

Article

Heterogeneous Behavioral Mechanisms Behind Farmers' Compensation Expectations for Fertilizer Reduction: A TPB-Based Analysis Using Choice Experiment Data

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Abstract

The compensation a farmer requires to reduce fertilizer use reflects the behavioral factors behind the decision to participate. This study examines how they are associated with compensation expectations, and whether these associations differ across operator types, by integrating the Theory of Planned Behavior with a discrete choice experiment. Using survey data from 1066 rice farmers in Jiangsu Province, China, we recover each farmer's willingness-to-accept (WTA) for fertilizer reduction as a money-metric proxy for the intention to participate, and model it as a function of behavioral attitude, social-institutional norm, and perceived behavioral control separately for conventional smallholders, specialized large-scale planters, and registered family farms. The pattern of associations differs across operator types. A favorable attitude is associated with a lower WTA only among smallholders, the social-institutional norm among smallholders and family farms, and perceived behavioral control among large-scale planters and family farms; the evidence for the attitude association among smallholders and for the norm association among family farms is relatively weaker. Each construct is thus associated with compensation expectations in a distinct subset of operator types, a structure that pooled estimation obscures. The findings suggest that differentiated policy could match attitudinal, capability-building, or institutional levers to the channel associated with each operator type, rather than relying on uniform payment increases.

Keywords: fertilizer reduction; willingness-to-accept; theory of planned behavior; choice experiment; operator heterogeneity



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1. Introduction

The overuse of chemical fertilizer is a major obstacle to agricultural sustainability. Intensive fertilizer application has supported large yield gains, but nutrients that are not taken up by crops contribute to soil acidification, water eutrophication, and greenhouse-gas emissions [1,2]. These environmental costs make fertilizer reduction part of the sustainable-development agenda in a precise sense, since the gains from reduction accrue over the long, intergenerational horizon that this agenda emphasizes while its costs fall on current farm incomes [3,4]. These problems are especially pronounced in China, the world's largest fertilizer consumer, where application rates per hectare exceed those of most other countries and rice production is a major source of agricultural non-point-source pollution [5]. In

response, fertilizer reduction has become a central component of China's agricultural green transition, supported by a sustained reduction program implemented since the start of the 14th Five-Year Plan [6]. This program has achieved measurable progress: the fertilizer-use efficiency of rice, wheat, and maize reached 43.3% in 2025, an increase of 3.1 percentage points relative to 2020. Even so, considerable reduction potential remains, and further progress depends on continued on-farm adoption of reduction measures [7–9].

Reducing fertilizer lowers input costs but raises concerns about yield loss, and farmers are often reluctant to depart from established fertilization routines that reduce production risk [10,11]. To offset the private costs of adoption, ecological-compensation schemes have become a widely used policy instrument [12]. Designing such schemes requires information on the compensation farmers are willing to accept, and discrete choice experiments are now widely used to elicit this information, estimating how compensation levels, technical support, and payment arrangements affect farmers' willingness to participate in reduction contracts [12–14]. A consistent finding of this literature is that required compensation varies substantially: across measures, across contract terms, and, most notably, across farmers [15,16]. This variation has clear policy relevance, because a payment that is sufficient to enroll one group of farmers may be inadequate for another. However, because the CE literature is concerned mainly with measuring the level of required compensation, it offers limited insight into why these requirements differ so widely across farmers.

Behavioral research provides a framework for explaining this variation. The Theory of Planned Behavior (TPB) treats a behavioral decision as arising from three belief-based channels: how favorably the actor evaluates the behavior, how much normative pressure they perceive, and how much control they feel over carrying it out [17]. Applied to agriculture, the framework has been used extensively to explain farmers' intentions to adopt sustainable and pro-environmental practices, showing that adoption turns on the evaluation of expected benefits, perceived social or institutional pressure, and perceived ability to act [18,19]. Within this body of work, a number of studies have focused specifically on fertilizer-related behavior, such as reducing fertilizer use and adopting scientific fertilization, identifying the same behavioral channels behind farmers' reduction decisions [20,21]. Almost all of this work, however, stops at intention, willingness to adopt, or self-reported behavior. It explains why farmers are disposed to adopt green practices, but says little about how much compensation they require before that disposition becomes action.

The two bodies of literature thus do not connect. Choice experiments measure the monetary threshold for participation but rarely ask where that threshold comes from; TPB studies explain the disposition to adopt but rarely connect it to the compensation farmers demand. The gap between them matters for policy. Adoption intention answers whether a farmer is willing to reduce fertilizer use; WTA answers under what monetary condition that intention becomes operational. The two need not move together: a farmer may fully endorse the value of reduction yet still demand high compensation if the measure feels risky or hard to execute, so that the same favorable disposition coexists with very different compensation demands. Explaining those demands therefore requires looking beyond the observable costs of the measure to the behavioral factors through which farmers form their monetary thresholds for participation.

This study takes that step. Building on work that embeds extended TPB constructs in stated-preference choice models to explain environmental preferences and willingness to pay [20,22], we apply this approach in the specific context of fertilizer-reduction compensation. We pair a discrete choice experiment on fertilizer-reduction compensation with a parallel set of survey items capturing the three TPB constructs, and recover each farmer's willingness-to-accept (WTA) from the choice data. Following the logic of TPB, in which attitude, subjective norm, and perceived behavioral control shape the intention to act, we

treat a farmer's intention to participate in fertilizer reduction as the latent outcome of interest and use WTA as its money-metric proxy, so that a lower required compensation indicates a stronger intention [23,24]. This reading of a stated compensation threshold as an expression of intention is grounded in valuation research that treats stated monetary valuations as behavioral intentions arising from the same belief-based channels [25–27]; Section 2.4 sets out the justification, and its limits, in detail. Modeling WTA as a function of the three constructs therefore lets us move from how much compensation farmers require to the behavioral factors associated with their willingness to accept reduction, and why some require more than others. These mechanisms need not operate uniformly across an increasingly stratified farming population: conventional smallholders, specialized large-scale planters, and registered family farms differ in scale, resource endowment, and institutional integration in ways that may change which of the three constructs translates into WTA, and how strongly, not merely the magnitude of a common effect [5,21]. We therefore estimate the behavioral model across the three operator types.

This paper makes two contributions. Methodologically, it applies an emerging integration of TPB constructs with stated-preference choice models, developed in environmental valuation and hybrid-choice research [22–27], to fertilizer-reduction compensation. Each farmer's willingness-to-accept, recovered from a mixed-logit choice model, serves as an explicit money-metric measure of participation intention and is modeled on the three TPB constructs. This design extends TPB from explaining the disposition to adopt to explaining the monetary threshold at which that disposition becomes operational in a policy contract. Empirically, it estimates the behavioral model across the three operator types in a multi-group model and finds that the constructs associated with WTA differ across operator types not only in magnitude but in which construct is operative, so that each behavioral channel matters for a different subset of operators, a form of heterogeneity that pooled estimation conceals. These estimates provide a behavioral basis for differentiated compensation policy, matching attitudinal, capability-building, or institutional levers to the channel associated with each operator type rather than relying on uniform payment increases.

The remainder of the paper is organized as follows. Section 2 describes the study area, the choice-experiment design, the TPB measurement, the construction of WTA, and the empirical strategy. Section 3 presents the empirical results. Section 4 discusses the behavioral mechanisms and their policy implications. Section 5 concludes.

2. Materials and Methods

2.1. Study Area and Data Collection

The empirical analysis draws on a farmer survey conducted in Jiangsu Province, a major rice-producing region in eastern China and a priority area for fertilizer-reduction policy. Jiangsu is well suited to the present study because the coexistence of conventional smallholders, specialized large-scale planters, and registered family farms within a common policy and agro-climatic setting provides the variation needed to examine whether the behavioral mechanisms underlying farmers' WTA differ across operator types while holding the broader institutional environment fixed. The province is also broadly representative in terms of fertilizer use: its provincial plan targets a fertilizer-use efficiency for major crops of 43% by 2025, essentially in line with the national level for the three major grain crops, so the reduction challenge it faces is representative of the country as a whole.

The survey covered six county-level units spanning the principal rice-growing zones of the province (two in the south, one in the center, one in the north, and two on the periphery of the provincial capital), so as to capture variation in cropping conditions, farm scale, and operator type across the province. Within each unit, townships, villages, and households were selected through successive sampling stages, and face-to-face interviews were admin-

istered by trained enumerators between October 2024 and March 2025. The questionnaire integrated a discrete choice experiment on fertilizer-reduction compensation schemes with a block of attitudinal and contextual items measuring behavioral constructs, alongside a standard module on household and farm characteristics. A translated example of the choice card used in the experiment is provided in Appendix A. A total of 1107 questionnaires were administered; after removing incomplete questionnaires, responses from households no longer cultivating paddy rice, and observations with inconsistent or out-of-range values on key items, 41 were excluded, yielding a final analysis sample of 1066 valid observations and a valid-sample rate of 96.3%.

Respondents were assigned to three operator types according to their predominant mode of rice operation, following the classification of agricultural operators in the Third National Agricultural Census [28] and national family-farm policy [29]. Conventional smallholder households cultivate small areas (typically up to about 30 mu) on their own contracted land, rely on family labor (often older or female members), have low levels of mechanization, and operate without a formal registered status. Specialized large-scale planters cultivate substantially larger areas (commonly one hundred to several hundred mu) accessed through informal land transfers within local social networks at low rental cost, work the land with family labor and limited hired help, and are commercially oriented and are themselves a recognized operator category in Chinese agricultural policy, but do not hold the family-farm registration that confers a higher level of formal institutional recognition. Registered family farms hold formal registration with the market regulation authorities as individual industrial-and-commercial households or small enterprises. They cultivate larger areas still (typically several hundred mu, in line with the 300-mu provincial floor for grain family farms), acquired through formal land-transfer contracts, and combine family labor with limited hired help. They are also more mechanized, and their certified status integrates them more directly into local agricultural-policy channels. We distinguish large-scale planters from registered family farms rather than grouping them at scale because their differing organizational form and institutional status may produce distinct behavioral responses. Because smallholder households constitute the overwhelming majority of agricultural operators (about 98% of agricultural operating households nationally [28]), the sample was not drawn in proportion to the three operator types; their relative shares were instead controlled at the household stage of sampling so that each subsample was large enough for separate estimation. The reported composition therefore reflects this analytical design rather than population shares, and the group-specific estimates, rather than the pooled column, constitute the primary results. Table 1 reports the socioeconomic profile of the three groups. Operating scale rises sharply across the three types, with mean rice area increasing from about 23 mu among smallholders to 339 mu among large-scale planters and 501 mu among family farms. Relative to smallholders, large-scale planters and family farms are on average younger, somewhat more educated, command larger household labor forces, and derive a substantially higher share of income from agriculture.

Table 1. Socioeconomic characteristics by operator type (sample means).

Variable	Smallholders	Large-Scale Planters	Family Farms	Full Sample
Age (years)	61.63 (11.70)	55.05 (9.25)	53.29 (9.18)	57.45 (11.08)
Male (=1)	0.75 (0.43)	0.94 (0.24)	0.91 (0.29)	0.85 (0.36)
Education (1–4)	2.09 (0.94)	2.18 (0.89)	2.38 (0.86)	2.20 (0.91)
Household labor force (persons)	2.30 (1.13)	2.60 (1.03)	3.03 (1.50)	2.60 (1.28)
Farming experience (1–6)	4.95 (1.69)	4.07 (1.48)	4.04 (1.29)	4.46 (1.59)

Table 1. Cont.

Variable	Smallholders	Large-Scale Planters	Family Farms	Full Sample
Household income (1–10)	3.16 (1.61)	5.67 (1.47)	6.08 (1.79)	4.67 (2.14)
Agricultural income share (1–5)	3.06 (1.64)	4.41 (1.07)	4.39 (1.07)	3.80 (1.51)
Rice cultivation area (mu)	23.25	338.53	501.32	247.90
Observations	481	242	343	1066

Notes: Values are group means. Standard deviations in parentheses (rice cultivation area reported as means only). Kruskal–Wallis tests reject equality across operator types for all ordinal and continuous characteristics ($\chi^2(2) = 24.47$ – 459.46 , all $p < 0.001$); gender, as a binary variable, is tested with a Pearson chi-square ($\chi^2(2) = 58.34$, $p < 0.001$). Male is a binary indicator (=1 if male). Education, farming experience, household income, and agricultural income share are ordinal variables, coded as follows. Education: 1 = primary school or below, 2 = junior high, 3 = senior high, 4 = college or above. Farming experience: 1 = under 3 years, 2 = 4–5, 3 = 6–10, 4 = 11–20, 5 = 21–30, 6 = over 30 years. Household income (annual gross, CNY): 1 = under 10,000; 2 = 10,000–30,000; 3 = 30,000–50,000; 4 = 50,000–100,000; 5 = 100,000–200,000; 6 = 200,000–500,000; 7 = 500,000–1,000,000; 8 = 1–2 million; 9 = 2–4 million; 10 = above 4 million. Agricultural income share (share of household income from agriculture): 1 = below 20%, 2 = 20–40%, 3 = 41–60%, 4 = 61–80%, 5 = above 80%. Rice cultivation area is the mean sown area of paddy rice; one mu equals approximately 0.067 hectares.

2.2. Behavioral Constructs and Measurement

The behavioral component of the study is grounded in TPB, under which behavioral decisions arise from three belief-based channels: the actor's evaluation of the behavior (behavioral attitude), the perceived social pressure to perform it (subjective norm), and the perceived ability to carry it out (perceived behavioral control) [17]. In our framework, these three constructs jointly shape a farmer's intention to participate in fertilizer reduction, which is proxied by the willingness-to-accept (WTA) recovered from the choice experiment (Section 2.4); the conceptual framework is summarized in Figure 1. The associations of the three constructs with WTA therefore coincide with their associations with the measured expression of intention. Each construct was measured by multiple items rated on five-point Likert scales, and the ten items are estimated within a structural-equation framework (Section 2.4). The item-level group means are reported in Table 2.

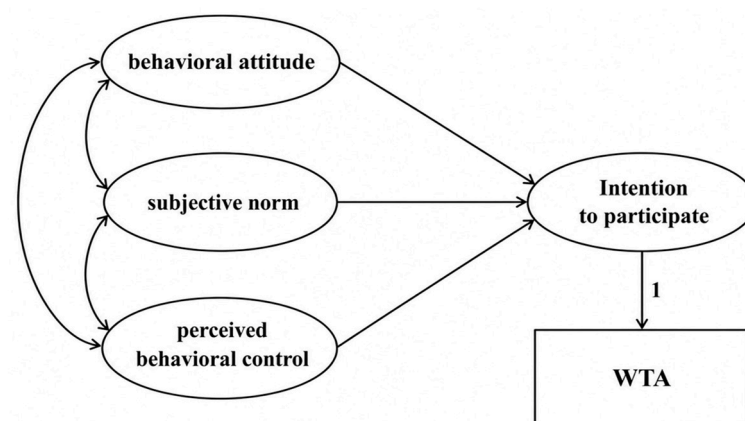


Figure 1. Conceptual framework relating the three behavioral constructs to participation intention, proxied by WTA. The three constructs point to the intention to participate, as in the standard TPB; the intention is measured by a single indicator, the individual-level WTA, with the loading fixed at 1 for identification [23,24,26], so a lower WTA corresponds to a stronger intention.

Behavioral attitude (Att) is defined as the degree to which a farmer holds a favorable evaluation of fertilizer reduction [17]. It was measured by four items capturing the perceived consequences of reduction for village water quality and farmland ecology (Att1), for environmental protection more broadly (Att2), for the cost-saving and income benefits of reduction (Att3), and for the quality of agricultural products (Att4) [18,20].

Table 2. Item-level means of the behavioral-construct measures by operator type.

Construct	Item	Description	Smallholders	Large-Scale Planters	Family Farms
Behavioral attitude (Att)	Att1	Reduction benefits village water quality and farmland ecology	3.17 (1.26)	3.16 (1.25)	3.41 (1.23)
	Att2	Reduction benefits environmental protection more broadly	3.80 (1.27)	3.95 (1.13)	3.98 (1.20)
	Att3	Reduction yields cost-saving and income benefits	3.41 (1.39)	3.56 (1.38)	3.73 (1.33)
	Att4	Reduction improves the quality of agricultural products	3.57 (1.34)	3.63 (1.35)	3.83 (1.27)
Social-institutional norm (Sn)	Sn1	Surrounding farmers adopt socialized fertilization/pesticide services	3.81 (1.00)	3.94 (0.99)	4.11 (0.86)
	Sn2	Local regulation and penalties for excessive input use are adequate	2.42 (1.15)	2.54 (1.06)	2.69 (1.05)
	Sn3	Perceived pressure from real-name purchase and quota management	2.10 (1.02)	2.65 (1.06)	2.84 (1.08)
Perceived behavioral control (Pbc)	Pbc1	Mastery of reduction techniques (e.g., soil-testing, deep placement)	2.78 (1.28)	2.83 (1.23)	3.00 (1.24)
	Pbc2	Capacity to acquire reduction knowledge via digital channels	3.48 (1.38)	3.66 (1.25)	3.92 (1.09)
	Pbc3	Adequacy of the supporting service environment	3.38 (1.48)	3.67 (1.23)	3.92 (1.13)

Notes: Entries are group means of five-point Likert items (1 = strongly disagree, 5 = strongly agree). Values are coded so that higher scores indicate stronger agreement; no items are reverse-worded. Standard deviations in parentheses. Kruskal–Wallis tests reject cross-group equality for all items except Att2 ($\chi^2(2) = 4.35, p = 0.114$); item $\chi^2(2)$ values range from 6.83 to 108.22, all other $p \leq 0.033$.

In TPB, the normative component, the subjective norm, is defined as the perceived social pressure to perform or refrain from a behavior [17]. In its standard form it refers to the influence of peers and family, but established practice in the agricultural TPB literature augments the construct with field-specific factors where the decision context warrants [20,22,30]. Fertilizer governance in China, and in Jiangsu in particular, is unusually institution-intensive: alongside peer influence, growers operate under regulatory enforcement against excessive chemical-input use and under administrative arrangements such as real-name fertilizer purchase and quota-based use, with large-scale operators targeted first [31]. Institutional theory provides a basis for treating such formal arrangements as a source of normative pressure: under its regulative dimension, formal rules, monitoring, and sanctions constitute legitimate expectations to which actors are expected to conform [32,33]. A construct restricted to peer influence would therefore omit a substantial part of the normative environment Jiangsu rice farmers actually perceive. Our normative construct is therefore deliberately broader than the subjective norm of the traditional TPB: it is a social-institutional normative construct spanning peer-level and formal institutional pressure. It nonetheless remains within the TPB normative component: the theory accommodates both injunctive and descriptive normative referents [17], and Sn1–Sn3 operationalize these referents for this institutional setting. The item set was refined through the pilot survey and an expert-panel discussion to reflect local farming and policy realities. To make this explicit and avoid conceptual ambiguity, we label the construct the social-institutional norm (Sn) throughout, reserving the term subjective norm for the traditional TPB concept; the item codes retain the Sn prefix. The specification and wording of the items were developed with explicit attention to farmers' cognitive capacity and to the local institutional and agricultural context, and were refined through expert panel discussions, the pre-survey focus groups, and the pilot survey described in Section 2.3, so that the construct captures the

normative environment as farmers themselves perceive it. Sn was accordingly measured by three items spanning this extended normative space: the extent to which surrounding farmers adopt socialized fertilization and pesticide services (Sn1, peer-level descriptive norm) [34], the perceived adequacy of local regulation and penalties for excessive chemical-input use (Sn2), and the perceived pressure associated with real-name fertilizer-purchase and quota-management arrangements (Sn3). As reported in Section 3, the three items load coherently on a single factor.

Perceived behavioral control (Pbc) is defined as the perceived ease or difficulty of performing the behavior, reflecting both internal capability and external facilitating conditions [17]. It was measured by three items reflecting the perceived mastery of reduction techniques such as soil-testing-based and deep-placement fertilization (Pbc1), the perceived capacity to acquire fertilizer-reduction knowledge through digital channels (Pbc2) [35], and the perceived adequacy of the supporting service environment (Pbc3) [18,20].

Table 2 reports the group means of the ten measurement items. For every item the level rises from smallholders to large-scale planters to family farms. The gradient is steepest for perceived institutional pressure (Sn3), which rises from 2.10 among smallholders to 2.84 among family farms, and for digital-information capacity and the supporting service environment (Pbc2 and Pbc3), each of which rises by roughly half a scale point. The regulation-related norm items (Sn2 and Sn3) are among the lower-rated items in every group, whereas the attitude items and the peer-adoption perception receive the most favorable ratings. Two features of the descriptives stand out. First, construct levels are moderate to favorable overall (most attitude and control items lie above the scale midpoint), so favorable evaluations of fertilizer reduction, and confidence in implementing it, are widespread. Second, the gradient itself is informative: more sophisticated, institutionally embedded operators report more favorable attitudes, stronger peer and capability perceptions, and higher perceived institutional pressure, consistent with their closer contact with extension services, socialized service providers, and regulatory programs (Table 1). The compressed range of several items nevertheless limits the variation available to the structural model and may attenuate the estimated associations.

2.3. Choice Experiment Design

Compensation expectations were elicited through a discrete choice experiment grounded in random utility theory and Lancaster's characteristics theory of value [36,37], under which a fertilizer-reduction compensation scheme is represented as a bundle of attributes and respondents are assumed to derive utility from the attribute levels. The attribute set was developed from the choice-experiment literature on fertilizer reduction, relevant national and provincial policy documents, and pre-survey focus groups with rice farmers and extension officials. It comprised eight attributes in four groups: five reduction-measure attributes, one support-service attribute, one compensation-mode attribute, and one compensation-level attribute (Table 3).

The five reduction measures (soil-testing-based fertilization, deep placement, organic substitution, crop rotation, and straw return) together form an integrated fertilizer-reduction measure bundle that constitutes the central object of our compensation analysis. A defining feature of the design is that this bundle is decomposed into five independent binary attributes rather than offered as a single aggregate or as mutually exclusive options. This decomposition serves two complementary purposes: it mirrors the way farmers in practice combine several reduction measures within a cropping system, and it allows the model to recover a distinct preference parameter for each measure while preserving the bundle as a coherent reduction-measure set. The compensation level was framed as the share of each scheme's incremental adoption cost that the program would reimburse.

The per-measure incremental cost benchmarks (in CNY per mu) underlying these shares were established from local market prices, focus-group elicitation, and consultations with extension officials, and were set at 30 for soil-testing-based fertilization, 50 for deep placement, 150 for organic substitution, 200 for crop rotation, and 30 for straw return. These benchmarks were disclosed to respondents before the choice tasks, so that each compensation share mapped to a transparent, bundle-specific monetary amount in CNY per mu; consequently, the marginal utility of compensation, and the willingness-to-accept values derived from it (Section 2.4), are identified against a cost-anchored monetary scale (CNY per mu) rather than against the raw percentage shares. The monetary compensation of an alternative therefore equals the offered share multiplied by the summed incremental costs of the measures it requires, so the amount varies with both the share and the composition of the bundle. Because the five share levels (0%, 30%, 50%, 80%, and 100%) vary independently of the measure combinations in the experimental design, the compensation amount is not a deterministic function of the measure indicators, and the compensation and measure parameters are separately identified.

Table 3. Attributes and levels of the choice experiment.

Attribute		Definition	Levels
Reduction-measure bundle	Soil-testing-based fertilization (x_1)	Adoption of soil-testing-based formulated fertilization, a precision technique that adjusts NPK application according to soil-test recommendations.	Not adopted; Adopted
	Deep placement (x_2)	Adoption of mechanized deep placement of fertilizer, which delivers fertilizer below the soil surface to reduce volatilization and runoff.	Not adopted; Adopted
	Organic substitution (x_3)	Partial substitution of chemical fertilizer with organic fertilizer (commercial organic fertilizer or composted manure).	Not adopted; Adopted
	Crop rotation (x_4)	Implementation of rice-based rotation in which a non-rice crop is grown on the same paddy following the rice harvest.	Not adopted; Adopted
	Straw return (x_5)	Mechanized incorporation of crop straw into the soil after harvest to enhance organic matter and reduce mineral-fertilizer demand.	Not adopted; Adopted
Support service		Form of technical support provided to farmers adopting the measures above.	Centralized classroom training; On-site field guidance
Compensation mode		Form in which compensation is delivered to participating farmers.	Income subsidy; Price subsidy; Input subsidy
Compensation level		Share of the alternative-specific incremental adoption cost reimbursed by the program.	0%, 30%, 50%, 80%, 100%

Notes: The notation $x_1, \dots, x_5$ denotes the five binary reduction-measure indicators used in the utility specification (Equation (1), Section 2.4). The five reduction-measure attributes together constitute the fertilizer-reduction measure bundle. Centralized classroom training is the reference level of the support-service attribute; income subsidy is the reference level of the compensation-mode attribute.

Because the full factorial combination of attribute levels ($2^6 \times 3 \times 5 = 960$ alternative profiles) was too large for field implementation, the choice tasks were generated in Ngene

1.2 [38] as a D-efficient fractional-factorial design under uninformative (zero) priors, yielding 36 tasks of two unlabeled alternatives each, in line with best-practice recommendations for stated-preference design [39,40]. Zero priors were adopted because no credible ex ante information on preference magnitudes was available for this multi-measure bundle; orthogonality and attribute-level balance were verified after generation. The 36 tasks were partitioned into 12 blocks of three, and each respondent was randomly assigned to one block. The design was further screened in Ngene 1.2 for dominated alternatives, and none was found; dominance is in any case only weakly defined ex ante here, because the subjective burden of each dummy-coded measure differs across farms. In each task, respondents chose among two alternative compensation schemes and a status-quo option (“do not participate in any reduction program”), under which no measure is required and no compensation is paid. With three choice tasks per respondent and three alternatives per task, the 1066 respondents yielded 9594 alternative-level observations for estimation. A sample choice card is shown in Table A1 (Appendix A).

The full questionnaire was piloted at a rice-farming cooperative in Nanjing to refine item wording and ordering before the main fieldwork. Interviews were administered face to face by trained enumerators, who read the attribute definitions and the cost information aloud and verified comprehension before the choice tasks began, so that each share mapped to a concrete amount per mu.

Several features of the design and survey protocol mitigate, although they cannot eliminate, hypothetical bias. Following protocols established in the stated-preference literature [41,42], enumerators delivered a cheap-talk reminder, adapted to the rural Chinese context, describing how stated choices may diverge from budget-constrained behavior, together with a budget reminder. In addition, the compensation attribute is anchored to disclosed, locally established incremental costs rather than to abstract payment amounts; the attributes correspond to instruments already operating in Jiangsu’s fertilizer-governance environment, which strengthens the credibility and consequentiality of the scenarios [40]; and the status-quo option was available in every task, so that no respondent was forced into a scheme. For respondents who selected the status quo in all three tasks (5.5% of the sample), a follow-up item elicited the reasons, allowing protest responses to be distinguished from substantive zero-bid preferences; the majority expressed reasoned zero-bid preferences, and all observations were retained. Finally, the number of choice tasks per respondent was deliberately limited to three, reflecting a trade-off between estimation efficiency and respondent burden in a population in which many respondents are older and formal schooling is limited (Table 1). A power analysis based on established choice-experiment sample-size guidance [43] supports this configuration: the rule-of-thumb minimum for main-effects estimation, $n \geq 500 c / (t \cdot a)$, with c the largest number of attribute levels, t the number of tasks per respondent, and a the number of alternatives per task, implies roughly 278–417 respondents, which the realized sample of 1066 exceeds severalfold, and most random-parameter standard deviations are precisely estimated within each operator type. The cost of the short sequence falls on the individual-level conditional estimates, which rest on few observations per respondent and are correspondingly shrunken toward the group means; this implication is discussed in Section 2.4.

2.4. Empirical Strategy

Our empirical strategy proceeds in two stages. In the first stage, we estimate preferences over the choice-experiment attributes and recover an individual-level willingness-to-accept (WTA) for each farmer. In the second stage, we treat WTA as a money-metric proxy for a farmer’s intention to participate in fertilizer reduction and model it as a function of the three behavioral constructs using structural equation modeling.

Preferences were estimated with a mixed-logit model, which accommodates unobserved preference heterogeneity by allowing attribute coefficients to vary randomly across respondents [44,45]. The utility that farmer n obtains from alternative j is specified as the sum of a systematic component and a random error term:

$$U_{nj} = \beta_n' x_{nj} + \varepsilon_{nj} \quad (1)$$

where x_{nj} is the vector of attribute levels of alternative j , β_n is a farmer-specific vector of taste parameters, and ε_{nj} is an independently and identically distributed extreme-value error term. The vector x_{nj} comprises the five binary reduction-measure indicators x_1, x_2, x_3, x_4 , and x_5 (soil-testing-based fertilization, deep placement, organic substitution, crop rotation, and straw return; see Table 3); a binary indicator for on-site field guidance (one if offered, zero for centralized classroom training, the reference category); separate indicators for the price-subsidy and input-subsidy compensation modes (with income subsidy as the reference); and the bundle-specific compensation amount in CNY per mu. The five reduction measures, the support-service attribute, and the two non-income compensation modes were specified as random parameters following normal distributions, while the compensation level was treated as a fixed parameter to keep the monetary scale constant across respondents and so facilitate the recovery of money-metric WTA values. The model was estimated by maximum simulated likelihood, separately for each operator type, so that the preference structure was allowed to differ across smallholders, large-scale planters, and family farms.

From the estimated model we then recovered each respondent's conditional (individual-specific) estimates of the non-monetary random parameters. These conditional estimates are the source of individual heterogeneity in WTA; because the compensation coefficient is fixed within each operator-type model, the marginal utility of compensation is common within a group but differs across groups. The individual-level WTA was computed for a reference scenario in which all five reduction measures are adopted, technical support is provided as on-site field guidance, and compensation is delivered as an income subsidy. Under this scenario, WTA is the negative ratio of the sum of the scenario's non-monetary preference parameters (the five measure parameters and the field-guidance parameter), net of the status-quo constant, to the group-specific marginal utility of compensation:

$$WTA_n = - \frac{\sum \beta_{nk} + \beta_{n,fg} - ASC_g}{\beta_{g,cost}} \quad (2)$$

where the numerator sums the individual-specific conditional estimates of the non-monetary preference parameters β_{nk} for the five required reduction measures and the conditional parameter of on-site field guidance $\beta_{n,fg}$, net of the alternative-specific constant (ASC) for the status-quo option, ASC_g , and $\beta_{g,cost}$ is the group-specific marginal utility of compensation. Netting out the status-quo constant expresses WTA relative to remaining outside any scheme rather than relative to a zero-utility baseline; being common within a group, this constant shifts all WTA values in the group by the same amount. The price- and input-subsidy parameters do not enter because compensation is evaluated at its income-subsidy base level. The resulting WTA is expressed in CNY per mu and serves as the dependent variable in the second stage.

Two features of this two-stage design deserve comment. An alternative would be full-information estimation, in which the latent constructs enter the utility function directly and the measurement, structural, and choice components are estimated jointly, as in integrated choice and latent variable (ICLV) models [23,46]. We prefer the two-stage design for reasons of transparency and fit to the research question. It keeps the recovery

of preferences free of assumptions about the behavioral structure, so that WTA retains a purely choice-theoretic interpretation and the behavioral model can be modified without re-estimating preferences; it delivers directly the object of policy interest, a money-metric summary of the intention to participate, rather than attribute-specific attitude effects; and joint estimation has known interpretational difficulties of its own, since an ICLV model can often be reduced to a choice model without latent variables that fits the choice data at least as well [47], although the framework can yield prediction, bias-correction, and efficiency benefits under particular conditions [47], and its latent-variable pathways do not by themselves support policy inference when the constructs are endogenous to the choice and the data are cross-sectional [48]. The cost of the two-stage design is statistical rather than conceptual. The individual-level WTA values are conditional (posterior-mean) estimates recovered from a small number of choices per respondent, so they contain estimation error and are shrunk toward the group means [44,49]. Because this estimated quantity serves as the dependent variable of the structural model, the error component inflates the residual variance and works against detecting the structural associations, and because the same group-level estimates of the compensation coefficient and the status-quo constant enter every respondent's WTA within a group, the estimation error is not independent across observations, so conventional second-stage standard errors may misstate the true uncertainty. We therefore read the structural estimates as conservative.

In the second stage, the behavioral mechanisms underlying WTA were analyzed using structural equation modeling (SEM). Behavioral attitude (Att), social-institutional norm (Sn), and perceived behavioral control (Pbc) are treated as latent variables, each measured by its respective survey items introduced in Section 2.2, with the measurement parameters and the structural relationships estimated jointly. Consistent with TPB, in which attitude, subjective norm, and perceived behavioral control shape behavioral intention, we treat participation intention as the latent outcome of the three constructs and use the individual-level WTA as its money-metric proxy [23,24]: at a given level of compensation, a lower WTA indicates a stronger intention to participate. This interpretation has an established basis in the valuation literature: Ajzen and Driver [25] analyzed contingent-valuation responses within TPB, treating stated willingness to pay for public goods as a behavioral intention arising from behavioral, normative, and control beliefs; early contingent-valuation applications then used the three constructs to explain stated monetary valuations of environmental goods [26], and recent studies continue to apply extended-TPB frameworks to predict stated willingness to pay [27], while hybrid-choice and latent-variable approaches connect attitudinal constructs to preferences and welfare estimates in choice models [22–24], including extended-TPB choice experiments in agri-environmental settings [20]. In TPB, intention captures a person's motivational readiness to perform a behavior, that is, how hard the person is willing to try [17], and the standing of this framework for the analysis of farmer decision making has been consolidated in a recent critical review [50]. In a compensation contract, that readiness has a natural monetary expression: the minimum payment at which the farmer is willing to enroll. The stronger a farmer's intention to reduce fertilizer use, the smaller the external inducement participation requires, so the WTA recovered from the choice data orders farmers on a monetary scale inversely related to the strength of their participation intention. The structural model relating WTA to the three constructs is

$$WTA = \gamma_1 Att + \gamma_2 Sn + \gamma_3 Pbc + \zeta \quad (3)$$

where γ_1 , γ_2 , and γ_3 are the structural coefficients of interest, capturing the associations of behavioral attitude, social-institutional norm, and perceived behavioral control with participation intention as expressed through WTA, and ζ is the structural disturbance. Because WTA is an inverse proxy for participation intention, a negative coefficient indicates

that a stronger construct is associated with a stronger intention to participate (i.e., with a lower required compensation), whereas a positive coefficient indicates the opposite. The model is estimated by maximum likelihood, and standardized coefficients are reported throughout to facilitate comparison of coefficient magnitudes across constructs.

We emphasize that WTA is a proxy for participation intention rather than a direct psychological measure of it. Because a reservation compensation is formed in an economic decision, it can also absorb considerations that lie outside the intention construct, including the expected on-farm cost of implementing the measures, production risk and the farmer's aversion to it, liquidity constraints, and preferences over contract attributes. Two features of the design limit, although they do not eliminate, these influences. First, WTA is computed for a common reference scenario (all five measures, on-site field guidance, and an income subsidy), so every respondent is evaluated against the same contract configuration rather than against self-selected attribute mixes. Second, compensation was framed as a share of disclosed, bundle-specific incremental costs, anchoring the monetary scale to implementation cost. Within TPB itself, perceived behavioral control is the channel through which perceived difficulty, resource constraints, and implementation risk are expected to operate, so part of the cost- and risk-related variation in WTA is captured by, rather than confounded with, the behavioral model. Residual influences of risk preferences and liquidity constraints nonetheless cannot be ruled out.

To examine whether the behavioral mechanism, rather than only the level of WTA, differs across operator types, the structural model was estimated as a multi-group SEM with operator type as the grouping variable. In this specification the measurement model is held common across groups (the factor loadings are constrained to be equal), while the three structural paths are left free to vary across the three operator types. This design isolates cross-group differences in the structural mechanism while maintaining a common measurement scale, so that the group-specific estimates of the three paths ($Att \rightarrow WTA$, $Sn \rightarrow WTA$, and $Pbc \rightarrow WTA$) are directly comparable in both magnitude and direction. The full-sample model was estimated alongside the multi-group specification for comparison. All models were estimated in Stata 16.0.

3. Results

3.1. Mixed-Logit Estimates by Operator Type

The mixed-logit model was estimated separately for each operator type to recover the preference structure underlying farmers' WTA. Table 4 reports the estimated means and standard deviations of the random parameters together with the fixed compensation and status-quo coefficients. Three features are relevant for the behavioral analysis. First, the marginal utility of compensation is positive and highly significant in all three groups (0.016 among smallholders, 0.015 among large-scale planters, and 0.012 among family farms), with family farms displaying the lowest value. Because WTA is inversely proportional to this coefficient, a given non-monetary preference translates into a higher WTA for family farms than for the other two groups. Second, the status-quo constant is strongly negative in every group, and its magnitude weakens across operator types, suggesting that smallholders are the most reluctant to remain in the status quo once a scheme is offered. Third, organic substitution and crop rotation carry significantly negative coefficients in all three groups, indicating broad reluctance toward the most operationally demanding measures, while soil-testing-based fertilization is valued positively and significantly only among family farms. The estimated standard deviations are significant for most attributes across all three groups, confirming that substantial preference heterogeneity persists within each operator type and motivating the individual-level extraction of WTA used in the structural analysis.

Table 4. Mixed-logit estimation results for the three operator types.

Variable	Smallholders		Large-Scale Planters		Family Farms	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Fixed parameters						
Compensation	0.016 ***	(0.003)	0.015 ***	(0.003)	0.012 ***	(0.002)
ASC (status quo)	−4.067 ***	(0.553)	−3.896 ***	(0.581)	−2.977 ***	(0.331)
Random parameters: means						
Soil-testing-based fertilization	0.081	(0.247)	0.279	(0.247)	0.385 **	(0.166)
Deep placement	−0.419	(0.265)	−0.113	(0.246)	0.275 *	(0.163)
Organic substitution	−1.033 ***	(0.325)	−1.571 ***	(0.347)	−1.305 ***	(0.247)
Crop rotation	−2.647 ***	(0.477)	−2.151 ***	(0.421)	−1.644 ***	(0.288)
Straw return	−0.420 *	(0.242)	−0.314	(0.235)	−0.104	(0.151)
Field guidance	0.403	(0.279)	−0.015	(0.243)	0.156	(0.151)
Price subsidy	−0.867 **	(0.337)	−0.591	(0.378)	−0.245	(0.212)
Input subsidy	−0.650 **	(0.285)	−0.249	(0.307)	−0.662 ***	(0.210)
Random parameters: standard deviations						
Soil-testing-based fertilization	1.864 ***	(0.547)	1.690 ***	(0.443)	1.293 ***	(0.340)
Deep placement	2.382 ***	(0.515)	1.136 **	(0.580)	1.185 ***	(0.355)
Organic substitution	2.600 ***	(0.541)	1.053 **	(0.507)	1.012 ***	(0.321)
Crop rotation	2.319 ***	(0.530)	1.797 ***	(0.529)	0.749 *	(0.401)
Straw return	1.904 ***	(0.472)	0.939 *	(0.548)	1.193 ***	(0.361)
Field guidance	3.502 ***	(0.633)	1.354 **	(0.560)	0.517	(0.509)
Price subsidy	3.439 ***	(0.691)	2.944 ***	(0.759)	1.661 ***	(0.445)
Input subsidy	1.897 ***	(0.578)	1.907 ***	(0.544)	0.726	(0.485)
Model statistics						
Observations	4329		2178		3087	
Log-likelihood (mixed logit)	−1144.49		−545.18		−773.69	
Log-likelihood (conditional logit)	−1230.89		−572.86		−793.19	
Log-likelihood (null)	−1290.45		−616.93		−864.49	
Mcfadden pseudo-R ²	0.113		0.116		0.105	
LR test vs. conditional logit, $\chi^2(8)$	172.80 ***		55.37 ***		39.00 ***	
AIC	2324.98		1126.36		1583.38	
BIC	2439.69		1228.71		1692.01	

Notes: Standard errors in parentheses. ***, **, * denote significance at the 1%, 5%, and 10% levels. Estimates are based on 500 Halton draws. The compensation coefficient and the ASC are fixed parameters; all other attributes are random parameters following normal distributions. Standard deviations are interpreted as positive regardless of sign.

3.2. Willingness-to-Accept Estimates

From the mixed-logit estimates we recovered each farmer's individual-level WTA for the full bundle of five reduction measures, which serves as the money-metric proxy for the intention to participate in fertilizer reduction. The distribution of these values is summarized in Table 5. Compensation expectations differ across operator types: smallholders and large-scale planters hold expectations close to zero on average (group means of −2.5 and 1.3, respectively), whereas family farms exhibit a substantially negative mean of −60.3, with the pooled mean at −20.2. The most institutionally embedded operators are thus, on average, the most willing to adopt the full bundle: family farms would forgo roughly 60 CNY per mu rather than remain outside the scheme, which corresponds to the strongest intention to participate at any given level of compensation. The wide standard deviations within each group confirm that WTA values are highly heterogeneous among individual farmers. Because individual WTA divides the individual-specific conditional bundle utility by the group-level marginal utility of compensation, the wide range and the extreme minima and maxima reflect genuine heterogeneity in conditional preferences; their

influence on the structural results is examined in Section 3.4. A negative WTA indicates that the farmer obtains positive net utility from the subsidized, guidance-supported bundle and would in principle accept it without additional payment. The predominance of negative values reflects the strongly negative status-quo constants (Table 4): farmers attach substantial disutility to remaining outside any scheme, and for most respondents this outweighs the burden of the reduction measures, a reading corroborated by the fact that only 5.5% of respondents chose the status quo in all three tasks, predominantly with reasoned justifications. Nor is the pattern an artifact of the ratio construction: the denominator is the group-level compensation coefficient, precisely estimated at the 1% level in every model and common within groups, and the sign pattern is robust to trimming and winsorizing of extreme values and to the inclusion of socioeconomic controls (Section 3.4). A negative value is therefore read as the amount a farmer would forgo rather than be excluded from the scheme, not as direct evidence of intention strength. Figure 2 displays the kernel-density distributions of WTA by operator type. The structural analysis below seeks to explain this heterogeneity. This raw difference in the level of compensation expectations provides a descriptive motivation for the central question of the paper: whether the behavioral mechanisms generating that demand differ across operator types, beyond differences in its level.

Table 5. Distribution of compensation expectations (WTA) by operator type.

Operator Type	Mean	Std. dev.	Min	Max
Smallholders ($n = 481$)	−2.49	274.71	−445.88	1059.65
Large-scale planters ($n = 242$)	1.29	134.26	−271.73	650.53
Family farms ($n = 343$)	−60.31	120.65	−286.51	521.27
Full sample ($n = 1066$)	−20.24	208.64	−445.88	1059.65

Notes: WTA is the individual-level willingness-to-accept the full bundle of five reduction measures under an income subsidy with on-site field guidance, computed from conditional mixed-logit parameters and expressed in CNY per mu. The formula includes the conditional parameters of the five reduction measures (x_1 – x_5) and of on-site field guidance, net of the status-quo constant; the constant structure embodies the income-subsidy, centralized-training base configuration, with centralized training replaced by on-site field guidance in the evaluated scenario. Medians (interquartile ranges): smallholders −12.43 (311.9); large-scale planters 9.93 (172.0); family farms −78.34 (126.6); full sample −40.88 (225.8). A lower WTA corresponds to a stronger intention to participate at a given level of compensation.

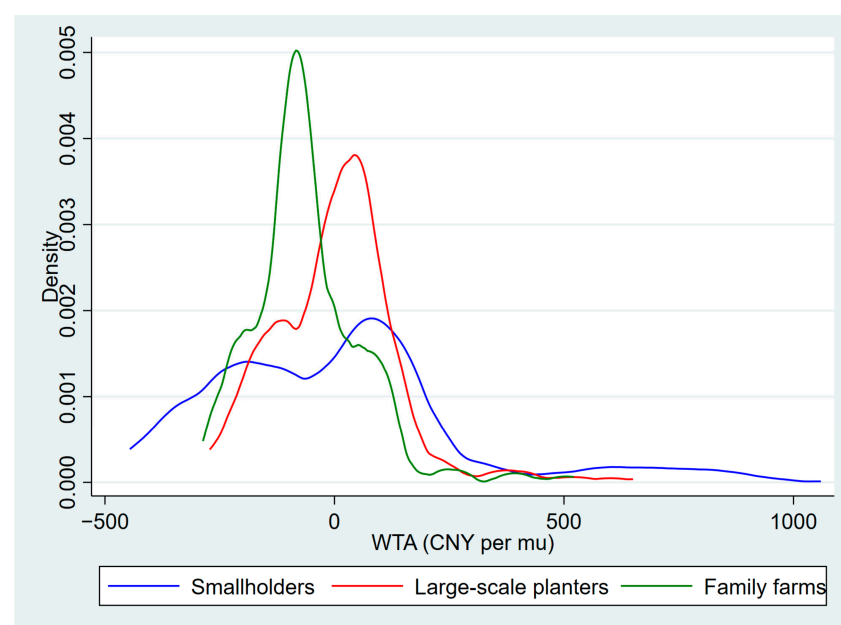


Figure 2. Kernel-density distributions of individual willingness-to-accept (WTA, CNY per mu) by operator type.

3.3. Measurement Model

Before estimating the structural relationships, we assessed the measurement properties of the three latent constructs. Table 6 reports the standardized factor loadings from the confirmatory measurement model, estimated on the full sample, together with the internal-consistency reliabilities. All ten items load significantly and substantially on their intended constructs, with standardized loadings ranging from 0.74 to 0.90 and all exceeding the conventional 0.70 threshold. The social-institutional norm construct, which integrates peer-level descriptive norms with institutional norms, achieves uniformly high loadings (0.77 to 0.79), indicating that perceived peer uptake of socialized services (Sn1), perceived regulatory adequacy (Sn2), and perceived institutional pressure (Sn3) cohere as a single normative dimension in this setting. Construct reliability and convergent validity are satisfactory for all three constructs: Cronbach's alpha [51] ranges from 0.824 to 0.856 and composite reliability from 0.826 to 0.888, both above the 0.70 threshold, while the average variance extracted (AVE) ranges from 0.613 to 0.666, above the 0.50 threshold [52]. Discriminant validity is also supported: following the Fornell–Larcker criterion [52], the square root of each construct's AVE (0.78 to 0.82) exceeds the construct's correlations with the other two constructs, which range from 0.354 to 0.593. These results indicate that the three constructs are reliable, internally coherent, and empirically distinct, supporting their use as measured latent variables in the structural model.

Table 6. Measurement model: standardized loadings and reliability.

Construct	Item	Std. Loading	α	CR	AVE
Behavioral attitude	Att1	0.896	0.856	0.888	0.666
	Att2	0.806			
	Att3	0.786			
	Att4	0.770			
Social-institutional norm	Sn1	0.786	0.824	0.826	0.613
	Sn2	0.791			
	Sn3	0.771			
Perceived behavioral control	Pbc1	0.843	0.848	0.852	0.659
	Pbc2	0.740			
	Pbc3	0.848			

Notes: Standardized loadings are from a confirmatory measurement model estimated by maximum likelihood on the full sample ($n = 1066$); all loadings are significant at the 1% level. Model fit: $\chi^2(32) = 149.83$, CFI = 0.979, TLI = 0.970, RMSEA = 0.059 [90% CI 0.049–0.068], SRMR = 0.041. Heterotrait–monotrait ratios: Att–Sn = 0.374, Att–Pbc = 0.522, Sn–Pbc = 0.599, all below the 0.85 criterion. Item codes (Att1–Pbc3) are defined in Table 2. α = Cronbach's alpha; CR = composite reliability; AVE = average variance extracted. Inter-construct correlations are 0.354 (attitude–norm), 0.495 (attitude–control), and 0.593 (norm–control); the square root of each AVE (0.78–0.82) exceeds these correlations, supporting discriminant validity.

3.4. Structural Model: Full Sample and Operator-Type Heterogeneity

We first estimated the structural model on the pooled sample, regressing the individual-level WTA on the three behavioral constructs. The results are reported in the first column of Table 7. In the pooled specification only the social-institutional norm carries a significant coefficient (standardized -0.103 , $p = 0.021$); behavioral attitude (-0.029 , $p = 0.441$) and perceived behavioral control (-0.045 , $p = 0.344$) are both insignificant. Taken at face value, the pooled estimates would suggest that attitude and perceived control play little role in how farmers form their WTA. As the multi-group estimates show, however, this apparent weakness reflects the aggregation of operator types in which attitude and perceived control are each operative only within a subset of groups: because these effects are concentrated in particular subgroups rather than shared across the sample, they attenuate toward zero when the groups are pooled. The social-institutional norm, by contrast, is associated with

a lower WTA among both smallholders and family farms, which together form the large majority of the sample, and so remains detectable in the pooled estimate.

Table 7. Structural and measurement estimates: full sample and multi-group SEM.

Parameter	Full Sample		Smallholders		Large-Scale Planters		Family Farms	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Structural model								
Behavioral attitude	−0.029	(0.038)	−0.100 *	(0.057)	0.114	(0.077)	0.060	(0.070)
Social-institutional norm	−0.103 **	(0.045)	−0.151 **	(0.068)	0.100	(0.094)	−0.125 *	(0.070)
Perceived behavioral control	−0.045	(0.048)	0.056	(0.075)	−0.234 **	(0.099)	−0.192 **	(0.080)
Measurement model								
Att1	0.896	(0.010)	0.891	(0.013)	0.906	(0.018)	0.896	(0.014)
Att2	0.806	(0.013)	0.785	(0.018)	0.810	(0.022)	0.830	(0.019)
Att3	0.786	(0.014)	0.789	(0.019)	0.761	(0.025)	0.795	(0.020)
Att4	0.770	(0.015)	0.765	(0.019)	0.755	(0.026)	0.785	(0.021)
Sn1	0.785	(0.017)	0.775	(0.022)	0.775	(0.031)	0.754	(0.028)
Sn2	0.791	(0.017)	0.800	(0.021)	0.792	(0.028)	0.725	(0.029)
Sn3	0.771	(0.017)	0.824	(0.019)	0.759	(0.029)	0.700	(0.031)
Pbc1	0.843	(0.013)	0.883	(0.015)	0.803	(0.027)	0.772	(0.026)
Pbc2	0.739	(0.017)	0.760	(0.021)	0.686	(0.030)	0.721	(0.026)
Pbc3	0.848	(0.013)	0.846	(0.017)	0.844	(0.025)	0.833	(0.022)
Observations	1066		481		242		343	

Notes: Entries in the structural panel are standardized structural coefficients with standard errors in parentheses; **, * denote significance at the 5%, and 10% levels. The full-sample column is estimated on pooled data (model fit: CFI = 0.979, RMSEA = 0.054, SRMR = 0.038; R^2 for WTA = 0.023). The multi-group model fits with CFI = 0.951, TLI = 0.945, RMSEA = 0.072, SRMR = 0.056; R^2 for WTA is 0.030, 0.036, and 0.061 by operator type. Measurement-invariance tests and robustness analyses are reported in Section 3.4. The three operator-type columns are estimated jointly in a multi-group SEM in which the factor loadings are constrained equal across groups while the structural paths are left free. The measurement panel reports standardized factor loadings (standard errors in parentheses), all significant at the 1% level; item codes are defined in Table 2. The dependent variable is the individual-level WTA, a money-metric proxy for the intention to participate (a lower WTA indicating a stronger intention).

The multi-group specification, which holds the measurement model common across groups while allowing the three structural paths to vary, recovers the behavioral structure that the pooled model conceals. The measurement loadings (reported in the lower panel of Table 7) are uniformly high and stable, confirming that the three constructs are measured consistently across operator types and that the cross-group differences are located in the structural paths rather than in measurement. The structural estimates reveal that each behavioral construct operates through a different subset of operator types. First, behavioral attitude is negative and marginally significant among smallholders (-0.100 , $p = 0.079$) but insignificant among large-scale planters (0.114 , $p = 0.138$) and family farms (0.060 , $p = 0.389$): a more favorable attitude is associated with a lower WTA, that is, a stronger intention to participate, only among smallholders. Second, the social-institutional norm is negative and significant among smallholders (-0.151 , $p = 0.027$) and marginally significant among family farms (-0.125 , $p = 0.073$), while remaining insignificant among large-scale planters (0.100 , $p = 0.287$), so that stronger perceived normative and regulatory pressure is associated with a lower WTA among smallholders and family farms but not among large-scale planters. Third, perceived behavioral control is insignificant among smallholders (0.056 , $p = 0.455$) but negative and significant among both large-scale planters (-0.234 , $p = 0.018$) and family farms (-0.192 , $p = 0.017$), so that greater perceived control is associated with a lower WTA only among the two larger-scale operator types. What varies across operator types is thus the behavioral mechanism behind WTA, not merely its level: attitude is operative among smallholders, the social-institutional norm among smallholders and family farms, and

perceived behavioral control among large-scale planters and family farms. Two of these paths (the attitude path among smallholders and the norm path among family farms) are significant only at the 10% level, and we accordingly treat them as suggestive throughout the interpretation that follows.

Two further analyses complete the multi-group evidence. Table A2 (Appendix B) reports the measurement-invariance sequence: metric invariance, the level required for comparing structural paths across groups, is adequately supported ($CFI = 0.973$, $\chi^2/df \approx 2.5$), whereas item-intercept (scalar) invariance is rejected and is reported transparently; no conclusion in the paper depends on it, as the analysis compares structural paths rather than latent means. Constraining the three structural paths equal across operator types is rejected ($\chi^2(6) = 15.39$, $p = 0.017$; parameter-level tests: social-institutional norm $p = 0.035$, attitude $p = 0.066$, perceived control $p = 0.095$), the formal counterpart of the heterogeneity documented above. Table A3 shows that this pattern is robust to trimming and winsorizing extreme WTA values, with one exception (the smallholder norm association weakens under trimming and is accordingly read as suggestive), and a bootstrap of the full two-stage procedure (100 replications, resampling respondents within operator type) indicates that the second-stage standard errors are not materially understated.

4. Discussion

This study examined how much compensation farmers require for fertilizer reduction, which behavioral factors are associated with their expectations, and whether those associations differ across operator types. Three results stand out: the behavioral correlates of WTA differ across operator types; this heterogeneity is obscured under pooled estimation; and the resulting pattern bears directly on the design of differentiated compensation policy.

These findings should be interpreted in light of the cross-sectional nature of the data. The relationships discussed below represent behavioral associations rather than causal effects: the analysis identifies how attitudes, social-institutional norms, and perceived behavioral control are associated with farmers' compensation expectations, but does not establish that changes in these constructs would necessarily lead to changes in WTA.

4.1. Heterogeneous Behavioral Mechanisms Behind Compensation Expectations

We read WTA as an inverse proxy for a farmer's intention to participate: a lower required payment indicates a stronger willingness to reduce fertilizer use. The clearest cross-group difference is in the attitude channel, which is operative only among smallholders. A more favorable attitude is associated with a lower WTA among smallholders, whereas it has no detectable association among large-scale planters or family farms. Smallholders farm small areas and, as Table 1 shows, earn only a small share of household income from agriculture, so adjusting fertilization is a low-stakes change and a favorable disposition is reflected directly in a lower required payment. Large-scale planters and family farms cultivate much larger areas and depend on farming for most of their income; because fertilizer is widely regarded as a risk-reducing input and cutting it raises output uncertainty [53], for these operators the payment demanded appears tied less to general attitude than by the capability and institutional considerations discussed below, and a favorable attitude alone is not associated with a lower payment. Because the smallholder coefficient is significant only at the 10% level, we read the attitudinal channel as suggestive rather than firmly established. This pattern speaks to prior TPB research on farmers' fertilizer-reduction intentions, which, estimated largely on undifferentiated samples, generally reports a favorable attitude as a positive driver of the willingness to reduce [18,20]; our smallholder estimate is consistent with that evidence, while the absence of a comparable

association among the two larger-scale operator types indicates that this attitudinal channel does not extend uniformly across operators, a distinction that pooled designs cannot reveal.

Perceived behavioral control follows a different logic, one that depends on whether felt confidence is backed by the resources to act. Among large-scale planters and family farms, greater perceived control is associated with a lower WTA. These operators command the land, equipment, capital, and access to socialized services needed to implement reduction techniques (soil-testing-based fertilization, deep placement, and organic substitution) at manageable cost, so feeling capable reflects a real ability to carry out the change cheaply. Among smallholders, perceived control shows no detectable association with WTA. For the least-resourced operators, the factors that actually determine implementation cost (access to capital and machinery, the availability of labor, and the reach of extension and socialized services) lie largely outside individual control, so subjective confidence is not associated with the payment a smallholder requires. Perceived control is thus associated with WTA only where the underlying resources make that control real.

The social-institutional norm shows a clearer pattern here than in many pooled studies: stronger perceived normative and regulatory pressure is associated with a lower WTA among both smallholders and registered family farms, while having no detectable association among large-scale planters. This fits how the two responsive groups are embedded in normative channels. Smallholders are tied into dense village social networks, in which descriptive norms about peer uptake of socialized services and the salience of fertilizer regulation are felt directly. Registered family farms hold formal status and are tied most directly into policy channels (extension programs, subsidy eligibility, and arrangements such as quota management and real-name fertilizer purchase), so regulatory signals reach them concretely and compliance is already part of how they operate. Large-scale planters, who often farm at scale as commercial producers without certified status and at arm's length from both village networks and the formal apparatus, are less exposed to either source of pressure, consistent with the absence of an effect in that group. Because our social-institutional norm construct integrates peer descriptive norms with formal institutional pressure [32,33], it captures the channel operating among both the village-embedded smallholders and the institutionally embedded family farms. As the family-farm coefficient is significant only at the 10% level, we treat the normative channel as well established among smallholders and suggestive among family farms.

These results explain why pooled estimation is uninformative about the underlying behavioral structure. In the pooled sample, attitude and perceived behavioral control show no detectable association with WTA, which taken at face value would suggest that these behavioral factors do not matter. The multi-group estimates show this to be largely an artifact of aggregation: the attitude coefficient is negative among smallholders but statistically absent among large-scale planters and family farms, and the perceived-control coefficient is negative among the two larger-scale types but absent among smallholders, so that effects concentrated in different subsets of operators wash out when the groups are combined. Only the social-institutional norm, which is associated with a lower WTA among both groups in which it is operative, survives pooling. The pooled nulls thus reflect not the absence of behavioral structure but the attenuation of group-specific effects. This has a wider implication for the choice-experiment literature on fertilizer reduction, which has documented extensive preference heterogeneity yet has typically estimated behavioral relationships on pooled samples, with heterogeneity entering through interaction terms or as variation around a common mean. Where the operative behavioral channel differs across operator types and is concentrated in particular groups rather than shared as a common effect, pooled estimation can understate or even erase relationships that are substantial within groups, so disaggregating by a structurally meaningful partition is a precondition for recovering them.

4.2. Implications for Differentiated Policy Design

The behavioral findings carry implications for compensation policy that go beyond the setting of payment levels. Because the constructs associated with compensation expectations differ across operator types, so may the most cost-effective policy levers. Raising payment rates addresses only the monetary margin and leaves untouched the behavioral channels through which expectations are formed.

For smallholders, the channels associated with WTA are attitudinal and normative: a more favorable view of reduction, and stronger perceived normative and regulatory pressure, are each associated with a lower required payment, while perceived control has no measurable association. Interventions that strengthen smallholders' appreciation of the benefits of reduction (demonstration plots, peer testimonials, and targeted communication of the cost savings from measures such as soil-testing-based fertilization, and farmer-education activities that explain the purpose and benefits of each measure), together with measures that raise the visibility of peer uptake and regulatory expectations, may lower their WTA more efficiently than payment increases alone, consistent with the comparatively low regulation-related ratings among smallholders (Table 2). Capability-building appears unlikely, on this evidence, to shift their expectations, because their binding constraints are material rather than perceptual; relaxing those resource constraints is a precondition for capability to matter.

For large-scale planters and family farms, perceived behavioral control is the channel associated with WTA: greater perceived control is associated with a lower required payment. Investments in technical training, extension contact, and the supporting service environment may reduce the payment these operators require, complementing or partly substituting for direct payments. Among registered family farms, the social-institutional norm is operative as well, suggesting that for these institutionally embedded operators strengthening institutional engagement (compliance expectations, monitoring, and the visibility of institutional signals) could complement financial incentives. These channels map directly onto the experimental attributes. First, because perceived control is the operative channel among large-scale planters and family farms, and on-site field guidance is the support modality these operators face in the program design, capability support is best delivered through field-based guidance rather than centralized training for these groups. Second, both alternative compensation modes carry significant disutility relative to the income subsidy in at least one group (Table 4), so the direct income-subsidy channel is the cost-effective default, and any shift toward price- or input-linked delivery would itself require additional compensation. Third, the largest estimated burdens attach to crop rotation and organic substitution in every group, so compensation schedules and guidance intensity should be weighted toward these measures, while soil-testing-based fertilization, which family farms value positively, requires little inducement among the more sophisticated operators. Together these patterns point to a differentiated policy design in which the instrument is matched to the channel associated with each operator type: attitudinal and normative interventions for smallholders, capability-building support for large-scale planters and family farms, and institutional engagement for registered family farms in particular. The relevant difference is not only how much to pay, but which non-monetary channel to engage.

5. Conclusions

This study examined the behavioral factors associated with rice farmers' compensation expectations for fertilizer reduction, asking how much compensation farmers require, which behavioral factors are associated with those expectations, and whether those associations differ across operator types. Combining choice-experiment data with a TPB framework,

we treated each farmer's willingness-to-accept the full bundle of reduction measures as the monetary threshold at which their willingness to reduce fertilizer becomes operational in a policy contract and modeled it as a function of behavioral attitude, social-institutional norm, and perceived behavioral control, estimating the model across conventional smallholders, specialized large-scale planters, and family farms.

The analysis yields three main findings. First, a more favorable attitude is associated with a lower WTA among smallholders, consistent with a stronger intention to participate, but has no detectable association among large-scale planters or family farms, so the attitudinal channel is specific to smallholders, though the evidence for it is tentative. Second, the social-institutional norm is associated with a lower WTA among smallholders and family farms (the latter again only at the 10% level), while perceived behavioral control is associated with a lower WTA among large-scale planters and family farms; the normative and capability channels thus operate among different, partly overlapping sets of operators, and each behavioral construct is operative for only a subset of operator types. Third, these heterogeneous mechanisms are masked in pooled estimation, where the group-specific effects offset one another or attenuate toward zero and yield a misleadingly weak aggregate relationship.

These findings have practical implications for differentiated compensation policy. Because the behavioral factors associated with WTA vary across operator types, uniform payment increases may not be the most efficient response. For smallholders, communication, peer-based demonstration, and clearer institutional signals may complement financial incentives, whereas technical and service support may be more relevant for large-scale planters and family farms. Stronger institutional engagement may also be particularly relevant for registered family farms. Compensation schemes should therefore consider not only how much farmers are paid, but also which forms of non-monetary support are most relevant to each operator type. Given the cross-sectional design, however, the effectiveness of these interventions should be assessed through pilot programs or experimental evaluation. More broadly, the analysis extends TPB from the explanation of adoption intentions to the explanation of WTA and suggests that the behavioral channel associated with compensation expectations may depend on the operator's structural position. Although this study focuses on rice farmers in Jiangsu Province, the framework may also be useful in other settings where farmers weigh private adoption costs against environmental benefits. Linking stated compensation expectations to behavioral and institutional factors could help analyze participation in other crops, regions, and agri-environmental programs, including nutrient management, climate-smart agriculture, and ecosystem-service schemes. The specific coefficients and compensation levels reported here should not, however, be assumed to transfer directly beyond Jiangsu. Their broader relevance needs to be tested using data from other production systems and institutional contexts. Several limitations should be noted. First, the analysis is cross-sectional, and although the behavioral constructs are measured independently of the choice tasks, reverse influence or common unobserved causes cannot be ruled out; the structural paths are therefore associations, and establishing causality would require panel data, experimental variation, or instruments. Second, WTA is a money-metric proxy for participation intention rather than a direct psychological measure [25–27]; a reservation compensation also reflects implementation costs, risk aversion, liquidity constraints, and contract preferences, and complementing it with psychometric intention items would allow the proxy relationship to be tested directly. Third, the dependent variable is itself estimated: the individual WTA values are conditional posterior means recovered from three choice tasks, so they carry estimation error and are shrunken toward group means [44,49]; the bootstrap reported in Section 3.4 indicates that the resulting understatement of second-stage uncertainty is limited, and one association, the smallholder

norm path, is sensitive to trimming extreme values and is read as suggestive. Fourth, the evidence rests on stated preferences from a single province, so hypothetical bias cannot be excluded, and validating the recovered WTA against actual program participation and replicating the analysis in other rice-producing regions would strengthen external validity.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. This non-interventional questionnaire survey was filed with and approved by the College of Economics and Management, Northwest A&F University before data collection (approval date: 2 September 2024; no formal approval/reference number was assigned). The College had not established a dedicated Institutional Review Board or Ethics Committee for this type of minimal-risk, anonymous questionnaire survey. The survey did not collect personally identifiable information, biological samples, medical/health data, images, or videos. Participants were informed of the study purpose, anonymity, data use, potential risks, and their right to refuse or terminate the survey at any time.

Informed Consent Statement: Verbal informed consent was obtained from all participants. Verbal consent was obtained rather than written because this was an anonymous, non-interventional, minimal-risk questionnaire survey, and written signatures would have created unnecessary identifiable records.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy or other restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Each respondent completed three choice tasks. In each, two designed compensation alternatives (A and B) were shown against a status-quo alternative (C, “do not participate”), under which no measure is required and no payment is made. Compensation is expressed as the share of a scheme’s incremental adoption cost that the program reimburses; the per-measure cost benchmarks (CNY per mu, Section 2.3) were disclosed to respondents beforehand, so each share mapped to a concrete amount. Table A1 gives an example.

Table A1. Example of a choice card as presented to respondents (translated).

Attribute	Alternative A	Alternative B	Alternative C (Status quo)
Reduction-measure bundle	Soil-testing-based fertilization; Organic substitution	Deep placement; Crop rotation; Straw return	None
Support service	On-site field guidance	Centralized classroom training	Not applicable
Compensation mode	Price subsidy	Input subsidy	Not applicable
Compensation level	30% of incremental cost	50% of incremental cost	0%
Please tick your preferred option	☐	☐	☐

Notes: One example card from the experimental design. Attribute levels of A and B varied across the three tasks under the experimental design; the status quo (C) was fixed. Each of the five reduction measures was binary (adopted/not adopted), and those listed under A and B are the measures required under each scheme. Per-measure incremental cost benchmarks (CNY per mu) are given in Section 2.3.

Appendix B

Appendix B reports supplementary estimation results. Table A2 traces the measurement-invariance and structural-equality sequence. Each model adds one further set of cross-group equality constraints to the model above it, so that a non-significant test against the preceding model indicates that the added constraints hold.

Table A2. Measurement-invariance and structural-equality tests across operator types.

Model	CFI	TLI	RMSEA	SRMR	Test vs. Previous Model
M1 Configural	—	—	—	—	—
M2 Metric (loadings equal)	0.973	0.966	0.057	0.051	$\chi^2(14) = 34.65, p = 0.002$
M3 Scalar (item intercepts equal)	0.955	0.949	0.070	0.053	$\chi^2(14) = 116.42, p < 0.001$
M4 Scalar + WTA intercept (Table 7 model)	0.951	0.945	0.072	0.056	$\chi^2(2) = 25.23, p < 0.001$
M5 Structural (paths equal)	0.949	0.945	0.072	0.057	$\chi^2(6) = 15.39, p = 0.017$

Notes: The configural baseline is established by group-wise estimation (summed log-likelihood = 16,418.62); the jointly estimated unconstrained model did not converge. Item intercepts are the intercepts of the ten survey items, and the WTA intercept is the intercept of the outcome. Each likelihood-ratio test compares the model with the one in the row above. The χ^2 tests are sensitive to the sample size ($n = 1066$).

Table A3. Robustness of structural paths to extreme WTA values (unstandardized coefficients, per 100 CNY).

Path	Baseline	Trim 2.5/97.5	Trim 5/95	Winsorize 2.5/97.5	Winsorize 5/95
Smallholders: Att	−0.244 *	−0.223 **	−0.239 ***	−0.224 *	−0.209 **
Smallholders: Sn	−0.540 **	−0.145	−0.177	−0.458 **	−0.353 **
Smallholders: Pbc	0.133	0.042	0.147	0.105	0.121
Planters: Att	0.140	0.086	0.054	0.136	0.106
Planters: Sn	0.186	0.264	0.267 *	0.193	0.245
Planters: Pbc	−0.327 **	−0.320 **	−0.160	−0.327 **	−0.282 **
Family farms: Att	0.068	0.069	0.026	0.067	0.049
Family farms: Sn	−0.237 *	−0.222 *	−0.216 *	−0.234 *	−0.205
Family farms: Pbc	−0.266 **	−0.247 **	−0.188 *	−0.265 **	−0.241 **

Notes: Estimation samples: $n = 1066$ (baseline and winsorized), 1014 (trim 2.5/97.5), 960 (trim 5/95). ***, **, * denote significance at the 1%, 5%, and 10% levels. Winsorizing caps extreme values at the stated percentiles; trimming excludes them.

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