Savior or Driver? Retailer recommendation and pesticide overuse

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Abstract: Pesticide overuse is commonly attributed to farmers, while pesticide retailers have received limited attention due to the challenge of observing their actual sales behavior. This study applies an a between-subject design audit experiment to examine the pesticide recommendation practices of retailers. In the control group, where simulated customers do not read pesticide labels and solely rely on retailers' guidance for purchase decisions, 79.80% of retailers suggest dosages surpassing the labeled maximum. Conversely, this figure decreases to 51.58% when the retailer discovers that the customer will read the label. Encouragingly, our findings demonstrate the influence of pesticide package size on retailer recommendations. Unlike previous studies, we reveal that both large and small packaging sizes contribute to over-recommendations, emphasizing the importance of aligning packaging size with label dosage for optimal outcomes. These insights offer novel avenues for addressing pesticide overuse through targeted interventions aimed at retailers.

Keywords: pesticide retailer; overuse; packaging size; audit study

1 Introduction

The overuse of pesticides is a crucial concern in both China and worldwide in the context of sustainable agricultural practices. Numerous studies have provided evidence of the detrimental impacts on the environment, food safety, and human health resulting from the intensive application of pesticides (Beketov et al., 2013; Lai, 2017; Larsen et al., 2017; Prahl et al., 2021; Tang et al., 2021; Verger & Boobis, 2013; Wilson & Tisdell, 2001). As the primary users of pesticides, farmers have been the focus of research aiming to regulate their use behavior. The Farmer Field School (FFS) program, which aims to educate and train farmers on the compliant use of pesticides is a well-known example of a farmer-focused approach to address the issue of pesticide overuse.

However, despite such efforts, the effect of these programs on farmers' actual usage behavior has been limited (Morse & Buhler, 1997; Tripp et al., 2005).

In reality, farmers' decision on how much pesticide to use is likely to be made when they purchase the pesticide rather than when it is used. Two factors are worth considering in this regard. First, the dynamic characteristics of pests and diseases, such as their variability and resistance, prevent farmers from stockpiling too much pesticides. Second, the particularity of pesticide products, whereby the efficacy of pesticides diminishes over time after the packaging is opened and which poses a risk to family members such as children, leads farmers to buy only the amount of pesticide they need. Therefore, pesticide dosage may not be determined at the use stage but at the purchase stage, emphasizing the importance of retailer behavior.

There is limited research available on pesticide retailers, but existing studies have emphasized the significant role they play in the dissemination of information related to pesticide use (Jin et al., 2022; Liu & Huang, 2013; Pan et al., 2021; Sun et al., 2019; Wuepper et al., 2021; Yang et al., 2014; Zhang et al., 2015). While the consensus is that retailers serve as the primary channel for farmers to obtain information on pesticides, opinions vary on whether they recommend responsible use or encourage overuse. The prevailing belief is that retailers may encourage farmers to use more pesticide to increase their profits (Cai, 2014; Jin et al., 2022; Kumar et al., 2022). However, there are contrasting viewpoints that suggest retailers may help in reducing pesticide application by providing appropriate information and guidance (Huang et al., 2021; Jallow et al., 2017; Liu & Huang, 2013; Pan et al., 2021).

Conflicting views regarding the influence of pesticide retailers on pesticide use may be related to data collection challenges. Many studies have examined the impact of retailers on pesticide use by comparing the dosage of pesticides used by farmers who obtain information from various sources, such as pesticide sellers, labels, or public agricultural extension agents (Huang et al., 2021; Jallow et al., 2017; Jin et al., 2022; Pan et al., 2021; Wuepper et al., 2021). However, this approach raises a significant endogeneity problem, as farmers' behaviors may be influenced by unobserved confounding factors. As a result, non-uniform and inconclusive results have been reported in the literature.

An alternative method for investigating the role of pesticide retailers is to directly interview them, which has been employed in only a few studies (Kumar et al., 2022; Li et al., 2022). One advantage of this approach is that it allows for the direct observation of the retailers' recommended behavior. However, a potential disadvantage is that the retailers' actual behavior may differ if they are aware of the survey's purpose. Kumar et al. (2022) noticed this issue and conducted an anonymous field study of retailers, which provided robust evidence regarding their recommendation behavior. Nonetheless, the potential influence of interviewer bias or behavior on the results cannot be ruled out since the interviewers are not same and differs from the farmers. For example, the impact of social relationships between farmers and retailers on the results cannot be adequately assessed or eliminated.

The first objective of this study is to assess the retailers' pesticide recommendations through an audit experiment. Considering that information asymmetry could contribute to over-recommendation, the introduction of external information sources, such as pesticide labels, is hypothesized to reduce recommended doses by retailers. Specifically, we employed a between-subject design, sending retailers label-reading or non-label-reading customers randomly. By comparing the pesticide recommendation strategies employed by retailers facing these two types of customers, it was possible to identify whether over-recommendation occurs. The randomized design of the pesticide purchase experiment serves to control for potential customer-related variables and effectively isolates other latent factors on the demand side, allowing for a more accurate understanding of the real recommendation practices of pesticide retailers.

Furthermore, this study attempts to identify ways to mitigate retailer over-recommendation by examining the role of pesticide package size. Previous research has shown that the size of a product's packaging can affect its consumption, with larger packaging sizes leading to higher levels of consumption (Aerts & Smits, 2017; Wansink, 1996). However, these studies have mainly focused on consumer goods such as food and cigarettes, with only a limited number of studies investigating agricultural inputs. Zhang and Luo (2022) is one such study, which found that larger pesticide packaging sizes increase the amount of pesticides used by farmers and thus suggested reducing pesticide packaging to achieve pesticide reduction. However, the potential impact of pesticide packaging sizes on retailer recommendation remains unknown. Given the influential role of retailers in pesticide usage, it is essential to explore the relationship between pesticide packaging sizes and retailer recommendation.

This research makes at least two important contributions. Firstly, it yields a precise portrayal of retailers' actual sales behavior through the utilization of an audit experiment. Robust empirical evidence is presented, highlighting that the overuse of pesticides in China is not solely a user problem, but is largely driven by the behavior of sellers. Secondly, this study introduces a novel approach for mitigating pesticide over-recommendation, centered on the matching package size and label-indicated dosage. Several solutions suggested in prior literature for retailers, such as training and regulation (Jallow et al., 2017; Li et al., 2022), have exhibited certain limitations. For instance, training and education might prove inadequate if retailers are profit-driven, while exclusive reliance on governmental regulations can prove inefficient in contexts where numerous small-scale pesticide retailers operate due to the high regulatory cost. By investigating the impact of pesticide package size on retailer recommendation, our study offers a potentially more feasible and effective solution to mitigate pesticide overuse at it source.

2 Background

2.1 Pesticide markets and retailers in China

Despite the vast volume, China's pesticide retail market operates in an informal manner. The market comprises around 320,000 agricultural supply entities that not only sell pesticide products but also various agricultural production supplies such as fertilizers and agricultural films[1]. Geographically, pesticide retailers are categorized as county-level, township-level, and village-level, with the small family-run operation being the predominant type. Additionally, there are some large-scale pesticide chain stores and retail stores operated by cooperatives. Although the Chinese government has formulated specific management measures for qualifications of employees in pesticide retail stores, some village-level family shops operate without obtaining a business license or renting licenses from others. The large number and small scale of pesticide retail stores make it difficult for the government to supervise them one by one.

The reform of public agricultural extension agencies (PAEA) and the failure of pesticide labeling have resulted in pesticide retailers becoming the primary source of information for farmers on pesticides. Prior to the 1980s, the purchase and use of pesticides were strictly controlled by the government and facilitated through PAEA (Hu et al., 2009). However, in an effort to reduce financial expenditures, the government implemented reforms that liberalized the operation of agricultural inputs, such as pesticides and fertilizers, and significantly reduced the number of agricultural extension staff. As a result, many laid-off agricultural extension agents became

[1] Source of information: Chinese Association for Plant Protection.
http://www.croplifechina.org/ui/content.aspx?c3ViY29sdW1uaWQ9OTMmbmV3aWQ9MTEwJmNvbHVtbmlkPTkz.

pesticide retailers. Moreover, the limited educational background of smallholders, combined with the user-unfriendly nature of pesticide labels, has made it challenging for farmers to acquire necessary pesticide information through label reading alone. As a consequence, farmers increasingly rely on the expertise of pesticide retailers when purchasing and applying pesticides (Chen et al., 2022). Thus, pesticide retailers have evolved beyond being mere a "pharmacy" to assume a more pivotal role, akin to that of a trusted "doctor".

2.2 Why use audit study

Compared to the significant number of studies that examine farmers' pesticide overuse behavior, inadequate attention has been given to the issue of retailer recommendation. This discrepancy can be attributed to the inherent difficulties associated with acquiring reliable data in this context. Retailers may be reluctant to expose their sales practices, recognizing that such disclosure could potentially have detrimental consequences, thereby making the identification of their actual recommendation behavior challenging. Even with anonymous surveys, the data collected concerning retailer recommendation behavior may not possess sufficient accuracy. This limitation arises from the presence of confounding factors that can influence the retailer's recommendation, including the buyer's attitudes towards pesticides and the manner in which the buyer describes the severity of the pest infestation. Consequently, the adoption of an appropriate data collection method becomes a prerequisite for effectively studying the actual recommendation behavior of retailers.

The audit study offers a valuable means of obtaining dependable data on individual behavior by employing researchers (auditors) who are trained employees possessing all relevant characteristics, except for the specific one being investigated for potential discrimination[2] (Gaddis, 2018). Within the framework of pesticide transactions, the audit study approach provides real-world data concerning the selling behavior of retailers, surpassing the limitations of laboratory studies because participants are a representative, randomly chosen, non–self-selected subset of the treatment population of interest. In comparison to field studies, the between-subject intervention design effectively mitigates the impact of demand-related factors and avoids endogenous problems.

2.3 Theoretical background

The belief that pesticide sellers recommend far more pesticides than the standard for more profit is prevalent widely, but that may not be the case. Firstly, pesticide transactions are not one-time events, but rather long-term relationships between sellers and clients. As such, it may not be in the best interest of sellers to mislead clients for short-term gains, especially if they want to maintain a positive reputation and secure long-term business (Alam & Wolff, 2016). Moreover, in rural China, where social relationships and reputation are highly valued, sellers may feel even more compelled to behave in an ethical manner. Secondly, the marketization of the pesticide business has led to increased competition among retailers. In order to attract and retain customers, sellers need to offer affordable and high-quality pesticide products. Therefore, whether retailers will over-recommend the dosage of pesticides needs a reliable empirical test.

The size of product packaging not only influences consumers' purchase and usage decisions, but also impacts the seller's sale strategy, as it is closely linked to the seller's profit. In the context of pesticides, the relationship between the size of pesticide product packaging and retailers' recommended dosage may not be linear. To examine this relationship, we present a theoretical

[2] Auditors trained auditors who conduct experiments are also often referred to as standardization individuals because they have standardized behaviors, except that the behavior of interest.

framework that elucidates retailers' recommendation strategies under large and small packaging size considering the reputation. Given that crops with distinct underlying pests may exhibit similar symptoms, the correct dosage based on symptom manifestation follows a normal distribution: $x^{correct} \sim N(\mu, \frac{1}{\sigma})$. The retailer's recommended dosage, expressed as an interval $[\mu - x, \mu + x]$, so the pest control effect of the recommended dosage can be expressed as the probability that the interval $[\mu - x, \mu + x]$ includes $x^{correct}$: $P(x) = F(\mu + x) - F(\mu - x)$, where $F(\cdot)$ represents the cumulative density function of the correct dosage. Retailers, considering their long-term interests, are concerned about their market reputation r when giving recommendations, which is determined by the pest control effectiveness of the recommended dosage: $r = \emptyset P(x)$, where $\emptyset$ is a parameter reflecting the importance retailers attach to their market reputation.

Furthermore, retailer recommendations are influenced by customer expectations, particularly the farmers' beliefs regarding the desired dosage, denoted as $\bar{x}$. It is assumed that retailers are aware of $\bar{x}$. When the recommended dosage x deviates from $\bar{x}$, retailers need to communicate with farmers to persuade them that x is the correct dosage. The extent of communication needed increases as x moves further away from $\bar{x}$. However, farmers are more likely to be convinced if they have higher trust in retailers. Thus, the cost of communication is given by $\frac{(x-\bar{x})^2}{trust}$.

The utility maximization of retailers when recommending large and small packaging sizes can be represented as U_1 and U_2 respectively:

$$U_1 = \max_x \left\{ \emptyset P(x) + p(N) - \frac{(x-\bar{x}(N))^2}{trust} \right\} \quad (1)$$

$$U_2 = \max_x \left\{ \emptyset P(x) + \frac{x}{N} p(N) - \frac{(x-\bar{x})^2}{trust} \right\} \quad (2)$$

where N indicates the net weight of the recommended pesticide product; $p(N)$ denotes the price of the recommended pesticide product, which is influenced by the net weight. When farmers are presented with pesticide products in large packages, their expected pesticide dosage $\bar{x}$ increases. However, the package size does not affect the farmers' expected dosage when they encounter small package products.

The first order conditions for large and small packaging sizes are given by:

$$f(\mu + x) = \frac{x - \bar{x}(N)}{\emptyset trust} \tag{3}$$

$$f(\mu + x) = \frac{x - \bar{x}}{\emptyset trust} - \frac{1}{2\emptyset}\frac{p(N)}{N} \tag{4}$$

where $f(\cdot)$ is the probability density function of the correct dosage; $\frac{p(N)}{N}$ represents the unit price of pesticides, which is inversely proportional to the net weight of the pesticide. The term $f(\mu + x)$ captures the marginal benefit of increasing x by increasing the probability of exceeding the correct dosage, while the right-hand side represents the marginal cost of increasing x through higher costs associated with over-recommendation. When the pesticide package size is either large or small, the marginal cost of increasing x decreases, leading to higher pesticide recommendations. Figure 1 illustrates the impact of net weight on the recommended dosage. which reveals that the relationship between the size of pesticide product packaging and retailers' recommended dosage may not be linear. Furthermore, retailers' pesticide recommendations are influenced by the importance they attach to their reputation and the level of trust farmers have in them.

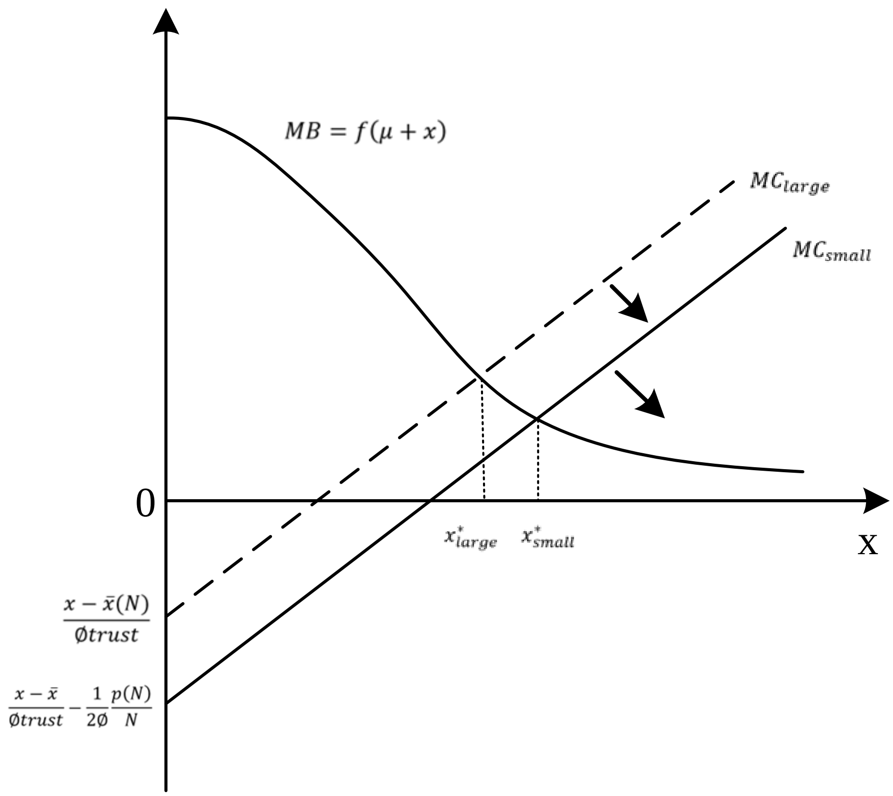

Figure 1 Optimal recommendation strategy under large and small packaging size.

3 Study design and empirical strategy

3.1 Study area and sample selection

The audit study was conducted in three provinces of China representing three different levels of pesticide use, namely Shandong, Hubei, and Shanxi, from 25 August 2022 to 3 September 2022. Shandong and Hubei are major regions for producing vegetables and rice respectively in China, and their pesticides use in terms of quantity and intensity is among the highest in the country. Shanxi is primarily an industrial province with relatively little pesticide use (Fig. 2a and 2b). To ensure the representativeness of the sample, a multilevel stratified sampling approach was employed to select the study sites. Firstly, the cities in the three provinces were ranked according to per capita GDP, and one city each was randomly selected from the top 50% and the bottom 50%.

Subsequently, the selected cities were grouped into two categories based on the per capita GDP ranking, and one county was randomly selected from each group. Two townships were then randomly selected from each county based on the same rule. Finally, two villages were randomly chosen from each selected towns. In total, 12 counties, 24 townships and 48 villages were involved to implement the audit experiment.

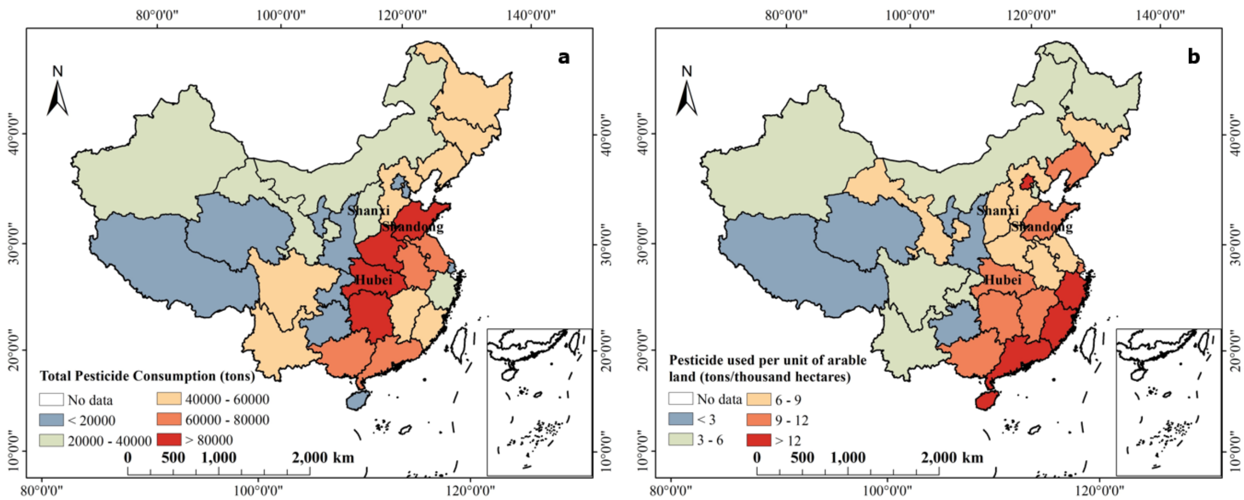

Figure 2 2021 Pesticide use in China and study area. a Total pesticide use by provinces in China in 2021. **b** The amount of pesticides used per unit of land by provinces in China in 2021.

Prior to the commencement of the study, we devised a plan to determine the locations of all pesticide retailers that were open during the investigation period, in order to establish the route for the audit. Firstly, we consulted with the local agricultural department to obtain information on the sales of local agricultural supplies and the distribution of retail stores. However, to avoid excessive government involvement, we did not rely solely on government resources to locate retailers. Rather, we also conducted interviews with farmers to gather information on where they usually buy pesticides. This was particularly useful in locating unofficial and itinerant stores. Thirdly, we used maps to identify the locations of the retail stores. Finally, any additional retailers that were accidentally encountered on the route were also investigated. In total, we investigated 195 retail stores, but one retailer who did not provide a recommendation was excluded from the analysis, resulting in a final sample of 194 valid store observations and 230 pesticide recommendations.

3.2 Experimental design

The experiment adopted a between-subject design: we randomly assigned two types of simulated customers to a pesticide retail store to purchase pesticides. All simulated customers follow the same fixed script when buying pesticides at the retail store (refer to Figure 3). Simulated customers initiated the interaction by expressing their need for insecticide to manage pests affecting their homegrown vegetables. To assess retailers' diagnostic abilities and convey the severity of the infestation, the customers promptly presented a photograph of the affected vegetables. Incorporating visual aids, such as pictures, served two purposes: providing a tangible representation of the pest issue and minimizing potential biases stemming from subjective descriptions. Lettuce infested with aphids was chosen as the case due to several reasons. Firstly, insecticides are commonly overused, particularly on fruits and vegetables. Secondly, lettuce has simple growing requirements and can be cultivated all year round, unrestricted by time or location. Lastly, aphids represent a prevalent pest that can be controlled using various insecticides, allowing us to observe retailers' recommended strategies across different products. Furthermore, aphids' rapid reproduction poses challenges for effective control, leading to higher pesticide concentrations and frequencies of application.

After displaying the photo, if the retailer does not proactively provide information on the pest type or offer a pesticide recommendation, the simulated customer is required to inquire about the diagnosis and recommendation explicitly. Subsequently, the simulated customers had to seek information from the retailer about the dosage of pesticides used, with two distinct customer types exhibiting different behaviors. In the control group, customer A does not read the pesticide label and directly inquiries the retailer about the quantity of pesticide to use per acre of land. In the treatment group, customer B first reads the label's dosage specified per acre of land and then queries the retailer that whether employing X grams per acre is enough, where X represents the labeled dosage. Other than this minimal difference, other conditions were completely identical in the two groups.

Finally, the simulated customer purchases the pesticide(s) recommended by the retailer. In cases where the retailer suggests multiple pesticides, the simulated customer purchases one of each. Following the purchase, the simulated customers express gratitude to the retailer and exit the store. Immediately after the transaction, the simulated customers are requested to complete a survey. This survey encompasses inquiries pertaining to the retailer's personal characteristics, the retailer's level, the role played by the auditors, whether the retailer has correctly diagnosed the pest, the recommended dosage by retailer and the uploading of photographs of all purchased pesticides onto the questionnaire system.

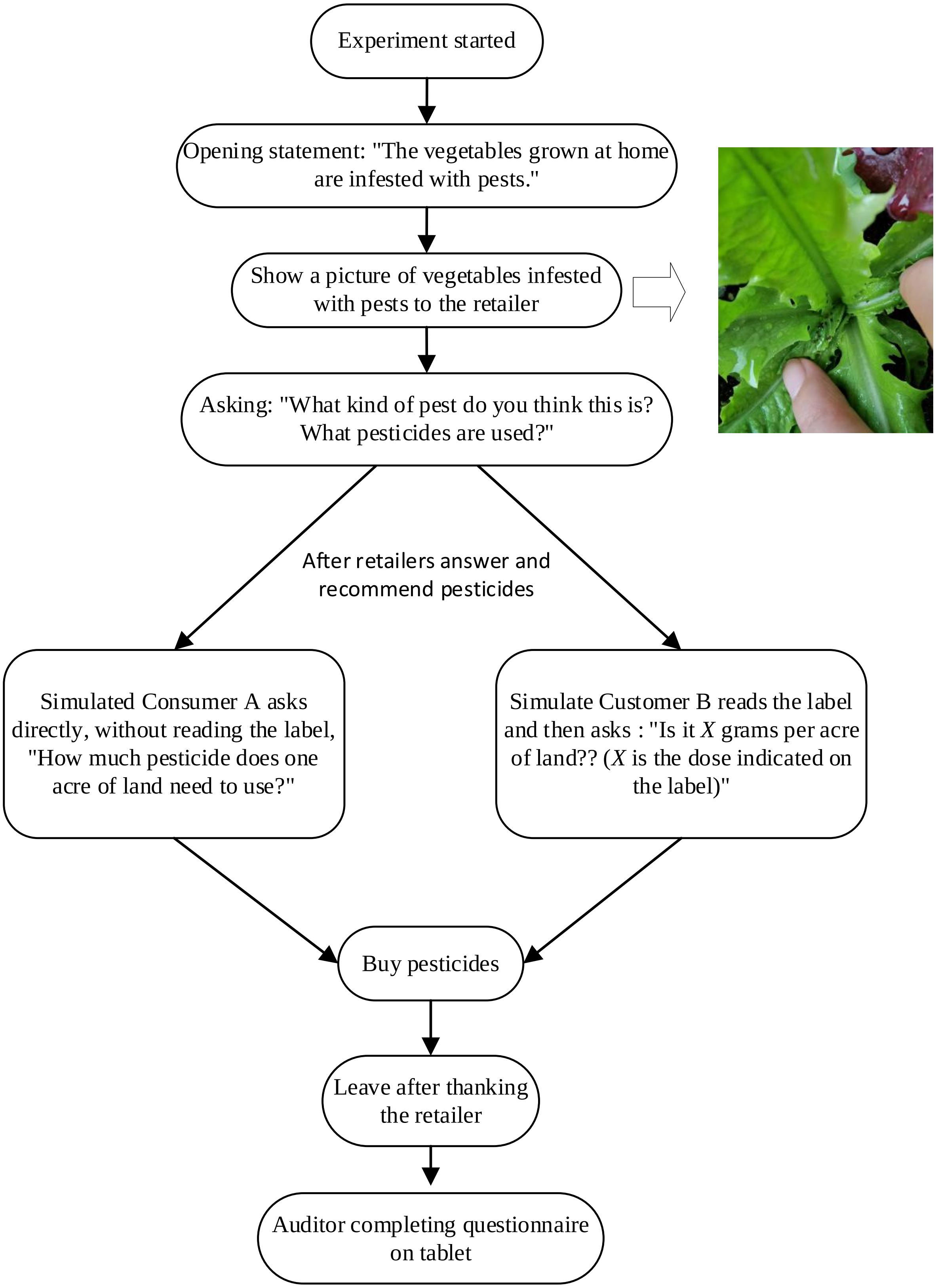

Figure 3 Pesticide purchase experiment protocol

The implementation of the audit study has two key factors. The first was the standardization of auditors. Local college students were recruited to act as customers purchasing pesticides. College students were preferred over farmers due to their higher level of comprehension and obedience, making them easier to be trained astrain standardized customers. Additionally, recruiting students from the experimental site prevented any dialect issues. As the survey took place during the summer vacation, it is normal for college students to return to their hometowns to help with farming, which will never arouse suspicion from retailers. Finally, 30 college students were selected after layers of screening, taking into consideration their personal expression ability and farming experience. Each student received at least 20 hours of training, which included rehearsals of a detailed script for pesticide purchases, standardized responses to a list of potential questions retailers could pose, pesticide labeling knowledge, and simulated purchases. The primary goal of training was to standardize the auditors' performance. To further avoid confusing each auditor's individual effects with specific scenarios, each auditor played both roles in the audit study.

The second key point was to minimize the risk of being suspected by retailers to avoid any Hawthorne effect (McCarney et al., 2007). To achieve this, each retailer was visited only once, which differs from the practice in previous audit studies (Currie et al., 2014; Das et al., 2016; Lagarde & Blaauw, 2022). Repeated visits to the same retailer within a short period of time are very likely to arouse suspicion[3]. However, one-time visits pose the risk of introducing noise in the results caused by differences in retailers. To address this issue, a two-round randomization of retail store level and customer role was implemented. Auditors were first randomly assigned to the level

[3] In July 2021, we conducted a pre-investigation on some county-level and township-level pesticide retailers in Quzhou County, Hebei Province. We found that retailers were highly cautious when dealing with unfamiliar customers, and that the frequency of customer visits was limited to a few per week. This made it difficult for similar purchase needs to arise twice in a short period of time without raising suspicions.

of the visiting retail store from county level to village level[4] and then visited two retailers to complete the pesticide purchase experiment. The customer roles faced by the two retailers are randomly assigned.

3.3 Empirical models

In order to assess whether retailers have over-recommendation behavior, we conduct a comparative analysis of the recommendation strategy of two groups of retailers. The recommendation strategy of the two groups of retailers includes multiple aspects: the percentage of retailers whose recommended dosage over the maximum dosage stated on the pesticide label, the degree of over-recommendation, and the degree of over-recommendation specifically among retailers exhibiting over-recommendation behavior. We observed that some retailers recommended more than one pesticide, resulting in 230 pesticide observations. Since the recommended dosage and label dosage of different pesticides cannot be directly aggregated, we adopted the methodology proposed by Zhang et al. (2015). This approach converts the doses of other pesticides based on the labeled dosage of pesticides with a specific concentration, enabling the aggregation of pesticide dosages recommended by each retailer. In this study, we used 70% imidacloprid, the most frequently recommended pesticide in the experiment, as the benchmark for dosage conversion. The statistical significance of the observed differences between the two groups was evaluated using the variance (ANOVA) estimate.

To examine the association between pesticide package size and the degree of over-recommendation, we employed pooled regression analysis. The standard errors were clustered at the individual retailer level. The model specification is as follows:

[4] Retailers within the same level can be considered as a relatively homogeneous group with respect to pesticide recommendation. Because they may operate in the same market environment and cater to similar customer needs.

$$y_{ij} = \beta_0 + \beta_1 \text{net weight}_i + \beta_2 \text{net weight}_i^2 + \beta_3 distance_i + \boldsymbol{\beta_4} \boldsymbol{x_{ij}} + \varepsilon_{ij} \quad (1)$$

where y_{ij} is the excess degree of the pesticide i recommended by retailer j, measured as (retailer recommended dose - label maximum dose)/ label maximum dose. net weight_i indicates the packaging size of recommended pesticide i; Additionally, we included a quadratic term, net weight_i^2, to capture any potential non-linear relationship with the net weight of pesticide i. The variable $distance_i$ measures the discrepancy between the net content and the label dose of the pesticide i, calculated as the absolute difference between the net weight and the label dosage. $\boldsymbol{x_{ij}}$ is a vector of control variables including retailer j' sex and age, the types of customers retailer j faced, whether the retailer j' diagnosis of pests is correct, the level of retailer j, the concentration and number of active ingredients of the recommended pesticide i. The net weight, concentration and number of active ingredients variables are derived from the pesticide product labels purchased in the experiment.

To ensure the robustness and stability of our findings, we conducted a series of additional analyses as part of a robustness check. As mentioned earlier, certain retailers recommended multiple pesticides, resulting in observable variations among retailers. To address this, we estimated models that incorporated retailer fixed effects using the following form:

$$y_{ij} = \beta_0 + \beta_1 \text{net weight}_i + \beta_2 \text{net weight}_i^2 + \beta_3 distance_i + \boldsymbol{\delta_j} + \varepsilon_{ij} \quad (2)$$

where $\boldsymbol{\delta_j}$ is a vector of retailer fixed effects.

4 Results

Prior to presenting the regression results, we present summary statistics concerning the characteristics of the retailers and attributes of the recommended pesticides. Subsequently, a balanced test is performed to ensure that the two groups of retailers are not significantly different. Based on the favorable outcomes of the balance test, we present the ANOVA results, which compare the recommendation strategies of the two retailer groups to identify any instances of over-recommendation behavior. Lastly, we provide regression results examining the impact of packaging size on the degree of over-recommendation, accompanied by relevant robustness checks.

4.1 Summary statistics

The descriptive statistics of the sample and attributes of recommended pesticides are displayed in Table 1. The majority of retailers fall in the 41-50 years age bracket, and the gender distribution is balanced. Most retailers are at the township level, followed by the county level, and the least are at the village level. The personal characteristics and distributions of retailers included in this study are consistent with those found in the research conducted by Li et al. (2022).

In terms of pest diagnosis, only 41.75% of the surveyed retailers made the correct pest diagnosis, with most retailers providing vague descriptions such as "cabbage patch" instead of identifying the pest as an aphid. However, this had little impact on their pesticide recommendations, as most of the recommended pesticides were broad-spectrum insecticides such as Imidacloprid, Acetamiprid, Emamectin Benzoate, and Cypermethrin, which were the four most frequently recommended insecticides (results not shown). Thus, this paper focuses more on the dosage of pesticides recommended rather than the type of pesticide.

In terms of product attributes, most of the recommended pesticides had low toxicity and were compounded, with an average concentration of about 25% and a net weight of approximately 60 grams or milliliters. It is noteworthy that compound pesticides with multiple active ingredients and concentration combinations made pesticide products both homogeneous and differentiated, giving retailers greater flexibility in their recommendations.

Table 1 Summary statistics

	Total	Control [C]	Reading label [T]
Male	52.06%	47.47%	56.84%
Age			
20-30	0.52%	0.00%	1.05%
31-40	27.84%	27.27%	28.42%
41-50	47.42%	47.47%	47.37%
51-60	18.04%	21.21%	14.74%
Over 60	6.19%	4.04%	8.42%
Level of pesticide retailers			
Village	18.04%	17.17%	18.95%
Township	55.15%	53.54%	56.84%
County	26.80%	29.29%	24.21%
The retailer made the right pest diagnosis	41.75%	42.42%	41.05%
Recommended pesticide attributes			
Net weight (g/ml)	58.53	55.95	61.21
Concentration (%)	24.62	23.23	26.06
Toxicity			
Slightly	2.08%	2.04%	2.11%
Low	75.13%	78.57%	71.58%
moderate	22.80%	19.39%	26.32%
Number of active ingredients for recommended pesticides	1.57	1.55	1.59

4.2 Balance test

To ensure the validity of outcomes, it is crucial to maintain the randomness of group assignment during implementation. We conducted a series of two-sided t-tests to verify the balance between treatment and control groups for retailer characteristics and recommended pesticide attributes. Since customer's label reading behavior occurs after the retailer has finished recommending the pesticide, there should be no significant difference in the recommended pesticide attributes of two groups. As shown in Table 2, column (1) presents the mean value of each variable for the control group, while column (2) report the difference in means between the treatment group (T) and the control group (C). The results showed that both personal characteristics and pesticide product attributes were well balanced, indicating that there was no difference between the two groups of retailers.

Table 2 Balance tests

	(1)	**(2)**
	Control group [C]	The difference between control group and reading-label group [T-C]
Sex of retailer (male=1)	0.475	0.094 (0.194)
Age of retailer	3.020	-0.010 (0.937)
Level of retailer (village=1; township=2; county=3)	2.121	-0.069 (0.475)
Pest diagnosis (right=1)	0.424	-0.014 (0.847)

Net weight of recommended pesticide (ml or g)	55.949	-5.261 (0.651)
Concentration of recommended pesticide (%)	23.230	2.833 (0.450)
Toxicity of recommended pesticide (slightly=1; low=2; moderate=3)	2.173	0.069 (0.296)
Number of active ingredients for recommended pesticide	1.545	0.044 (0.674)

Note. The first column reports means of the data in the control group. Columns (2) reports difference of means as treatment minus control. Significance tests for differences between groups are based on two-sided t-tests, with P values in parentheses.

4.3 Are retailers overrecommending?

Figures 4-6 present the ANOVA results for the recommendation strategy of the two retailer groups. The group comparisons reveal that retailers facing label-reading customers perform well in terms of both the percentage of over-recommending retailers and the overall degree of over-recommendation, displaying a lower proportion and a reduced extent of over-recommendation. However, concerning the degree of over-recommendation among retailers who have over-recommendation behavior, no significant difference is observed between the two groups. These results provide evidence that there is an over-recommendation behavior among retailers, and also indicate that reducing over-recommendation requires increasing the percentage of retailers who comply with the label. Furthermore, Figure 4 indicates that the average degree of over-recommendation is substantial, surpassing the maximum label dosage by several multiples, indicating significant potential to reduce pesticide use from retailers.

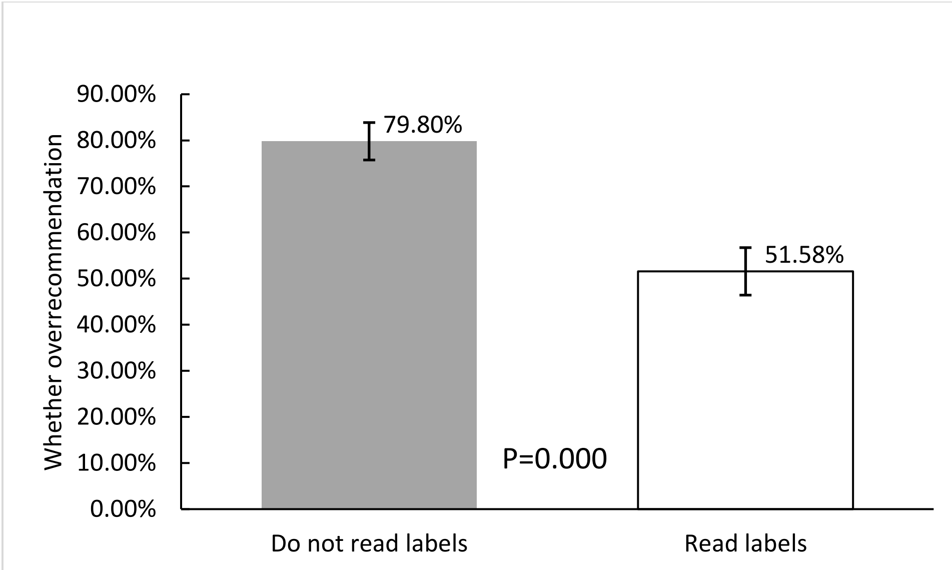

Figure 4 Percentage of over-recommended pesticide retailers by group

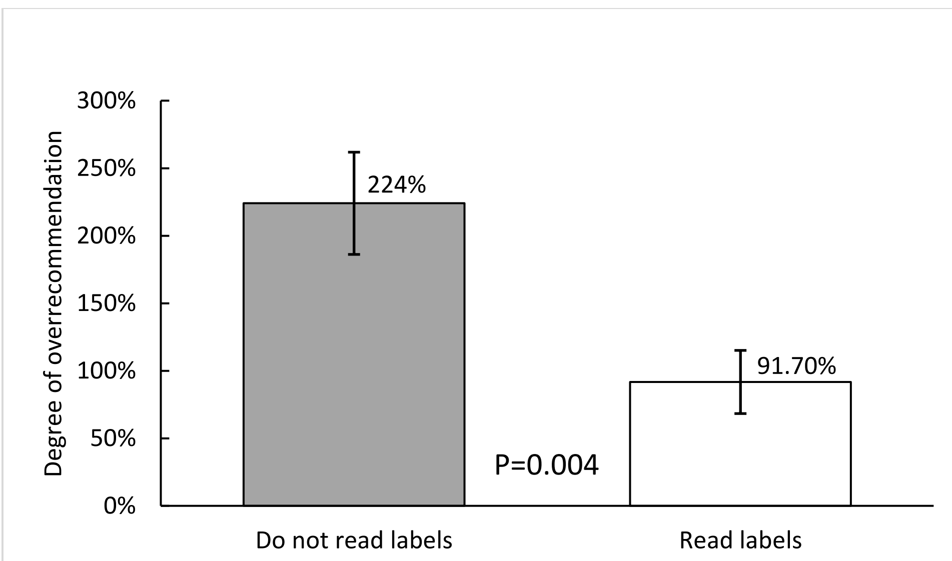

Figure 5 Degree of over-recommendation by retailer in each group (full sample)

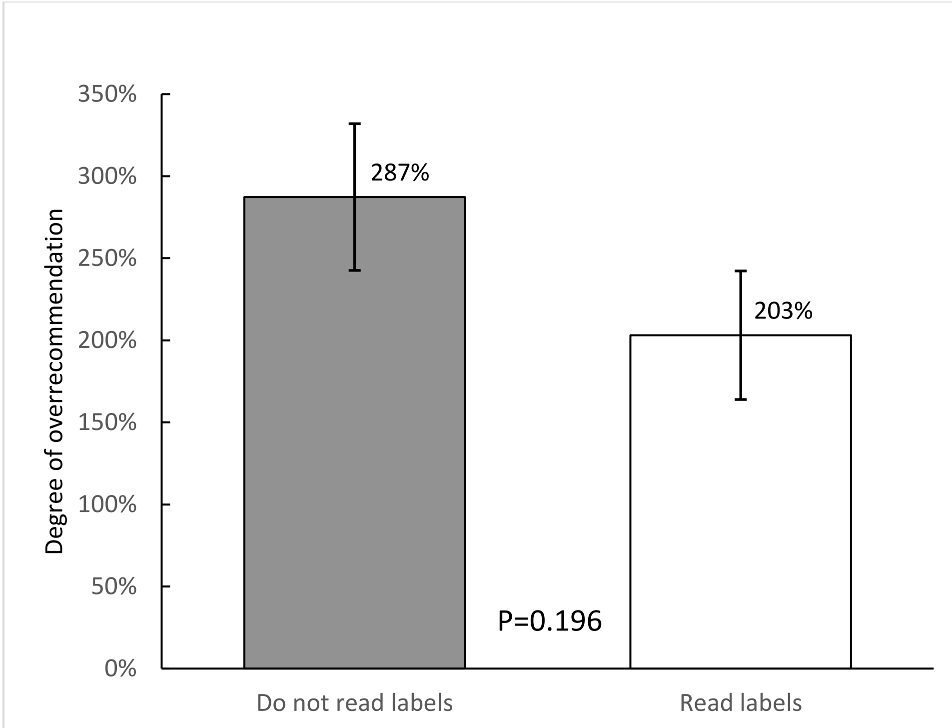

Figure 6 Degree of over-recommendation by retailer in each group (overrecommended sample)

Note: Error bars represent ±1 SE. n=196 retailer observations.

4.4 Ways to mitigate over-recommendation: secrets from the packaging size

Column (1) in Table 3 presents the initial regression results examining the impact of pesticide product packaging size on the degree of retailer over-recommendation, while controlling for retailer demographic characteristics and pesticide product attributes. The analysis reveals no significant influence of net weight on retailer over-recommendation. However, when introducing the quadratic term of net weight (see Column (2)), both the net content coefficient and the net content quadratic term exhibit statistical significance, indicating a non-linear relationship between pesticide packaging size and retailer over-recommendation. Specifically, the negative net content coefficient and positive quadratic coefficient suggest a U-shaped relationship between pesticide package size and retailer recommendation, as illustrated in Figure 7a. To further support this relationship, a scatter plot was generated, displaying the net weight of pesticide products against the degree of over-recommendation, as presented in Figure 7b. These results indicate that retailers are recommending more pesticides when the packaging size is either small or large.

Table 3 Effects of net weight and net content distance from label dosage on the degree of overrecommendation

	(1)	(2)	(3)
Net weight	-2.120	-20.836*	-26.130**
	(2.357)	(10.778)	(10.152)
Net weight^2		0.072*	0.025
		(0.040)	(0.045)
Distance between net weight and label dosage			0.024***
			(0.008)
Role	-1.236***	-1.254***	-1.168***
	(0.383)	(0.379)	(0.371)
Diagnosis	-0.286	-0.299	-0.303
	(0.457)	(0.455)	(0.453)
Concentration	-0.009	-0.016**	-0.015**
	(0.006)	(0.008)	(0.008)
Active ingredient quantity	-0.292	-0.198	-0.335
	(0.403)	(0.381)	(0.369)
Sex of retailer	0.262	0.291	0.323
	(0.426)	(0.431)	(0.427)
Age of retailer	-0.061	-0.106	-0.078

	(0.185)	(0.184)	(0.183)
Township level (village level as based)	-0.019	-0.020	-0.009
	(0.475)	(0.464)	(0.446)
County level	-0.167	-0.198	-0.306
	(0.638)	(0.627)	(0.620)
Province		Control	
Constant	2.715**	3.344***	3.351***
	(1.086)	(1.263)	(1.243)
R^2	0.060	0.077	0.108
Pesticide observations	230	230	230

Note. *role* is a dummy takes a value of 1 if the retailer faces label-reading customer, otherwise, it equals 0; *diagnosis* is a dummy takes a value of 1 if the retailer' pest diagnosis is correct; concentration and active ingredient quantity are continuous variables, obtained from the label of the pesticide purchased by the auditor. * denotes significance at the 10% level, ** at the 5% level, and *** at the 1% level. Standard errors are in parentheses.

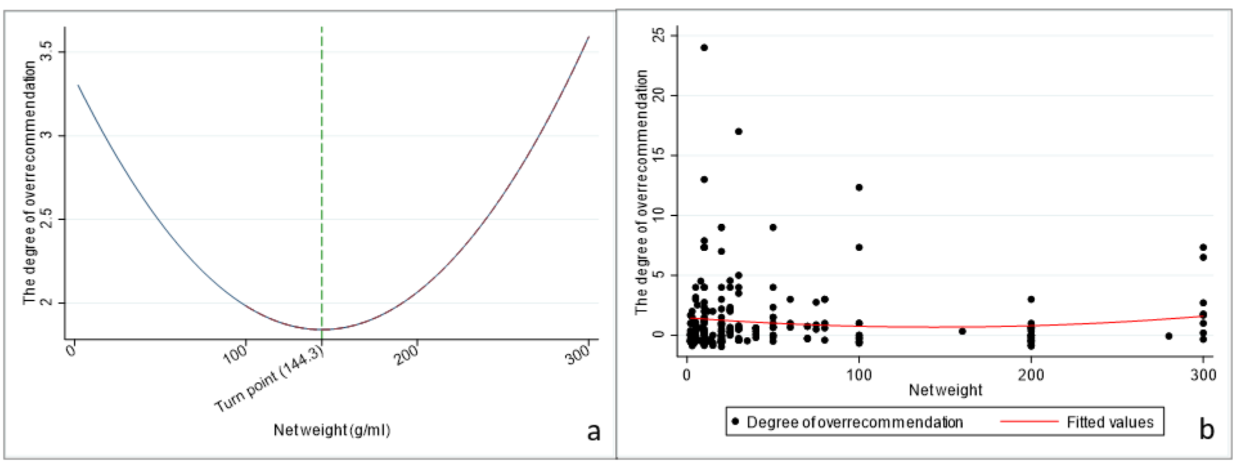

Figure 7 Relationship between pesticide package size and degree of overrecommendation by retailers

Naturally, we wondered what would be the optimum pesticide package size? To investigate this, we introduced the variable "distance," which measures the discrepancy between the net weight and label dosage, into the regression model. Column (3) of the results reveals that as the net weight approaches the label dosage, the degree of over-recommendation decreases. This suggests that when the packaging size aligns more closely with the labeled dosage, retailers are less inclined to engage in over-recommendation. Notably, the quadratic term of the net content becomes statistically insignificant after incorporating the "distance" variable, indicating that the mismatch between package size and labeled dose is one of the drivers of over-recommendation. This finding highlights the significance of aligning the size of pesticide packaging with the labeled dosage, rather than solely focusing on making the package as small or large as possible. Policymakers should consider this crucial aspect when addressing the issue of pesticide overuse.

4.5 Robustness

Table 4 presents the robustness results regarding the impact of distance on the degree of over-recommendation using pooled OLS, Fixed Effects model, and Random Effects model. While the significance level of the fixed effect estimator for the distance variable decreased, the direction and significance of the coefficients remained consistent across all three models. This consistent and significant relationship supports the robustness of the findings.

Table 4 Robustness check results

	Pooled OLS	FE	RE
Net weight	-26.130**	-29.399	-23.274***
	(10.152)	(22.641)	(8.899)
	0.025	-0.089	0.001

Net weight^2	(0.045)	(0.081)	(0.042)
Distance between net weight and	0.024***	0.075*	0.027***
label dosage	(0.008)	(0.040)	(0.008)
Concentration	-0.015**	-0.031**	-0.019***
	(0.008)	(0.014)	(0.007)
Active ingredient quantity	-0.335	0.372	-0.229
	(0.369)	(0.809)	(0.326)
Constant	3.351***	1.263	2.326***
	(1.243)	(1.172)	(0.795)
R^2	0.108	0.040	0.059
Pesticide observations	230	230	230

Note. * denotes significance at the 10% level, ** at the 5% level, and *** at the 1% level. Standard errors are in parentheses.

5 Discussion and conclusions

The overuse of pesticides has often been attributed to farmers, prompting discussions on modifying their behavior to reduce pesticide usage. However, the pesticide retailers, a key player on the supply side, has barely received attention due to challenges in observing their actual sales practices. This study employs the audit experiment method to examine whether retailers engage in excessive pesticide dosage recommendation, shedding light on the unexplored territory of retailer recommendation behavior. Furthermore, the study proposes strategies for reducing recommended pesticide dosages by focusing on the optimal packaging size of pesticides. These findings are significant as they contribute valuable insights into addressing the issue of pesticide overuse at its source.

Firstly, the overuse of pesticides cannot be solely attributed to farmers, and pesticide retailers also have a responsibility. Although it is unclear whether retailers are acting intentionally or unknowingly in overrecommending, it is certain that they have sever over-recommendation behavior, exceeding the maximum dosage stated on the label by several times. Therefore, it is very potential and necessary to reduce the recommended dosage of pesticides from the supply side.

On an encouraging note, our findings suggest that the excess dosage recommended by retailers can be mitigated by optimizing pesticide package size. Different from previous research findings that pesticide packaging should be miniaturized (Zhang & Luo, 2022), our study shows that pesticide packaging that is too large or too small will increase the degree to which retailers overrecommend pesticides. A possible explanation is that the mismatch between net content and label dose gives retailers more scope for over-recommendation. Large packages of pesticides incur higher storage costs and increase the risk of reduced efficiency, making it harder for farmers to purchase these products. As a result, retailers may increase the recommended dosage of these products to sell them successfully. Rather, small-pack pesticides reduce the visibility of label information and aggravate the information asymmetry between retailers and farmers, which leads to over-recommendation by retailers in pursuit of profit.

The optimal packaging size should align with the standard dosage specified on the pesticide product label. In principle, when the net content of a pesticide pack corresponds to the quantity required for one unit of land, retailers should have no role in recommending pesticide amounts. An applicable example is the dosage determination of laundry detergent. Prior to the introduction of laundry pods, individuals often used insufficient or excessive amounts of detergent due to limited knowledge. However, laundry pods effectively address this issue by matching the number of clothes with the appropriate detergent quantity. Pesticide packaging designs can draw inspiration from this concept, although pesticide dosage decisions are more complex due to various factors involved.

While our study offers robust evidence regarding the over-recommendation behavior of Chinese pesticide retailers and the potential advantages of optimizing pesticide packaging, further research is required to examine the heterogeneous behavior of retailers based on different characteristics. While audit studies offer a powerful tool for disentangling supply and demand effects, their sample size limitations hinder the exploration of variation in retailer behavior. Future studies should address this gap by conducting sub-sample analyses of retailers with distinct characteristics to gain a deeper understanding of the mechanisms underlying their over-recommendation behavior.

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