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Farmers' Risk Preferences and Pesticide Use Decisions: Evidence from Field Experiments in China

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Abstract

China faces health and environmental problems resulting from the use of agricultural chemicals, including pesticides. While other authors have found that risk aversion affects pesticide use in China, previous studies have focused primarily on commercial cotton farmers. In this study, we consider the case of smaller, semi-subsistence and subsistence farmers in a poor and landlocked province of China (Yunnan). We use a field experiment to measure risk aversion and collect detailed data on farm production and input use to specifically ask whether risk aversion affects pesticide use, and whether this effect differs for subsistence farmers producing exclusively for home consumption versus semi-subsistence farmers who produce both for home and the market. We find that risk aversion significantly increased pesticide use, particularly for subsistence farmers and for market plots by semi-subsistence farmers. Further, this effect of risk aversion significantly decreased with farm size for subsistence farmers, but not for semi-subsistence farmers, implying that pesticides may be used to ensure sufficient food supply for home consumption. Finally, we find barriers to the use of pesticides for subsistence farmers, both in terms of financial constraints and economies of scale. Given these different motivations for pesticide use, policy-makers may wish to consider effective tools to support rural food security for farmers in the poorer regions of China in order to decrease the intensity of pesticide use.

Keywords: risk aversion, pesticide use, subsistence farmers, food security, China

1. Introduction

China is the world's largest user of pesticides and its use is rapidly growing, along with associated human and environmental health concerns. From 1999 to 2012, China's annual pesticide use increased from 1.32 million tons to 1.81 million tons, an annual increase of 2.7% (China Statistical Yearbooks, 2010, 2013). Pesticides are known to be linked to human health and environmental problems in China and have been shown to be a cause of deteriorating water quality and poisoning in farmers (Huang and Rozelle, 1995; Huang et al., 2003; Zhu et al., 2003; Wu and Chen, 2004; Hu et al. 2007; Huang et al., 2008; Patton, 2014; Atreya et al., 2011). Pesticides have also induced pest resistance that is decreasing the effectiveness of pest-resistant Chinese-bred plant varieties (Hu et al, 2002; Pray et al., 2002; Chen et al., 2013). Thus, addressing the problem of farmer's overuse or misuse of agricultural pesticides is a major challenge faced by China (Huang et al., 2003; Chen et al., 2013; Liu and Huang, 2013).

Most research on pesticide use in China has focused on commercial farmers, specifically commercial cotton producers (Chen et al., 2013; Jin et al. 2014; Liu and Huang, 2013). This work has found that Chinese farmers' pesticide use is driven by a lack of knowledge of pest management and pesticide use (Chen et al., 2013), inadequate extension services, distorted information on pesticides (Jin et al., 2014), and risk aversion (Liu and Huang, 2013). In our paper, we explore pesticide use by semi-subsistence[1] and subsistence farmers, where the former produce both for market and home consumption and the latter produce exclusively for home consumption.

[1] Semi-subsistence farmers are loosely defined as farmers who cultivate small-scale farm land primarily for their own consumption, while selling a small fraction of their output (Davidova et al., 2013). Typically, semi-subsistence farmers have relatively small plots, a relatively low degree of market participation, limited cash income, a lack of capital, and inefficient land and labor practices (Davidova et al., 2013).

Specifically, we ask whether risk aversion affects their pesticide use decisions, whether this effect differs between farmer types and whether it differs on food grown for home consumption versus food grown for the market.

Although agricultural commercialization has often been blamed for the increased use of pesticides in China (e.g. Ecobichon, 2001), semi-subsistence and subsistence farmers, especially those living in poorer regions of China, may be pressed to have enough food to eat and, therefore, use pesticides intensively to stabilize food production for home consumption. Chinese farm sizes are small, averaging 0.50 ha/family (Ministry of Land and Resources, 2014), and semi-subsistence and subsistence farmers comprise a large fraction of the 70.2 million rural people living under the national poverty line in 2014 (where the poverty line is defined as an annual per capita income of less than 2,300 yuan at 2010 constant prices) (National Statistical Bureau, 2015). Small-scale semi-subsistence and subsistence farmers in China are like many small-holder farmers in developing countries in that they play a key role in securing food supply (Fan et al., 2013), but may lack knowledge of the correct and safe use of pesticides and have limited resources to purchase equipment and supplies for the proper use of pesticides (Atreya et al., 2011). Hence, understanding the drivers of these farmers' pesticide use decisions may help Chinese governments design programs to encourage them to use pesticides more efficiently, limiting some of the detrimental side-effects on the environment and their health. Nonetheless, empirical evidence on their pesticide use and its determinants is generally scant.

Farmers who grow food for the market may behave differently than those farmers producing food exclusively for home consumption. Farmers growing for the market may be more concerned about stabilizing income from their commercial production, whereas subsistence farmers may be specifically concerned about ensuring food security. These differences may occur between farmer types, or between different types of plots, where some plots are used to grow food for their home consumption (*hereafter referred to as "consumption plots*") as compared to plots where food is grown for the market (*hereafter referred to as "market plots*"). One might anticipate that, on the market plots, semi-subsistence farmers behave more like their larger, commercial counterparts. Further, one might also anticipate that some farmers, particularly wealthier households, may cultivate family plots with the primary concern of food safety and health.

The study has two main objectives: [1] to analyze the effect of semi-subsistence and subsistence farmers' risk preferences, farm size and other household socio-economic characteristics on pesticide use decisions; and [2] to compare the effect of risk preferences across types of farmers and types of plots.

The empirical strategy used for this study follows the theoretical models of Just and Zilberman (1983) and Knight et al. (2003) who consider the role played by risk in farmers' pesticide use decisions (e.g. Just and Pope, 1978; Pope and Kramer, 1979; Coady 1993; Horowitz and Lichtenberg, 1993; Babcock and Shogren, 1995; Isik and Khanna, 2003; Knight et al., 2003). From these models, we derive hypotheses that predict how farm size may affect how risk aversion differentially affects pesticide use by subsistence versus more semi-subsistence farmers. Then, to test these hypotheses, we conduct a field experiment to measure risk aversion along with a household survey in Yunnan, China, an underdeveloped region populated by relatively poor, small-holder farmers.

2. Risk aversion and agricultural production decisions

Just and Zilberman (1983) develop a model to explain farmer input decisions under risk, using a framework of technology adoption with production uncertainty. In their model, they assume that the adoption of a new production technology requires a fixed cost of adoption and, therefore, farmers may choose not to adopt a new technology when their farm size is below some critical level. In other words, the fixed adoption cost could discourage the adoption of new production technologies on small farms.

Just and Zilberman (1983) model the production of crops using alternative rates of modern inputs (e.g. fertilizer and pesticides) as alternative portfolio choices. Thus, the intensity of the modern input use depends on: [1] the riskiness of the modern input, i.e. whether it is risk increasing, reducing or has no effect on risk; and [2] the characteristics of farmers' relative (or absolute) risk aversion, i.e., whether it is decreasing, constant, or increasing. They hold that, because pesticides are risk-reducing, an area with less intensive pesticides could be considered as a "more risky asset" with a more variable crop output. Following their logic, when farmers have a smaller area of farmland, they may be willing to pay a higher premium to avoid risk in their production, i.e. they tend to apply pesticides more intensively to stabilize production. As a result, they hold a relatively smaller portion of the plots without pesticides. In contrast, when farmers hold more farmland, they may be able to afford to absorb a greater yield shock and can hold a higher portion of plots without pesticides.

Knight et al. (2003) show that under risky conditions, farmers may make tradeoffs between expected income and security (smaller variance of income). On one hand, many households struggle to meet their own subsistence needs and have limited capacity to absorb risk when facing income shortfalls. On the other hand, their longterm food security requires them to produce a surplus which can be invested or saved. Thus, they have a necessary minimum level of food security, and will be willing to trade off future expected income to ensure that sufficient food production. Applying their model to the context of pesticide use decisions of farmers in poor regions, it can be reasonably speculated that even though farmers may know that costly pesticide use might reduce their expected income, they would still decide to use pesticides on consumption-oriented plots to avoid a potential shortfall in crop production.

From the above models, we get the following testable hypotheses: [1] more risk averse farmers are likely to use more pesticides; [2] due to the fixed costs of pesticide use, farmers with more farm land are more likely to use pesticides; and [3] the relation between risk aversion and pesticide use may decrease with farm size, particularly for subsistence farmers.

3. Field experiment and survey design

In the fall of 2007, we conducted risk experiments[2] and surveys in 30 villages in six targeted counties located in different regions of Yunnan Province. Yunnan represents a number of regions in western China, where most of China's poorest people reside. Taking 2012 as an example, among 592 national-level poverty stricken counties[3], 375 (63%) are located in western China. Yunnan has the highest number of national-level poverty stricken counties (73 counties, 12% of 592), followed by

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[2] Risk aversion has been measured using econometric and experimental methods. The econometric method was used to empirically derive farmers' risk preferences from their observed behavior and socio-economic characteristics (Moscardi and de Janvry, 1977, Antle 1987, 1988). The econometric method has a drawback of confounding risk behavior with farmers' resource constraints (Eswaran and Kotwal 1990; Wik et al. 2004). Alternately, the experimental method has come under criticism for its lack of external validity (Carpenter, 2002; Lusk et al., 2006).

[3] The national-level poverty stricken counties are defined according to annual income per capita, i.e counties having an annual per capita income below RMB 2,300 yuan (using 210 constant price), i.e. a per capita income of one dollar a day, are listed as national-level poverty stricken counties.

Guizhou (50 counties) and Shaanxi (50 counties), both in western China (The State Council Leading Group Office of Poverty Relief and Development, 2012).

In each county, we randomly selected five administrative villages. In each administrative village, ten households were randomly chosen from rosters kept by village leaders. The family head from each selected household was asked to participate in the survey and the risk experiment. In total, 300 family heads from 30 administrative villages were surveyed and participated in risk experiments.

3.1. Survey designs

The household surveys were conducted prior to the risk experiments. They were used to collect the following information: [1] household demographic and socio-economic characteristics; [2] the total area of farm operated by the farmers' households; [3] the types of crops planted in 2006 and the corresponding sown area for each type of crop; and [4] the expenditures for various types of input for each crop, including chemical fertilizers, pesticides, seeds, labor, and machinery.

The village-level surveys were conducted with village leaders. They were used to collect information regarding village demographic, socio-economic, and other characteristics. Information on village geographic characteristics was collected using GPS equipment.

3.2. Experimental design

In the risk experiment, we were able to measure risk preferences through direct observations on choices made by the participating subjects over different lotteries that have different expected payoffs and variances (Bingswanger, 1980; Grisley, 1980; Holt and Laury, 2002; Schechter, 2003; Hills, 2009; Liu and Huang, 2013). Our experimental design followed Holt and Laury (2002), with minor modifications to keep our payments in round numbers. Table 1 presents the 10 pair-wise lotteries used (detailed information on steps taken in the experiments and the experimental protocol are presented in the Appendix).

Table 1

The ten pair-wise lotteries

Decision	Option A (low-risk) (Probabilities and Payoffs)	Option B (high-risk) (Probabilities and Payoffs)	Difference in Expected Payoff
1	1/10 of ¥20, 9/10 of ¥16	1/10 of ¥35, 9/10 of ¥5	¥ 8.4
2	2/10 of ¥20, 8/10 of ¥16	2/10 of ¥35, 8/10 of ¥5	¥ 5.8
3	3/10 of ¥20, 7/10 of ¥16	3/10 of ¥35, 7/10 of ¥5	¥ 3.2
4	4/10 of ¥20, 6/10 of ¥16	4/10 of ¥35, 6/10 of ¥5	¥ 0.6
5	5/10 of ¥20, 5/10 of ¥16	5/10 of ¥35, 5/10 of ¥5	¥ -2.0
6	6/10 of ¥20, 4/10 of ¥16	6/10 of ¥35, 4/10 of ¥5	¥ -4.6
7	7/10 of ¥20, 3/10 of ¥16	7/10 of ¥35, 3/10 of ¥5	¥ -7.2
8	8/10 of ¥20, 2/10 of ¥16	8/10 of ¥35, 2/10 of ¥5	¥ -9.8
9	9/10 of ¥20, 1/10 of ¥16	9/10 of ¥35, 1/10 of ¥5	¥ -12.4
10	10/10 of ¥20, 0/10 of ¥16	10/10 of ¥35, 0/10 of ¥5	¥ -15

Notes: ¥ = RMB yuan

In Table 1, both options A and B have high and low payoffs, but option B has a higher risk (variance), since its payoffs (RMB 35 yuan and RMB 5 yuan) are more variable than the payoffs for option A (RMB 20 yuan and RMB 16 yuan). Therefore, option A is considered a relatively safe choice and option B a risky choice. However, as the questions progress, the expected value of option B increases relative to that of option A. Column 3 (Table 1) gives the difference in expected payoffs between the two options for each lottery.

We assess a subject's risk-preferences by observing the choice at which a subject switched from option A to B in our risk experiments. A risk neutral subject who maximized the expected payoffs would be expected to switch to option B, once its expected payoffs exceeded those of A (at decision 5). Therefore, a risk-neutral subject would prefer to choose four "safe choices" (i.e. option A), a risk-taker would choose less than four safe choices, and a risk-averse subject would choose more than four safe choices.

4. Summary Statistics

In total, we were able to elicit risk-preferences for 295 subjects. Of them, 25 (8%) switched back and forth between options A and B more than once, indicating potentially inconsistent risk preferences, while the other 270 subjects switched over to option B only once. We used those 270 consistent subjects for the main model specifications in our econometric analysis, while excluding those 25 "inconsistent" subjects to minimize the potential errors made by the subjects (Harless and Camerer 1994; Hey and Orme 1994; Carbone and Hey 2000).

Table 2 presents the summary statistics for the outcomes of our risk experiments for all 295 subjects and the 270 consistent ones. Subjects participating in our risk experiments were risk averse on average, which echoed the findings of Young (1979) that farmers in developing countries can be assumed to be risk averse. For all 295 subjects in our experiments, they chose an average number of 5.34 safe choices, 1.34 safe choices more than the risk-neutral level of four safe choices. A little over half (165 or 56%) chose more than five to nine safe choices, while roughly one-third (92) of them chose less than four safe choices (Table 2). The 270 consistent subjects chose an average number of 5.49 safe choices; about 60% (163) of them chose five to nine safe choices, while 26% (71) of them chose one to three safe choices. About 22% (62) of them were extremely risk averse as they chose nine safe choices. Only 3% (7) of them were extremely risk-loving and did not choose any safe choices.

Table 2

Outcomes of the risk experiments

No of Safe Choices	All Subjects		Consistent Subjects	
	Frequency	Percent	Frequency	Percent
0-3	92	31	71	26
4	38	13	36	13
5-9	165	56	163	60
Average no of safe choices	5.23 (2.67)		5.49 (2.60)	

Notes: Standard errors are given in parenthesis.

The surveyed villages were very remote as shown by key village characteristics in Table 3. The 30 surveyed villages have an average altitude of about 1,546 meters and are relatively far away (41 km on average) from the county seats, the political and cultural center of the counties. The average distance from these villages to the nearest towns, the local marketplaces, is about 9 km. Some villages are very remote at a distance of 82 km from the county's seat or almost 45 km from the nearest town. In 2006, three (10% of 30) villages in one county did not yet have access to electricity. Given the remote location, one may reasonably anticipate that some villagers may primarily cultivate their farm plots to produce food for their families.

Table 3

Surveyed village characteristics (2006)

Variables	Mean	Std. Dev.	Min	Max
No of families living in the village	548.00	248.00	143	1212
Village altitude (m)	1566.25	423.95	893	2201
Distance to county seats (km)	40.94	21.42	0	82
Distance to the nearest towns (km)	8.89	10.39	0	44.5
Access to electricity (1 = yes)	0.92	0.27	0	1
No of surveyed villages		30		

For those 270 survey respondents who made consistent choices in the risk experiments, only 259 of them were able to provide the cost information of their family's pesticide use. Almost all 259 respondents' families were small-scale subsistence farmers or semi-subsistence farmers, who have a very low degree of market participation. Their families cultivated 995 plots in total. Among these 259 respondents' families, only one family, who cultivated one plot in total, was completely engaged in commercial farming. Ninety-five (36% of 259) families were subsistence farmers, who cultivated 287 plots in total (nearly one-third of the 995) to produce food exclusively for home consumption. The remaining 163 families (63% of 259) were semi-subsistence farmers, who were engaged in a mixture of producing crops both for sale and home consumptions. These 163 semi-subsistence farmers cultivated 707 plots in total (71% of the 995) and almost half of their plots were cultivated completely for home consumption. More specifically, 442 (44% of 707) plots were cultivated to produce food for home consumption, 150 (20% of 707) plots to produce crops for both market and home consumption and 115 (16% of 707) plots to produce crops for market.

We divided the 994 plots run by the subsistence and semi-subsistence farmers into three groups: [1] 287 *consumption plots*, run by 95 subsistence farmers; [2] 442 *consumption plots*, run by 160 semi-subsistence farmers to produce crops completely for home consumption; [3] 115 *market plots*, run by 100 semi-subsistence farmers to produce crops completely for market purpose; and [4] 150 *mixed plots*, run by 112 semi-subsistence farmers to produce crops for a mix of home consumption and market purposes.

Regarding those 95 subsistence farmers producing only for home consumption, we suspected that some of them may earn their primary income from off-farm activities and run plots for home consumption with purposes other than food security. Considering specific localities in our study area, which still has a relatively high poverty incidence, we focused on those "subsistence farmers" whose main concern is food security rather than food safety. We then used a cut-off line in terms of off-farm income to define our subsample of subsistence farmers, i.e. subsistence farmers whose families' off-farm income was below RMB 20,000 yuan[4] in the survey year (2006) were defined as subsistence farmers, cultivating "consumption plots" mainly for food

[4] The cutoff point of RMB 20,000 Yuan was chosen based on the following: [1] RMB 20,000 yuan is at the 90th percentile of all complete subsistence farmers in our sample; and [2] it translates closely to the average per capita income for households in rural Yunnan. The per capita income for rural households in Yunnan was RMB 2,250.50 yuan in 2006, which, at 4.7 people per household, translates to approximately RMB 10,577 yuan per household.

security. As a result, those 14 subsistence farmers, whose families' off-farm income was above RMB 20,000 yuan in 2006, were excluded from our subsample. The remaining 81 subsistence farmers, cultivating 254 "consumption plots", accounted for one-third of the surveyed families in our sample. We focused on understanding these farmers' pesticide use decisions in the econometric analyses and also conducted some robustness checks using alternative definitions of "subsistence farmers".

Table 4 provides summary statistics for key variables of interest by plot types run by subsistence and semi-subsistence farmers. The intensity of pesticide use was calculated for each plot using the unit cost of pesticides, derived from the total costs of pesticides applied by a family on the plot divided by the plot size. Farmers' risk aversion was measured by the number of safe choices selected in the risk experiments: the higher the number of safe choices a person made, the more risk averse he/she was. A family's farm size is the total area of farm operated by the family, which is the sum of plots run by the family in the surveyed year. A family's wealth was measured by the total value of fixed assets and durable assets owned by a family. The family labor ratio, which is the ratio of the number of healthy family members aged 16-65 years old in 2006 to the total family size, was constructed to approximate a family's labor supply. The information related to whether or not a family borrowed loans from the bank in 2006 was used to approximate a family's potential access to credit.

Table 4

Household characteristics (by plots)

	All farmers' plots	Subsistence farmers' plots	Semi-subsistence farmers' plots			
			All plots	All home consumption	Mixed	All market
No of observations (plots/families)	995/259	254/81	707/163	442/160	150/112	115/100
Proportion of plots with positive amount of pesticides	70%	57%	75%	67%	85%	90%
Intensity of pesticide use (yuan/ha)	412.32	318.10	450.91	403.12	430.47	661.26
	(696.66)	(520.63)	(758.80)	(734.57)	(586.93)	(986.99)
Intensity of pesticide use on plots with positive amount of pesticides	587.76	557.22	603.78	601.95	504.45	731.20
	(767.38)	(584.86)	(823.94)	(828.59)	(605.42)	(1013.18)
Annual per capita income (yuan/person/year)	3431.74	1760.49	3683.60	3579.50	4142.45	3485.18
	(3590.28)	(1411.71)	(2906.15)	(2823.84)	(3144.63)	(2858.97)
Risk aversion (no of safe choices)	5.51	5.34	5.63	5.67	5.77	5.68
	(2.61)	(2.68)	(2.60)	(2.62)	(2.51)	(2.66)
Farm size (ha)	0.56	0.38	0.62	0.64	0.56	0.66
	(0.45)	(0.31)	(0.48)	(0.50)	(0.45)	(0.48)
Family assets (1,000 yuan)	40.72	28.86	38.29	39.18	39.85	32.82
	(65.56)	(41.27)	(58.31)	(58.60)	(58.92)	(56.52)
Family labor ratio	0.81	0.80	0.81	0.81	0.82	0.79
	(0.18)	(0.18)	(0.18)	(0.18)	(0.19)	(0.18)
Family head's age (years)	45.52	43.78	45.98	45.97	46.65	45.12
	(10.82)	(11.17)	(10.49)	(10.34)	(10.06)	(10.31)
Access to credit (1=Yes, 0=No)	0.27	0.32	0.25	0.24	0.27	0.30
	(0.44)	(0.47)	(0.44)	(0.43)	(0.45)	(0.46)
Plot size (ha)	0.13	0.09	0.14	0.14	0.13	0.15
	(0.11)	(0.08)	(0.11)	(0.11)	(0.10)	(0.12)
Non-farm income (1,000 yuan)	7.82	3.82	7.93	7.69	9.87	6.32
	(12.71)	(4.91)	(11.74)	(11.75)	(12.95)	(9.654)

The families surveyed in our sample were relatively poor with little farm land (column 2, Table 4). Their average annual income per capita was about RMB 3,421 yuan/person/year (about 1.5 dollars per day per person), indicating that people in this region were quite poor. They had an average farm size of 0.56 ha/family and cultivated on plots with an average size of 0.13 ha. Their average family labor ratio was 0.81, showing that most members of surveyed families were potentially capable of being engaged in agricultural production or earning off-farm income. On average, their family heads[5] were 46-years old. About one-third of families had potential access to credit. Eighty-one subsistence farmers were extremely poor and small-scale producers (column 3, Table 4). Their families earned an average annual per capita income of 1,760 yuan (a per capita income less than one dollar a day), which is about three-quarters the level of the national poverty line. They cultivated little land (0.38 ha/family).

Overall, semi-subsistence farmers used more pesticides more than subsistence farmers (450.91 yuan/ha vs. 318.10 yuan/ha) (columns 3&4, Table 4) and the difference is significant at the 1% significance level. Approximately 70% of plots run by the semi-subsistence farmers were applied with pesticides, while about 57% of plots run by the subsistence farmers were applied with pesticides (line 2, Table 4). However, once the decision regarding whether to use pesticides was made, pesticide use on subsistence farmers' plots (557.22 yuan/ha) was slightly higher than that on semi-subsistence

[5] In our study, the family heads were also the subjects of the risk experiment.

farmers' consumption plots (504.45 yuan/ha) (line 3, Table 4). Nonetheless, t-test shows that the difference is not statistically significant.

Among the different types of plots, pesticides were used most intensively on "market plots" run by semi-subsistence farmers (661.26 yuan/ha) (column 7, Table 4) and least intensively on plots run by subsistence farmers (318.10 yuan/ha) (column 3, Table 4). T-tests further show that: [1] pesticide use on "market plots" was significantly higher than those on "mixed plots" (column 6, Table 4) or those on "consumption plots" run by semi-subsistence farmers (column 5, Table 4) or subsistence farmers (column 3, Table 4); and [2] pesticides use on "mixed plots" (column 6, Table 4) was significantly higher than those on "consumption plots" run by subsistence farmers (column 3, Table 4), but not significantly different from those applied on "consumption plots" run by the semi-subsistence farmers (column 5, Table 4).

T-tests show the following significant difference in key household characteristics between the 81 subsistence farmers and the 163 semi-subsistence farmers: [1] the 163 semi-subsistence farmers had a significantly larger average farm size than the subsistence farmers (0.62 ha/family vs. 0.38 ha/family); [2] on average, they also earned significantly higher family income than the subsistence farmers (17,346 yuan/family vs. 7,802 yuan/family); and [3] they also earned significantly higher off-farm income than the subsistence farmers (7,933 yuan/family vs. 3,816 yuan/family).

T-tests also show allow for the comparison of key household characteristics of the semi-subsistence farmers who cultivated different types of plots. The key results are:

[1] families cultivating “market plots” had significantly larger farms (0.66 ha/family) than those cultivating “mixed plots” (0.56 ha/family), but they did not have significantly bigger farm size than those running “consumption plots”; and [2] families running “consumption plots” had significantly bigger farm sizes than those running “mixed plots” (0.66 ha/family vs. 0.56 ha/family). That said, families running different types of plots did not earn significantly different incomes.

5. Empirical specifications and main model results

Our empirical model specifications largely follows the theoretical models of Just and Zilberman (1983) and Knight et al (2003), by taking into account the fixed costs of using pesticides and the role of farm size in determining farmers’ risk preferences. We interact family farm size with risk aversion to allow for the effect of risk aversion on pesticide use decisions to vary with farm size. Specifically, we test whether: [1] more risk averse farmers are likely to use more pesticides; [2] farmers with more farm land are more likely to use pesticides, and [3] the effect of risk aversion on pesticide use decreases in farm size, particularly for subsistence farmers.

Main model specifications

We first estimate pesticide use for all farmers on all plots. We used a Tobit model specification to address the censoring issue, since 299 of 995 plots were not applied with pesticides, showing a censoring rate of 30%.[6] We then ask whether pesticide use differs by farmer type, and separately estimate pesticide use on the 254 plots run by the subsistence farmers, and 707 plots run by the semi-subsistence farmers. We apply the Tobit model specification for subsistence farmers' plots, which have a censoring rate of above 40% (109 of 254 plots), and semi-subsistence farmers' plots, which have a censoring rate of 25% (179 of 707 plots). In all model specifications, we control for household demographic and socio-economic characteristics as well as plot characteristics (e.g. plot size).[7] We include village dummy variables to account for village-specific unobserved heterogeneity, and crop dummy variables to control for crop-specific effects, such as different levels of pest pressure. For the combined regression and the regression on semi-subsistence farmers, we also include plot type dummies. Unobserved household effects, such health or financial shocks on the family, may affect pesticide use on all household plots. We thus include household random effects (RE) in the regression.

We next estimate the regression by plot type to ask whether any observed differences between subsistence and semi-subsistence farmers are driven by the plot use. For this purpose, we run separate regressions for 442 "consumption plots", 150 "mixed plots" and 115 "market plots". Given the censoring rate of 33% (146 of 442 plots) in the

[6] Given the distribution of the unit pesticide costs was highly skewed with a skewness coefficient of 4.97, we used a log transformation of this variable.

[7] For all model specifications, we ran a model including family head's education as a controlled variable, this variable was never significant. It was also insignificant in model specifications for all home consumption plots and all market plots. Therefore, we did not include this variable in the final regressions in this paper. These results are available from the authors.

consumption plots and that of 15% (22 of 150 plots) in the mixed plots, we estimate these two regressions using a Tobit model. "Market plots" have a censoring rate less than 10% (11 of 115 plots), thus, we used the OLS model specification. We used the same set of variables as those used in the previous Tobit model specifications and included random effects.

Pesticide use is driven by two decisions: first, whether to use pesticides on a plot at all, and second, how much pesticide to use. To explore each of these decisions we first estimated the probability of using any pesticide on a plot, and then the intensity of use. To address possible selection bias in the second stage, we used a Heckman model.[8] We split the sample by farmer type and used the same specifications as earlier. We included random effects and cluster standard errors at the household level.

Results and discussion

We first consider what factors affect pesticide use over our entire sample (column 2, Table 5). We see little evidence that risk aversion affects pesticide use for the average farmer in our sample. We do observe that total assets and credit increase the use of pesticides, and the greater the ratio of household labor, the lower the pesticide use. We also find that on average, farmers use less pesticide on plots for home consumption. Compared to pesticide use on "consumption plots", farmers spent about RMB 0.96

[8] While, the Tobit model implicitly assumes that the two decision processes are the same, we can also run both stages separately, controlling for the potential selection concern in the intensity regression using a Heckman selection model, also known as the type II Tobit model (Amemiya, 1984).

yuan per mu[9] (equivalent to 14.4 yuan per hectare) more on pesticide use on market plots. The lower use of pesticides on "consumption plots" might be explained by farmers' concerns for food safety. Alternatively, more consumption plots may be run by farmers who are financially constrained; one-third of families running "consumption plots" were poor farm households.

[9] 1 ha = 15 mu

Table 5

The determinants of farmers' pesticide use decisions (Tobit RE models)

	All farmers' plots	Subsistence farmers	Semi-subsistence farmers' plots
Risk aversion	0.056	0.279**	0.026
	(0.050)	(0.139)	(0.052)
Farm size	0.021	0.400***	-0.043
	(0.037)	(0.132)	(0.039)
Risk aversion*farm size	-0.003	-0.064***	0.003
	(0.005)	(0.019)	(0.005)
ln(total asset)	0.101*	0.383***	-0.002
	(0.053)	(0.140)	(0.059)
Family labor ratio	-1.656***	-3.445**	-0.684
	(0.470)	(1.347)	(0.472)
Family head's age	0.008	-0.001	0.009
	(0.008)	(0.022)	(0.008)
Credit	0.373**	1.288***	0.239
	(0.177)	(0.474)	(0.188)
Plot size	0.037	-0.244	0.190
	(0.085)	(0.289)	(0.119)
Consumption plot dummy	-0.958***	-	-0.858***
	(0.267)	-	(0.263)
Mixed plot dummy	-0.337	-	-0.255
	(0.299)	-	(0.286)
Village fixed effect	YES	YES	YES
Crop dummies	YES	YES	YES
No of observations	995	254	707

Notes:[1] Standard errors are in parentheses; [2]*, **, *** are significance levels of 10%, 5% and 1%, respectively; [3] the reference group left out in plot types is market plots.

We next split the data by farmer type to compare the factors that affect pesticide use by subsistence farmers (column 3, Table 5), who produce exclusively for home consumption, versus those semi-subsistence farmers, who produce both for the market and for consumption (column 4, Table 5). For subsistence farmers, we find that risk aversion appears to have a positive effect on their pesticide use with a marginal effect of 0.25 at the farm size of 0.38 ha (i.e. the subsistence farmers' average farm size). Moreover, as their farm size increases, the effect of risk aversion on their pesticide use diminishes. Since subsistence farmers were generally poor, had relatively little farm land and earned low off-farm income, they may have relied more on their farms to produce food to feed their families. Thus, they may have been concerned with food security and mitigating yield risk. Having a larger farm might have helped them to mitigate the risk of having too little food production.

We do not observe a significant effect of risk aversion on semi-subsistence farmers' pesticide use. Nor do we find that the risk aversion and its interaction term with farm size are jointly significant for these farmers' pesticide use (column 4, Table 5).

The above difference in the effect of risk aversion on pesticide use between the subsistence farmers and the semi-subsistence farmers may be explained by different risk concerns and risk-mitigating objectives between these two different types of farmers. Subsistence farmers are more concerned with food security and yield risks than subsistence-farmers. Therefore, holding other things constant, risk-aversion drives subsistence farmers to use more pesticides than semi-subsistence farmers.

We also observe that farm size is positively and significantly correlated with pesticide use for subsistence farmers (column 3, Table 5), implying there may be economies of scale in pesticide use for these smaller landholders. We further notice that other variables associated with wealth, such as assets and credit also both increase the use of pesticides, implying that subsistence farmers may be credit constrained (column 3, Table 5). However, these variables do not significantly affect pesticide use by semi-subsistence farmers (column 4, Table 5). Last we find that the effect of the family labor ratio on pesticide seems to be largely driven by subsistence farmers (column 3, Table 5). For families in poor regions, especially those engaged in securing food for their families, labor may act as a substitute for pesticide use.[10]

Next we ask whether the differences we observe between farmer types are driven by the fact that different farmer types run different types of plots. We split semi-subsistence producers' plots into market plots, mixed plots and consumption plots (Table 6).

Table 6

Determinants of pesticide use decisions by semi-subsistence farmers

	Consumption plots	Mixed plots	Market plots
Risk aversion	0.020	-0.040	0.138*
	(0.076)	(0.077)	(0.074)
Farm size	-0.093	-0.017	0.001
	(0.061)	(0.053)	(0.045)
Risk aversion*farm size	0.004	0.000	-0.004
	(0.007)	(0.008)	(0.006)
ln(total asset)	0.007	-0.010	-0.116
	(0.087)	(0.084)	(0.101)
Family labor ratio	-0.922	-0.721	0.951
	(0.704)	(0.701)	(0.773)
Family head's age	0.010	0.001	0.013
	(0.013)	(0.012)	(0.011)
Credit	0.214	0.294	0.176
	(0.294)	(0.258)	(0.238)
Plot size	0.410**	0.119	0.090
	(0.203)	(0.162)	(0.151)
Constant	2.441**	4.263***	2.199*
	(1.185)	(0.980)	(1.204)
Village fixed effects	YES	YES	YES
Crop dummies	YES	YES	YES
No of observations	442	150	115

Notes: [1] Standard errors are in parentheses; [2]*, **, *** are significance levels of 10%, 5% and 1%, respectively; [3] the reference group left out in plot type is the market plot.

[10] Labor is used as a substitute for pesticides in integrated pest management. In our setting, one might think that farmers use labor to identify the specific location and timing of the pest outbreak to target their use of pesticides.

Note that subsistence farmers only cultivate consumption plots by definition. The overall results shown in the last column of the Table 5 and those in column (2) of the Table 6 indicate that the differences in farmers' pesticide application appear not to be largely driven by plot type, in that pesticide use by the semi-subsistence farmers' on consumption plots is driven by different factors than for subsistence farmers. Unlike subsistence farmers' plots, risk aversion does not affect pesticide use on semi-subsistence farmers' consumption plots (column 2, Table 6). The different effect of risk aversion on pesticide use by subsistence farmers on their plots vs. that by semi-subsistence farmers on their consumption plots may be explained as follows. Although semi-subsistence farmers may also care about producing food for their families from their consumption plots, they may have alternative options to supply food for their families. For example, they may have more cash to purchase food from the market to supply their families. Thus, these farmers might not have the same level of concerns with food security and yield risks as the subsistence farmers.

For semi-subsistence farmers, we also observe that risk aversion affects pesticide use on market plots, while farm size does not affect the degree to which risk aversion affects their pesticide use on market plots (column 4, Table 6). The significant effect of risk aversion on pesticide use by the semi-subsistence farmers on their market plots may be because when cultivating market plots, these farmers care about earning profits and thus tend to use pesticides to mitigate income risks.

We also notice that credit, assets and farm size do not affect pesticide use on all types of plots run by the semi-subsistence farmers, implying that these farmers may be less credit constrained and their farm sizes may be sufficient to overcome economies of scale. Plot size significantly affects pesticide use on consumption plots, but not on mixed plots or market plots.

In Table 7, we consider the factors that affect the decision to use pesticides separately from the decision about intensity of use. The Mills ratio is significant at 10% level for semi-subsistence farmers' equations while it is insignificant for subsistence farmers' equations. This indicates that there might be a potential selection bias in the subsample of plots run by semi-subsistence farmers while we do not observe such selection bias in the subsample of plots run by those poor subsistence farmers.

Table 7

Heckman model results for semi-subsistence and subsistence farmers' plots

	Subsistence farmers' plots		Semi-subsistence farmers' plots	
	Probability of using pesticides	Pesticide use intensity	Probability of using pesticides	Pesticide use intensity
Risk aversion	0.106	0.152***	0.047	0.018
	(0.086)	(0.059)	(0.049)	(0.034)
Farm size	0.190***	0.049	-0.021	-0.008
	(0.071)	(0.098)	(0.037)	(0.025)
Risk aversion*farm size	-0.022**	-0.027***	0.000	-0.001
	(0.011)	(0.010)	(0.005)	(0.003)
ln(total asset)	0.261***	0.073	-0.009	0.019
	(0.097)	(0.068)	(0.053)	(0.030)
Family labor ratio	-1.849**	-0.953	-0.718*	-0.027
	(0.855)	(0.811)	(0.414)	(0.266)
Family head's age	0.008	-0.015	0.009	0.000
	(0.014)	(0.009)	(0.007)	(0.005)
Credit	0.754**	0.278	0.105	0.082
	(0.301)	(0.244)	(0.167)	(0.112)
Plot size	-0.128	0.062	0.208*	-0.014
	(0.133)	(0.169)	(0.116)	(0.059)
Consumption plot dummy	-	-	-0.989***	-0.027
	-	-	(0.244)	(0.148)
Mixed plot dummy	-	-	-0.300	0.068
	-	-	(0.269)	(0.144)
Constant	0.004	3.464***	1.765**	2.446***
	(1.329)	(0.886)	(0.699)	(0.527)
Village fixed effect	YES	YES	YES	YES
Crop dummies	YES	YES	YES	YES
Inverse mills ratio		-0.399		0.559*
		(0.685)		(0.333)
No of observations	253	145	707	528

Notes:[1] Standard errors are in parentheses; [2]*, **, *** are significance levels of 10%, 5% and 1%, respectively; [3] the reference group left out in plot types is market plots.

We first note that risk aversion largely appears to affect how much pesticides subsistence farmers use (column 3, Table 7), not whether they use them at all (column 4, Table 4). This result seems to be consistent with the notion that subsistence farmers are using pesticides to ensure sufficient food production, and not avoiding pesticide use for the sake of food safety. Second, we observe that farm size significantly increases the probability that subsistence farmers use any pesticides, not their intensity, which is consistent with the hypothesis of there being fixed costs to using pesticides. Third, we see that farm size decreases the effect of risk aversion both on the probability of using pesticides, and more strongly, the amount of their use, consistent with the story that as subsistence farmers have more land, they are less concerned with using pesticides as their primary mean to ensure food security. Fourth, we find that assets and credit largely affect the probability of pesticide use for subsistence farmers, not its intensity, consistent with the explanation that some subsistence farmers are financially constrained from purchasing pesticides at all. Lastly, we find family labor is significant in determining the probability of pesticide use, not its intensity.

We find that the semi-subsistence farmers are much less likely to use pesticides on plots for home consumption, but that once the decision is made to use pesticides, the amount of pesticides does not differ between consumption plots and other plots. We then observe that they are more likely to use pesticides on larger plots, whereas, if anything, the reverse is true for subsistence farmers.

To summarize, we find the difference in the effect of risk aversion on pesticide use largely lies between farmers. Risk aversion affects the pesticide use of subsistence farmers, particularly those with small farms, but largely does not influence pesticide use of semi-subsistence farmers except on their market plots. We also observe evidence of barriers to pesticide use for subsistence farms, be they financial or economies of scale.

One might be concerned that, in as much as farm size is correlated with household wealth, the interaction may capture the effect of risk aversion decreasing with wealth instead of a specific desire for food security. To address this concern, we ran an additional specification where we also included an interaction between assets and risk aversion to control for the potential wealth and found that the coefficient on risk aversion and farm land size remains qualitatively unchanged.

6. Robustness Checks and Their Results

We ran a number of tests to check the robustness of our results to various assumptions in our estimation. First, we test whether the inclusion of those farmers who exhibited "inconsistent" risk preferences in the risk experiments would change the results. Second, we ran several tests of our definitions of subsistence farmers. Third, we checked whether the results would change when we used alternative wealth measures. Fourth, we also test alternate definitions of family labor. Last, we consider how proximity to market centers affects both the use of pesticide and how risk aversion affects pesticide decisions.

Robustness check 1: some studies argue that those subjects who indicate inconsistent risk preferences could convey useful information (Jacobson and Petrie, 2009). Thus, we ran a model for all farmers that included those "inconsistent" subjects, who jumped across options A and B more than once. We test whether the results are sensitive to their inclusion, and find that results are not significantly affected.

Robustness check 2: since the cut-off line of RMB 20,000 yuan in off-farm income used in the main models to define subsistence farmers was largely arbitrary, we test three alternate definitions for subsistence farmers. First, we included all farmers who produce only for consumption, regardless of their off-farm income. Second, we used off-farm income less than RMB 7,500 yuan as an alternate cut-off to redefine subsistence farmers, where RMB 7,500 yuan is the mean off-farm income of subsistence farmers who cultivated "consumption plots". We then used an alternative cut-off line to define subsistence farmers by dropping 44 families whose share of off-farm income in family's total income was higher than the 90th percentile of the share of off-farm income related to substance farmers cultivating "consumption plots". By using these three alternative sharper cut-off lines, we hoped that the subsample could drop those families whose primary income was not from agriculture and may cultivate "consumption plots" for food safety reasons.

Tobit model and Heckman model specifications were both used to analyze the data with the new definitions of subsistence farmers. The results for Tobit model specifications and Heckman model specifications are presented in the Appendix Table 1-A and Appendix Table 1-B, respectively. We find the signs and significance levels of the key variables were consistent with the results from the main models, implying that our results are not sensitive to the specific cut-off used to define subsistence farmers.

Robustness check 3: because we were concerned that our measure of family wealth might be imprecise, we used two alternate measures of wealth to test the robustness of the results in the main models, where the total asset value (i.e. the sum of the value of durable and fixed assets) was used as a proxy for family wealth. Given that fixed assets could represent a family's productive assets and could be depleted to smooth consumption in times of hardship, we used fixed assets as one alternative measure of a family's wealth. We also used durable assets as another alternative measure of a family's wealth. Using these two alternative wealth measures, we analyzed the data for 115 market plots run by semi-subsistence farmers, home consumption plots" run by semi-subsistence and subsistence farmers, semi-subsistence farmers' plots. We used the same model specifications as those in the main models to do estimations. The results are presented in Appendix Table 2.

In all equations, the results essentially remained unchanged when the value of fixed assets was used as an alternative measure of family wealth. However, when the value of durable assets was used as an alternative measure for family wealth, the results were not as robust as the case, where we use fixed asset as the alternative measure of the wealth. This implied that fixed asset value might be a better measure for family wealth than the durable asset value in the case involving investment in agricultural production, such as pesticide use.

Robustness check 4: we suspected that the family labor ratio used in our main models might capture family members' off-farm employment options, because to construct the variable of family labor ratio, we included those family members working outside of their towns who returned home to harvest crops during peak farming seasons. We used a separate variable, i.e. the number of days spent by family members outside of their towns, as a measure of a family's outside options, to see whether this measure would affect our results. After we controlled for family members' outside options, the results were consistent with those from our primary specifications.

Robustness check 5: Market access could affect the use of pesticides. Farmers living in villages nearer to the local market may be less dependent on food from their home production since they may find it easier to buy supplementary food from the market. As a result, they may be less concerned with food security and therefore risk aversion may have less of an effect on pesticide use on their plots for home consumption. Another possible argument is that farmers living in villagers nearer to the local market may face lower transaction cost of pesticide application (i.e. spending time buying pesticides and spraying equipment).

Considering that subsistence farmers are the ones with the greatest concerns about food security, we focus on the relation between market accessibility and intensity of pesticide use for these farmers. In the first model specification, we added the distance to villages to the nearest township, the local market. In the second model specification, we also included an interaction term of risk aversion and the villages' distance to the market. To further understand whether accessibility to the market would increase the probability of using pesticides or the intensity of pesticides, we also ran a Heckman model using the second model specification, i.e. with an interaction term of risk aversion and villages' distance to the market. Results of the robustness check 5 are presented in Appendix Table 3.

We found that: [1] living in a village closer to the local market significantly increased the probability of using pesticides on plots run by the subsistence farmers; [2] more risk averse subsistence farmers tended to use pesticides more intensively on their plots, but the effect of their risk-aversion on their pesticide use did not significantly decrease with improved access to local markets; [3] access to the market and its interaction with risk aversion were jointly significant in predicting the probability of pesticide use at 10% significance level but they were not jointly significant for the intensity of pesticide use. Thus, access to market, including access to pesticides, may have contributed to the increased use of pesticides while access to market for purchased food may not mitigate the risk of home food production.

7. Conclusions

In this paper, we combined household survey and experimental data collected in Yunnan Province of western China to empirically explore the determinants of pesticide use decisions by subsistence versus semi-subsistence farmers. We particularly examined the effect of farmers' risk preferences on pesticide use for their plots.

More than 60% farmers in our sample are engaged in agricultural production with mixed purposes of market and home production. However, their level of market participation level is quite low, with more than 60% of the family plots run by these farmers exclusively for home consumption compared to slightly less than 15% of the plots which were cultivated for producing crops destined for the market. About one-third of the farmers in our sample, most living under the national poverty line, were complete subsistence farmers who were engaged in cultivating all of their family plots exclusively for securing food for their families.

We found that about 60% of the farmers in our study with consistent risk preferences were risk-averse, while slightly more than 22% of them were extremely risk averse. Further, this risk aversion significantly increased subsistence farmers' pesticide use and semi-subsistence farmers' pesticide use on their "market plots". However, the effect of risk aversion diminished with farm size for subsistence farmers, while the effect of risk aversion did not significantly vary with farm size for semi-subsistence farmers cultivating "market plots". As discussed by Just and Zilberman (1983), when farmers have smaller farm area, they may be more willing to pay a higher premium to avoid risk in their production, i.e. they tend to apply pesticides more intensively to stabilize production and hold a relatively smaller portion of the plots without pesticides. The risk to production might be particularly salient for a small-scale subsistence farmer for whom a production loss means not having enough to eat, as opposed to a semi-subsistence farmer for whom a loss in production means lower income, but not decreased household food security.

Subsistence farmers appear to be constrained in their use of pesticides, both by economies of scale in that more farm land increases the probability of pesticide use, and financially in that both greater wealth and better access to credit increase the probability of pesticide use. Once a subsistence farmer has decided to use pesticides, however, these factors do not affect the intensity of use.

Our findings have some important policy implications for poorer regions in China and similar localities in other parts of the developing world. In particular, there seems to be a need to provide small-scale semi-subsistence farmers and subsistence farmers with risk management options, such as crop insurance for semi-subsistence farmers and aid for food security for subsistence farmers, which may incentivize them to reduce pesticide use.

Some pesticide use is clearly demanded by farmers. Providing subsistence farmers in poor regions with access to credit may help them to mitigate the potential yield risk and help secure their family food security, since farmers at the lower strata of the family wealth seem to be hindered from using pesticides given their limited accessibility to credit or family assets to pay for fixed costs required for pesticide use. However, a positive (though insignificant) association between these farmers' access to credit and the intensity of their pesticide use also raises the following concern. Providing greater access to credit for poor subsistence farmers may increase their food security, but it may also lead to a higher rate of their pesticide use. This poses a serious challenge for policy-makers in a number of developing countries, especially if they aim to pursue a balance between poor farmers’ food security and environmental health.

References

Amemiya, T., 1984. Tobit models: a survey. J. Econometrics 24, 3-61.

Antle, J.,1987. Econometric estimation of producers' risk attitudes. Am. J. Agric. Econ. 69, 509-522.

Antle, J., 1988. Nonstructural risk estimation. Am. J. Agric. Econ. 71, 774-784.

Antle, J., Pingali, P., 1994. Pesticides, productivity, and farmer health: a Philippine case study. Am. J. Agric. Econ., 73, 418-430.

Arrow, K., 1971. *Essays in the Theory of Risk Bearing*. North Holland, Amsterdam.

Atreya, K., Sitaula, B.K., Johnsen, F.H., Bajracharya, R.M., 2011. Continuing issues in the limitations of pesticide use in developing countries. Journal of Agricultural and Environmental Ethics 24(1), 49-62.

Babcock, B., Shogren, J., 1995. The cost of agricultural production risk. Agric. Econ. 12, 141-150.

Bertrand, M., Mullainathan, S., 2001. Do people mean what they say? Implications for subjective data. Am. Econ. Rev. 91, 67-72.

Binswanger, H., 1980. Attitudes toward risk: experimental measurement in rural India. Am. J. Agric. Econ. 62, 395-407.

Binswanger, H., Sillers, D., 1983. Risk aversion and credit constraints in farmers' decision-making: a reinterpretation. J. Dev. Stud. 20, 5-21.

Carbone, E., Hey, J., 2000. Which error story is best? J. Risk Uncertainty 20, 161-176.

Carpenter, J.,2000. Negotiation in the commons: incorporating field and experimental evidence into a theory of local collective action. J. Inst. Theor. Econ. 156, 661-684.

Chinese Academy of Sciences, 2012. China Sustainable Development Report 2012 - China's Sustainable Development in the Shifting Global Context. Science Press: Beijing, China.

National Bureau of Statistics of China, 2010. China Statistical Year Book. China Statistics Press, Beijing.

Coady, D., 1993. An empirical analysis of fertilizer use in Pakistan. Economica 62, 213-234.

Ecobichon, D.J., 2001. Pesticide use in developing countries. Toxicology 160, 27-33.

ENRD (2010). Semi-subsistence farming in Europe: concept and key issues. Background paper for the "Semi-subsistence farming in the EU: current situation and future prospects" conference in Sibiu, Romania, 13-15 October 2010. Brussels, European Network for Rural Development. http://enrd.ec.europa.eu/enrd-static/fms/pdf/FB3C4513-AED5-E24F-E70A-F7EA236BBB5A.pdf accessed on 5/12/2015.

Eswaran, M., Kotwal, A., 1990. Implications of credit constraints for risk behavior in less developed economies. Oxford Econ. Pap. 42, 473-482.

FAO, 2015. FAOSTAT Database on Pesticides Use. http://faostat3.fao.org/browse/R/RP/E.

Feder, G., 1979. Pesticides, information and pest management under uncertainty. Am. J. Agric. Econ. 61, 97-103.

Feder, G., 1980. Farm size, risk aversion and the adoption of new technology under uncertainty. Oxford Econ. Pap., 32,263-283.

Feder, G., Just, R., Zilberman, D., 1985. Adoption of agricultural innovations in developing countries: a survey. Econ. Dev. Cult. Change, 33, 255-298.

Godfray, H.C.J., Beddington, J. R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food security: the challenge of feeding 9 billion people. Science, 327, 812–818.

Grovermann, C., Schreinemachers, P., Berger, T., 2013. Quantifying pesticide overuse from farmer and societal points of view: an application to Thailand. Crop Protection 53, 161-168.

Harless, D., Camerer, C., 1994. The predictive utility of generalized expected utility theories. Econometrica 62, 1251-1290.

Hey, J., Orme, C., 1994. Investigating generalization of expected utility theory using experimental data. Econometrica 62, 1291-1326.

Hill, R., 2009. Using stated preferences and beliefs to identify the impact of risk on poor households. J. Dev. Stud. 45, 151-171.

Holt, C., Laury, S., 2002. Risk aversion and incentive effects. Am. Econ. Rev. 925, 1644-1655.

Horowitz, J., Lichtenberg, E., 1993. Insurance, moral hazard, and chemical use in agriculture. Am. J. Agric. Econ. 75, 926-935.

Horowitz, J., Lichtenberg, E., 1994. Risk-reducing and risk-increasing effects of pesticides. Agric. Econ. 45, 82-89.

Hu, R., Cao, J., Huang, J., Peng, S., Huang, J., Zhong, X., Zou, Y., Yang, J., Buresh, R.J., 2007. Farmers participatory testing of standard and modified site-specific nitrogen management for irrigated rice in China. Agr. Syst. 94, 331-340.

Hua, J., Hu, R., Pray, C., Qiao, F., Rozelle, S., 2003. Biotechnology as an alternative to chemical pesticides: a case study of Bt cotton in China. Agric. Econ. 29, 55-67.

Huang, J., Qiao, F., Zhang, L., Rozelle, S., 2003. Farm pesticide use, rice production and human health. EEPSEA Research Report ACF268, Singapore. Available at http://www.idrc.ca/uploads/user-S/10536115330ACF268.pdf.

Huang, J., Hu, R., Cao, J., Rozelle, S., 2008. Training programs and in-the-field guidance to reduce China's overuse of fertilizer without hurting profitability. J Soil Water Conserv. 63, 165A-167A.

Huang, J., Yang, J., 2011. China's agricultural biotechnology regulations—export and import considerations. International Food & Agricultural Trade Policy Council Discussion Paper. Washington, DC, 2011. Available at: http://www.agritrade.org/Publications/documents/LLPChina.pdf.

Ireson, R., 1986. Subsistence and market farming in Northern Thailand: differential effects of purchased input and farm size on productivity. Studies in Comparative International Development 21, 95-111.

Isik, M., Khanna, M., 2003. Stochastic technology, risk preferences, and adoption of site-specific technologies. Am. J. Agric. Econ. 85, 305-317.

Jacobson, S., Petrie, R., 2009. Learning from mistakes: what do inconsistent choices over risks tell us? J. Risk Uncertainty 38, 143-158.

Just, R., Pope, R., 1978. Stochastic Specification of Production Functions and Economic Implications. J. Econometrics 7, 67-86.

Just, R., Zilberman, D., 1983. Stochastic structure, farm size, and technology adoption in developing agriculture." Oxford Econ. Pap. 35, 307-328.

Knight, J., Weir, S., Woldehanna, T., 2003. The role of education in facilitating risk-taking and innovation in agriculture. J. Dev. Stud. 39, 1-22.

Liu, E., Huang, J., 2013. Risk preferences and pesticide use by cotton farmers in China. J. Dev. Econ. 103, 202－215

Lusk, J., Pruitt, J.R., Norwood, B., 2006. External validity of a framed field experiment. Econ. Lett. 93, 285-290.

Masson, R.T., 1972. The creation of risk aversion by imperfect capital markets. Am. Econ. Rev. 62, 77-86.

Meng, Y., 2012. The damaging truth about Chinese fertiliser and pesticide use. https://www.chinadialogue.net/article/show/single/en/5153-The-damaging-truth-about-Chinese-fertiliser-and-pesticide-use accessed on 5/12/2015.

Ministry of Land and Resources, 2014. Land and Resources Communique of People's Republic of China.

Morduch, J., 1995. Income smoothing and consumption smoothing. J. Econ. Perspect. 9, 103-114.

Moscardi, E., de Janvry, A., 1977. Attitudes towards risk among peasants: an econometric approach. Am. J. Agric. Econ. 59, 710-716.

Oerke, E-C., 2005. Crop losses to pests. J. Agr. Sci. 144, 31-43.

Patton, D., 2014. China looking to curb fertilizer, pesticide use. Reuters news http://www.reuters.com/article/2014/12/05/us-china-grain-fertilizers-idUSKCN0JJ0SO20141205 accessed on 5/12/2015.

Pope, R., 1982. Empirical estimation and use of risk preferences: an appraisal of estimation methods that use actual economic decisions. Am. J. Agric. Econ. 64, 376-383.

Pope, R., Kramer, R., 1979. Production uncertainty and factor demands for the competitive firm. Southern Econ. J. 46, 489-501.

Popp, J., Peto, K., Nagy, J., 2013. Pesticide productivity and food security: a review. Agronomy for Sustainable Development 33, 243-255.

Reardon, T., Matlon, P., Delgado, C., 1988. Coping with household-level food insecurity in drought-affected areas of Burkina Faso. World Dev. 16, 1065-1074.

Schechter, L., 2007. Traditional Trust Measurement and the Risk Confound: An Experiment in Rural Paraguay. J. Econ. Behav. Organ. 62, 272-292.

Schreinemachers, P., Tipraqsa, P., 2012. Agricultural pesticides and land use intensification in high, middle and low income countries. Agric. Econ. 37, 616-626.

The State Council Leading Group Office of Poverty Relief and Development, 2012. List of national economically deprived counties.

http://www.cpad.gov.cn/publicfiles/business/htmlfiles/FPB/fpyw/201203/175445.html

Travisi, C.M., Nijkamp, P., 2008. Valuing environmental and health risk in agriculture: A choice experiment approach to pesticides in Italy. Ecological Economics 67(4), 598-607.

Turvey, C., Kong, R., 2010. Weather risk and the viability of weather insurance in China's Gansu, Shaanxi, and Henan provinces. China Agricultural Economic Review 2, 5-24.

Wik, M., Kebede, T., Bergland, O., Holden, S., 2004. On the measurement of risk aversion from experimental data. Appl. Econ. 36, 2443-2451.

Wilson, J.S., Otsuki, T., 2004. To spray or not to spray: pesticides, banana exports, and food safety. Food Policy 29 (2), 131-146.

World Bank, 2008. World Development Report 2008: Agriculture for Development. Washington D.C.

Young, D., 1979. Risk preferences of agricultural producers: their use in extension and research. Am. J. Agric. Econ. 61, 1063-1070.

Yao, H., Ren, Z., 2007. Report on economic development in western region of China. Social Science Academic Press: Beijing, China.

Yunnan Statistical Yearbook, 2008. Yunnan Statistics Bureau, National Bureau of Statistics Survey Office in Yunnan. Kunming: Yunnan Publishing House.

Appendix: Experimental steps and instructions for subjects

Experimental steps

The experiments were conducted with three steps.   At the beginning of the experiments, a subject was informed that he would receive a monetary payment from the experimenter and the final payment he would get would depend on the choices he would make in 10 questions, in each of which he would have to make a choice between option A and B. After he would have finished all 10 questions, one of them would be randomly chosen and the option he had made in the chosen question would be used to determine the final payment made to him.

To ensure the subjects understood the experiment, the experimenters used visual aids. For example, to explain the probabilities of getting a high versus a low payoff, the experimenters first showed the subjects 10 white balls marked with numbers 1-10, and then put all the balls in an empty opaque bag to make sure that neither the subjects nor the experimenters could see the marked balls. Next, the experimenters explained the concept of probabilities using the balls marked with numbers 1-10. For example, for the probability of 1/10 of getting a high payoff (RMB 20 yuan) and 9/10 of getting a low payoff (RMB 16 yuan) for option A, it was explained to the subjects as follows: “if you draw a ball marked with number one from the bag containing the 10 marked balls, then you will be paid RMB 20 yuan; if you draw any other balls marked with numbers between 2 to 10, then you will be paid RMB 16 yuan.” The experimenters worked with subjects through a number of examples to help the subjects to understand the differences between the option A and option B. The experiments were formally started after subjects had obtained a good understanding of the relation between the choices they would make in each question and the final payment that they would earn from the experiment.

Instructions for the subjects

Thank you very much for your time. Today we will play a game with real money. I will provide the money and you will get a certain amount of money by playing the game. Whatever amount of money you will win in the game will be your own money and you can keep that in your own pocket. However, how much money you will get in the game highly depends on the actions you will be taking in the game, so it is very important for you to have a good understanding of rules and process of the games. You might have played some other games, but our games today are completely different from any other games that you have played. Therefore, please do not use the rules in the previous games that you have played.

In the meantime, you might not have idea on how the game is going to be played, but I will explain rules and process of the game to you and then run through some examples together with you. It is very important to keep in your mind that only when you understand the game, you will be able to play the game. Please do not hesitate to ask me questions if you are not sure that you understand the game.

Now let me explain to you how our game is to be played:

Our game is to ask you to make 10 choices between 2 alternatives, alternative A and B. You will have to make 10 choices one by one by making a decision on choosing A or B. Both alternatives A and B have a high earning and a low earning: alternative A has a high earning of RMB 20 yuan and a low earning of RMB 16 yuan, while alternative B has a high earning of RMB 35 yuan and a low earning of RMB 5 yuan. After you finish making 10 choices, we will ask you to draw one card randomly from 10 cards, which are marked with number of 1-10 representing 1-10 choices correspondingly, to decide which choice will be used by us to make your payment, i.e. whether we should pay you RMB 35 yuan, RMB 20 yuan, RMB 16 yuan or 5 yuan. This means that you will make 10 choices, but only 1 choice will be chosen to determine how much you will earn from playing this game. It is important for you to understand that how much you will finally get from us depends on which alternative you will choose in each choice. It also depends on things you can not affect, because the number of choice will be randomly chosen.

The game will be played in 3 steps:

Step 1: you make 10 choices according to your own thought. The 10 choices will be made one by one by making decisions between alternative A and B in each choice.

Step 2: after you finish making 10 choices, I will ask you to randomly draw a card from 10 cards marked with 1 to 10. The marked number on each card represents the number of the choice. For example, if you draw a card with 6, it means that the number 6 choice is to be chosen. You will be paid according to the alternative you will choose in that particular choice. Because you can possibly draw any card with a number from 1 to 10, each choice will have equal chance of being selected for me to make you payment. Therefore, you should make your decision very carefully in each of 10 choices.

Step 3: after the choice is selected in step 2, I will pay you according to the alternative you will choose in the selected choice. Given that in the alternative, there is a high earning or a low earning. I will ask you to randomly draw a ball among 10 white balls marked with 1-10 from an opaque bag to decide whether I will give you a high earning or a low earning. Therefore, a ball with any number from 1-10 can be chosen.

Next, let me explain to you about each choice situation first and then go through some examples together with you. We will play the game formally, until you have a good understanding of our game.

First, let us look at the plates and price tags on the table now. On the table, we have 2 big plates. On the left plate, we have 2 price tags of RMB 20 yuan and 16 yuan, representing a high earning of 20 yuan and a low earning of 16 yuan, respectively, and 10 white balls marked with 1-10. On the right plate, we have 2 price tags of RMB 35 yuan and 5 yuan, representing a high earning of 35 yuan and a low earning of 5 yuan, respectively, and 10 white balls marked with 1-10 as well. Please remember that the price tags on the left plate stand for alternative A and the price tags on the right plate stands for alternative B.

Next, let us look at 10 choice situations one by one.

In choice 1, you will have to choose alternative A or B. The alternative A means a 10% chance of having a high earning of 20 yuan and a 90% chance of having a low earning of 16 yuan; the alternative B means a 10% chance of having a high earning of 35 yuan and a 90% chance of having a low earning of 5 yuan.   For you to understand what alterative A means, let us look at the left plate with price tags of 20 yuan and 15 yuan, and 10 balls. If a ball with number 1 is drawn, you will earn 20 yuan; if any ball market with 2-10 is drawn, you will earn 16 yuan. For you to understand what alterative B means, let us look at the right plate with price tags of 35 yuan and 5 yuan, and 10 balls. If a ball with number 1 is drawn, you will earn 35 yuan; if any ball market with 2-10 is drawn, you will earn 5 yuan.

In choice 2, you will have to choose alternative A or B. The alternative A means a 20% chance of having a high earning of 20 yuan and a 80% chance of having a low earning of 16 yuan; the alternative B means a 20% chance of having a high earning of 35 yuan and a 80% chance of having a low earning of 5 yuan.   For alterative A, let us look at the left plate with price tags of 20 yuan and 15 yuan, and 10 balls again. If a ball with number 1 or 2 is drawn, you will earn 20 yuan; if any ball market with 3-10 is drawn, you will earn 16 yuan. For alternative B, let us look at the right plate with price tags of 35 yuan and 5 yuan, and 10 balls again too. If a ball with number 1 or 2 is drawn, you will earn 35 yuan; if any ball market with 3-10 is drawn, you will earn 5 yuan.

…

In choice 10, the alternative A means a 100% chance of having a high earning of 20 yuan; the alternative B means a 100% of chance of having a high earning of 35 yuan. Alternative A means that whichever ball on the left plate is drawn, you earn 20 yuan; Alternative B means that whichever ball on the left plate is drawn, you earn 35 yuan.

Now let us go through some examples and do some practice before we start.   Assume you will have made the following choices as shown in the table:

An example

	A	B
1	20 yuan if ball 1 16 yuan if 2,3,4,5,6,7,8,9,10	35 yuan if ball 1, 5 yuan if 2, 3,4,5,6,7,8,9,10
2	20 yuan if 1,2 16 yuan if 3,4,5,6,7,8,9,10	35 yuan if ball 1,2 5 yuan if 3, 4,5,6,7,8,9,10
3	20 yuan if 1,2,3 16 yuan if 4,5,6,7,8,9,10	35 yuan if ball 1,2,3 5 yuan if 4, 5,6,7,8,9,10
4	20 yuan if 1,2,3,4 16 yuan if 5,6,7,8,9,10	35 yuan if ball 1,2,3,4 5 yuan if 5,6,7,8,9,10
5	20 yuan if 1,2,3,4,5 16 yuan if 6,7,8,9,10	35 yuan if ball 1,2,3,4,5 5 yuan if 6,7,8,9,10
6	20 yuan if 1,2,3,4,5,6 16 yuan if 7,8,9,10	35 yuan if ball 1,2,3,4,5,6 5 yuan if 7,8,9,10
7	20 yuan if 1,2,3,4,5,6,7 16 yuan if 8,9,10	35 yuan if ball 1,2,3,4,5,6,7 5 yuan if 8,9,10
8	20 yuan if 1,2,3,4,5,6,7,8 16 yuan if 9,10	35 yuan if ball 1,2,3,4,5,6,7,8 5 yuan if 9,10
9	20 yuan if 1,2,3,4,5,6,7,8,9 16 yuan if 10	35 yuan if ball 1,2,3,4,5,6,7,8,9
10	20 yuan if 1,2,3,4,5,6,7,8,9,10	35 yuan if ball 1, 2,3,4,5,6,7,8,9,10

After you will have made the 10 choices as above, I will have to determine how much to pay you. Suppose you drawn a card marked with 6 from 10 cards. It means that the number 6 choice will be used for me to make payment. According to your decision, you chose alternative B in the choice 6, which means that if you draw a ball marked with 1,2,3,4,5 or 6, you will get 35 yuan from me; otherwise, you will get 5 yuan. Suppose, you draw a ball with a number of 3, you get 35 yuan from me. Do you have any question?

Appendix Table 1-A

Robustness check 2: redefined “subsistence farmers” (Tobit RE models)”

	All subsistence farmers	Off-farm income less than RMB 7,500 yuan	Excluding those families whose families’ income is from off-farm income but cultivate plots for home consumption
Risk aversion	0.286**	0.420**	0.299*
	(0.125)	(0.168)	(0.170)
Farm size	0.368***	0.445**	0.509***
	(0.104)	(0.205)	(0.191)
Risk aversion*farm size	-0.063***	-0.083***	-0.071***
	(0.017)	(0.025)	(0.022)
ln(total asset)	0.390***	0.369**	0.437**
	(0.121)	(0.173)	(0.180)
Family labor ratio	-2.632**	-1.489	-2.662
	(1.185)	(1.616)	(1.626)
Family head's age	-0.009	-0.048	-0.027
	(0.019)	(0.029)	(0.028)
Credit	1.024**	1.545**	1.307**
	(0.422)	(0.622)	(0.551)
Plot size	-0.134	-0.310	-0.541
	(0.190)	(0.519)	(0.474)
Constant	-0.329	1.230	1.047
	(1.943)	(2.910)	(2.869)
Village fixed effect	YES	YES	YES
Crop dummies	YES	YES	YES
No of observations	287	208	228

Note: [1] standard errors are in parentheses; [2] *, ** and *** are significance levels of 10%, 5% and 1%, respectively.

Appendix Table 2-B

Robustness check 2: redefined “subsistence farmers” (Heckman RE models)

	All subsistence farmers		Off-farm income less than RMB 7,500 yuan		Excluding those families whose families' income is from off-farm income but cultivate plots for home consumption	
Risk aversion	0.120	0.143**	0.150	0.128	0.092	0.132*
	(0.083)	(0.059)	(0.104)	(0.093)	(0.101)	(0.069)
Farm size	0.193***	0.021	0.197*	0.001	0.210*	-0.007
	(0.065)	(0.089)	(0.117)	(0.137)	(0.117)	(0.101)
Risk aversion*farm size	-0.025**	-0.022**	-0.030**	-0.019	-0.023*	-0.020*
	(0.011)	(0.010)	(0.014)	(0.018)	(0.013)	(0.011)
ln(total asset)	0.223***	0.021	0.233**	0.010	0.271**	0.070
	(0.079)	(0.064)	(0.110)	(0.100)	(0.110)	(0.081)
Family labor ratio	-1.628**	-0.419	-0.149	-1.252*	-1.087	-0.890
	(0.813)	(0.659)	(1.038)	(0.660)	(0.977)	(0.662)
Family head's age	0.005	-0.019**	-0.030*	0.001	-0.013	0.000
	(0.013)	(0.008)	(0.018)	(0.016)	(0.017)	(0.009)
Credit	0.663**	0.128	0.865**	-0.020	0.750**	0.025
	(0.293)	(0.220)	(0.374)	(0.430)	(0.346)	(0.219)
Plot size	-0.096	0.069	-0.165	0.097	-0.219	0.155
	(0.107)	(0.147)	(0.289)	(0.272)	(0.297)	(0.192)
Constant	-0.009	3.780***	0.638	3.359***	0.931	2.221**
	(1.219)	(0.760)	(1.660)	(1.132)	(1.536)	(0.868)
Village fixed effect	YES	YES	YES	YES	YES	YES
Crop dummies	YES	YES	YES	YES	YES	YES
Inverse Mills ratio		-0.335		-0.556		-0.321
		(0.683)		(1.006)		(0.640)
No of observations	286	169	190	123	227	128

Note: [1] standard errors are in parentheses; [2] *, ** and *** are significance levels of 10%, 5% and 1%, respectively.

Appendix Table 3

Results of robustness check 4: using alternative proxies for asset (Tobit RE models)

	Semi-subsistence farmers		Semi-subsistence and subsistence farmers		Subsistence farmers	
	All market plots		All home consumption plots		All home consumption plots	
Risk aversion	0.114	0.155**	0.048	0.045	0.172	0.235*
	(0.073)	(0.064)	(0.064)	(0.064)	(0.134)	(0.133)
Farm size	-0.009	0.004	0.031	0.021	0.388***	0.353**
	(0.044)	(0.043)	(0.049)	(0.049)	(0.148)	(0.154)
Risk aversion*farm size	-0.003	-0.005	-0.004	-0.004	-0.046**	-0.063***
	(0.005)	(0.005)	(0.007)	(0.007)	(0.018)	(0.019)
ln(durable asset)	-0.005	-	0.064	-	0.099	-
	(0.054)	-	(0.042)	-	(0.077)	-
ln(fixed asset)	-	(0.147)	-	0.098**	-	0.352***
	-	-0.128***	-	(0.041)	-	(0.094)
Family labor ratio	0.652	1.058*	-2.041***	-2.005***	-3.690**	-3.903***
	(0.802)	(0.638)	(0.618)	(0.615)	(1.441)	(1.285)
Family head's age	0.014	0.013	0.010	0.006	0.002	0.003
	(0.011)	(0.010)	(0.010)	(0.010)	(0.022)	(0.021)
Credit	0.199	0.199	0.446*	0.397*	1.276***	1.099**
	(0.248)	(0.242)	(0.234)	(0.233)	(0.478)	(0.469)
Plot size	0.076	0.121	0.048	0.044	-0.347	-0.336
	(0.145)	(0.147)	(0.109)	(0.110)	(0.349)	(0.377)
Constant	1.407	1.211	2.483***	2.989***	3.090*	3.059**
	(1.132)	(0.983)	(0.882)	(0.784)	(1.789)	(1.452)
Village fixed effect	YES	YES	YES	YES	YES	YES
Crop dummies	YES	YES	YES	YES	YES	YES
No of observations	115	115	726	726	254	254

Note: [1] standard errors are in parentheses; [2] *, ** and *** are significance levels of 10%, 5% and 1%, respectively.

Appendix Table 4

Results of robustness check 6: effect of villages' accessibility to the market on pesticides used on subsistence farmers' plots

	Tobit RE model		Heckman RE model	
	Without interaction terms	With interaction term	Probability of using pesticides	Pesticide use intensity
Risk aversion	0.298**	0.294*	0.097	0.139*
	(0.143)	(0.160)	(0.098)	(0.074)
Farm size	0.376***	0.378***	0.163**	-0.008
	(0.125)	(0.130)	(0.079)	(0.085)
Risk aversion*farm size	-0.057***	-0.057***	-0.014	-0.023**
	(0.020)	(0.020)	(0.012)	(0.010)
ln(total asset)	0.413***	0.413***	0.235***	0.017
	(0.136)	(0.136)	(0.088)	(0.082)
Family labor ratio	-3.696***	-3.687***	-2.471***	1.182
	(1.324)	(1.333)	(0.857)	(0.839)
Family head's age	0.021	0.021	0.024	-0.027**
	(0.023)	(0.023)	(0.015)	(0.011)
Credit	0.497	0.495	0.277	-0.116
	(0.464)	(0.465)	(0.287)	(0.214)
Plot size	-0.319	-0.320	-0.217	0.167
	(0.231)	(0.232)	(0.146)	(0.176)
Total no of households in the village	0.002***	0.002***	0.002***	-0.001**
	(0.001)	(0.001)	(0.001)	(0.001)
Village altitude	-0.001	-0.001	-1.97E-04	-1.22E-04
	(0.001)	(0.001)	(0.000)	(0.000)
Distance to the county seat	-0.026**	-0.026**	-0.014**	0.010
	(0.010)	(0.011)	(0.006)	(0.007)
Distance to the nearest township	-0.047**	-0.049	-0.019	-0.004
	(0.020)	(0.035)	(0.021)	(0.015)
Risk aversion*distance to the township	-	3.45E-04	-0.002	0.002
	-	(0.006)	(0.004)	(0.002)
Constant	-0.364	-0.365	-0.877	3.722***
	(1.937)	(1.937)	(1.190)	(1.009)
Inverse Mills ratio	-	-	-	-0.979*
No of observations	254	254	253	145

Note: [1] standard errors are in parentheses; [2] *, ** and *** are significance levels of 10%, 5% and 1%, respectively; [3] crop dummies are included in all models.