012). The relationship between economic preferences and psychological personality measures. *Annu. Rev. Econ., 4*, 453–478.

Binswanger, H. P. (1980). Attitudes toward risk: Experimental measurement in rural India. *American Journal of Agricultural Economics, 62*(3), 395–407.

Borghans, L., Duckworth, A. L., Heckman, J. J., & Ter Weel, B. (2008). The economics and psychology of personality traits. *Journal of Human Resources, 43*(4), 972–1059.

Chadwick, D., Wei, J., Yan'an, T., Guanghui, Y., Qirong, S., & Qing, C. (2015). Improving manure nutrient management towards sustainable agricultural intensification in China. *Agriculture, Ecosystems & Environment, 209*, 34–46.

Costa Jr, P. T., & McCrae, R. R. (1992). Four ways five factors are basic. *Personality and Individual Differences, 13*(6), 653–665.

Daly, M., Harmon, C. P., & Delaney, L. (2009). Psychological and biological foundations of time preference. *Journal of the European Economic Association, 7*(2–3), 659–669.

De Janvry, A., & Sadoulet, E. (2006). Progress in the modeling of rural households' behaviour under market failures. In A. De Janvry, & R. Kanbur (Eds.), *Poverty, inequality and development: Essay in honor of erik thorbecks*. New York: Springer.

Dick, W. A., & Gregorich, E. G. (2004). Developing and maintaining soil organic matter levels. In P. Schonning, S. Elmbolt, & B. T. Christensen (Eds.), *Managing soil quality: Challenges in modern agriculture*. Wallingford: CAB International.

Dohmen, T., Falk, A., Huffman, D., & Sunde, U. (2010). Are risk aversion and impatience related to cognitive ability? *The American Economic Review, 100*(3), 1238–1260.

Donato, K., Miller, G., Mohanan, M., Truskinovsky, Y., & Vera-Hernández, M. (2017). Personality traits and performance contracts: Evidence from a field experiment among maternity care providers in India. *The American Economic Review, 107*(5), 506–510.

Duflo, E., Kremer, M., & Robinson, J. (2011). Nudging farmers to use fertilizer: Theory and experimental evidence from Kenya. *The American Economic Review, 101*(6), 2350–2390.

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. New York: Oxford University Press.

Falk, A., Becker, A., Dohmen, T., Enke, B., Huffman, D., & Sunde, U. (2018). Global evidence on economic preferences. *Quarterly Journal of Economics, 133*(4), 1645–1692.

Falk, A., Becker, A., Dohmen, T. J., Huffman, D., & Sunde, U. (2016). *The preference survey module: A validated instrument for measuring risk, time, and social preferences*. New York: Mimeo.

Fuhrmann-Riebel, H., D'Exelle, B., & Verschoor, A. (2021). The role of preferences for pro-environmental behaviour among urban middle-class households in Peru. *Ecological Economy, 180*, Article 106850.

Guo, Y., Chen, Y., Searchinger, T. D., Zhou, M., Pan, D., Yang, J., … Mauzerall, D. L. (2020). Air quality, nitrogen use efficiency and food security in China are improved by cost-effective agricultural nitrogen management. *Nature Food, 1*(10), 648–658.

Hong, Y., Heerink, N., & van der Werf, W. (2020). Farm size and smallholders' use of intercropping in Northwest China. *Land Use Policy, 99*, Article 105004.

Huang, J., & Yang, G. (2017). Understanding recent challenges and new food policy in China. *Global Food Security, 12*, 119–126.

Jacoby, H. G., Li, G., & Rozelle, S. (2002). Hazards of expropriation: Tenure insecurity and investment in rural China. *The American Economic Review, 92*(5), 1420–1447.

Jin, S., Zhang, B., Wu, B., Han, D., Hu, Y., Ren, C., … Chen, J. (2021). Decoupling livestock and crop production at the household level in China. *Nature Sustainability, 4* (1), 48–55.

John, O. P., & Srivastava, S. (1999). The Big Five trait taxonomy: History, measurement, and theoretical perspectives. *Handboek Personenbelastingen: Theory Res., 2*(1999), 102–138.

Keshk, O. M. (2003). CDSIMEQ: A program to implement two-stage probit least squares. *STATA Journal, 3*(2), 157–167.

Khor, L. Y., Ufer, S., Nielsen, T., & Zeller, M. (2018). Impact of risk aversion on fertilizer use: Evidence from Vietnam. *Oxford Development Studies, 46*(4), 483–496.

King, G., & Zeng, L. (2001). Logistic regression in rare events data. *Political Analysis, 9*(2), 137–163.

Lades, L. K., Laffan, K., & Weber, T. O. (2021). Do economic preferences predict pro-environmental behaviour? *Ecological Economy, 183*, Article 106977.

Le Cotty, T., Maître d'Hôtel, E., Soubeyran, R., & Subervie, J. (2018). Linking risk aversion, time preference and fertilizer use in Burkina Faso. *Journal of Development Studies, 54*(11), 1991–2006.

Li, Y., Kahrl, F., Pan, J., Roland-Holst, D., Su, Y., Wilkes, A., & Xu, J. (2012). Fertilizer use patterns in Yunnan Province, China: Implications for agricultural and environmental policy. *Agricultural Systems, 110*, 78–89.

Li, S., Zhang, Y., Nadolnyak, D., Wesley, J. D., & Zhang, Y. (2014). Fertilizer industry subsidies in China: Who are the beneficiaries? *China Agricultural Economic Review, 6* (3), 433–451.

Maddala, G. S. (1983). *Limited-dependent and qualitative variables in econometrics*. Cambridge: Cambridge University Press.

Marenya, P. P., & Barrett, C. B. (2009). Soil quality and fertilizer use rates among smallholder farmers in western Kenya. *Agricultural Economics, 40*(5), 561–572.

Menegat, S., Ledo, A., & Tirado, R. (2022). Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. *Scientific Reports, 12*(1), Article 14490.

Moe, K., Htwe, A. Z., Thu, T. T. P., Kajihara, Y., & Yamakawa, T. (2019). Effects on NPK status, growth, dry matter and yield of rice (Oryza sativa) by organic fertilizer applied in field condition. *Agriculture and Forestry, 9*(5), 109.

Place, F., Barrett, C. B., Freeman, H. A., Ramisch, J. J., & Vanlauwe, B. (2003). Prospects for integrated soil fertility management using organic and inorganic inputs: Evidence from smallholder african agricultural systems. *Food Policy, 28*(4), 365–378.

Qian, C., Li, F., Antonides, G., Heerink, N., Ma, X., & Li, X. (2020). Effect of personality traits on smallholders' land renting behaviour: Theory and evidence from the North China Plain. *China Economic Review, 62*, Article 101510.

Rammstedt, B., & John, O. P. (2007). Measuring personality in one minute or less: A 10-item short version of the Big five inventory in English and German. *Journal of Research in Personality, 41*(1), 203–212.

Roberts, B. W. (2009). Back to the future: Personality and assessment and personality development. *Journal of Research in Personality, 43*(2), 137–145.

Roosen, J., & Hennessy, D. A. (2003). Tests for the role of risk aversion on input use. *American Journal of Agricultural Economics, 85*(1), 30–43.

Rustichini, A., DeYoung, C. G., Anderson, J. E., & Burks, S. V. (2016). Toward the integration of personality theory and decision theory in explaining economic behaviour: An experimental investigation. *J. Behav. Exp. Econ., 64*, 122–137.

Schröder, D., & Gilboa Freedman, G. (2020). Decision making under uncertainty: The relation between economic preferences and psychological personality traits. *Theory and Decision, 89*(1), 61–83.

Smith, L. E., & Siciliano, G. (2015). A comprehensive review of constraints to improved management of fertilizer in China and mitigation of diffuse water pollution from agriculture. *Agriculture, Ecosystems & Environment, 209*, 15–25.

Staiger, D., & Stock, J. H. (1997). Instrumental variables regression with weak instruments. *Econometrica*, 557–586.

Stuart, D., Schewe, R. L., & McDermott, M. (2014). Reducing nitrogen fertilizer application as a climate change mitigation strategy: Understanding farmer decision-making and potential barriers to change in the US. *Land Use Policy, 36*, 210–218.

Tomz, M., King, G., & Zeng, L. (2003). ReLogit: Rare events logistic regression. *Journal of Statistical Software, 8*, 1–27.

Van Wesenbeeck, C. F. A., Keyzer, M. A., Van Veen, W. C. M., & Qiu, H. (2021). Can China's overuse of fertilizer be reduced without threatening food security and farm incomes? *Agricultural Systems, 190*, Article 103093.

Wang, Y., Zhu, Y., Zhang, S., & Wang, Y. (2018). What could promote farmers to replace chemical fertilizer with organic fertilizer? *Journal of Cleaner Production, 199*, 882–890.

Westjohn, S. A., Singh, N., & Magnusson, P. (2012). Responsiveness to global and local consumer culture positioning: A personality and collective identity perspective. *Journal of International Marketing, 20*(1), 58–73.

Wu, Y. (2011). Chemical fertilizer use efficiency and its determinants in China's farming sector: Implications for environmental protection. *China Agricultural Economic Review, 3*(2), 117–130.

Wuepper, D., Bukchin-Peles, S., Just, D., & Zilberman, D. (2023). Behavioral agricultural economics. *Applied Economic Perspectives and Policy*, Article 13343.

Zhang, T., Hou, Y., Meng, T., Ma, Y., Tan, M., Zhang, F., & Oenema, O. (2021). Replacing synthetic fertilizer by manure requires adjusted technology and incentives: A farm survey across China. *Resources, Conservation and Recycling, 168*, Article 105301.

Zhang, C., Liu, S., Wu, S., Jin, S., Reis, S., Liu, H., & Gu, B. (2019). Rebuilding the linkage between livestock and cropland to mitigate agricultural pollution in China. *Resources, Conservation and Recycling, 144*, 65–73.

Zhang, T., Meng, T., Hou, Y., Huang, X., & Oenema, O. (2022). Which policy is preferred by crop farmers when replacing synthetic fertilizers by manure? A choice experiment in China. *Resources, Conservation and Recycling, 180*, Article 106176.

Zhang, Z., Zhao, W., & Gu, X. (2014). Changes resulting from a land consolidation project (LCP) and its resource–environment effects: A case study in tianmen city of hubei province, China. *Land Use Policy, 40*, 74–82.

Zhou, Y., Yang, H., Mosler, H. J., & Abbaspour, K. C. (2010). Factors affecting farmers' decisions on fertilizer use: A case study for the chaobai watershed in northern China. *Consilience*, (4), 80–102.