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Estimating farmers' willingness to pay for photovoltaic industry to improve agricultural green resources and environment

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Based on the consideration of the level of the regional radiation effect of the photovoltaic industry, four main regions were selected as case sites in Pingluo County, Ningxia Province, for this research. The study used the double-bound dichotomous CVM model and C-optimal design to revise the bidding value of the payment scheme that reduced the WTP range error. Five independent sub-sample questionnaires, including seven bidding value payment schemes, along with four internal range tests and six external range tests, were designed. The results showed that the comparison of the WTP for the improvement of agricultural resources and the environment among different independent sub-samples in the same region passed the external quantitative scope test, indicating that the questionnaire design, survey implementation, and WTP estimation results of the double-bound dichotomous CVM in this study were reliable. Saturation degree, diminishing marginal utility, and substitution effect are the main influencing factors of low marginal WTP added value and embedding effect. When the quantity range changes, the utility of respondents tends to saturate and marginal utility rapidly decreases. Influenced by the aforementioned factors, the sum of the independent estimates of the respondents on the WTP for the improvement of agricultural green resources and environment of the photovoltaic industry in the four research areas is 3.04 times the average value of the overall estimates of the four areas. In order to obtain and maintain the local photovoltaic industry for agricultural production resources and environmental improvement, the average WTP of each respondent was 99.80 yuan per year.

KEYWORDS

double-bound dichotomous CVM method, embedding effect, quantitative scope test, solar industry, Ningxia Province

Introduction

Agricultural green development is based on high-quality resources and the environment (Riti et al., 2021). In recent years, various countries have adopted a series of policy measures to promote the improvement of agricultural resources and the environment (Brock and Reinhilde, 2014). On one hand, they promote the development of the green energy industry and use external forces to help the green development of the agricultural modernization industry and the upgrade of green production technology, and on the other hand, they improve the utilization rate of agricultural waste resources and use the internal power of agricultural production to improve the green circulation ability of agriculture (Li et al., 2022). As a kind of clean energy, solar energy is not only an alternative to power generation but also integrated with farm production and management in various countries based on local climate and land reserve and produced good benefits (Nizam et al., 2013). It can be seen that the development of the photovoltaic industry can drive the upgrading and transformation of agricultural green production technology, improve the utilization rate of agricultural green resources, drive new economic benefits, and play a significant role in promoting agricultural green development. However, the quality of the agricultural production environment is still not optimistic, and an imbalance and insufficient development of agricultural green resources and the environment still exist. The development of the agricultural green energy industry has just started, and the radiation improvement of agricultural green resources and the environment still needs to be continuously performed (Lu et al., 2020; Yu, 2020; Rahim, 2022). To sum up, in the important development stage of the agricultural green energy industry, how to investigate the effect of the green energy industry on the improvement of agricultural resources and the environment from the perspective of truly benefiting rural residents is of great significance not only for farmers to improve their awareness and utilization of green energy technology but also for farmers to upgrade production technology and optimize the agricultural production environment.

Agricultural green resources and the environment have typical public goods' attributes, which can bring beneficial effects to other economic parties and have positive externalities. When the development of green energy industries has a certain incentive effect on the improvement of local agricultural green resources and the environment, beneficiaries are willing to pay for the resources of potential benefits of environmental public goods (Carson et al., 1992), which involves the preferences of beneficiaries and is related to the non-use satisfaction benefits of environmental public goods (Ressurreio et al., 2012). Taking the photovoltaic industry in the green energy industry as an example, this study measures the value of the beneficiaries to the photovoltaic industry to improve agricultural production resources and the environment and maintain the current state without declining so as to make these resources and environment sustainable existence (existence value), use by future generations (bequest value), and their future use (option value) (Fitzpatrick et al., 2017). It is also the content of farmers' willingness to pay (WTP) the non-use value of agricultural resources and environmental improvement.

The contingent valuation method (CVM) is the most important non-use valuation method for public goods (Waldo et al., 2016). It is widely used in the non-use value assessment of resources and the environment, such as environmental economy, solid waste treatment, ecosystem services, and biodiversity protection (Tonin, 2019). The CVM model application of the theory of consumer surplus and welfare changes according to the state of resources, and the environmental impact assessment method used to estimate the value of public goods, namely, by constructing illusions in the market, and evaluate people's WTP of resource environmental quality will improve to a certain extent or a certain degree of deterioration of intention as the foundation, the resources, and the environment, such as currency valuation of non-market goods or services (Ferreira and Marques, 2015). It plays an important role in the cost-benefit and damage analyses of resources and environmental public policies, as well as the formulation, implementation, and effect evaluation of related policies (Hanley and Czajkowski, 2019).

When the CVM is applied to the evaluation of familiar public goods dominated by the use value, construct validity estimation can be generated (Ronald and Glenn, 1995). However, when the CVM is applied to the evaluation of public goods dominated by the non-use value, the validity and reliability of the results have generated many debates (Baron, 2017). Embedding effects are the main internal debate (Bateman et al., 2004) and one of the main sources of error (Veisten et al., 2004) when researchers use the CVM. It is the most difficult one to deal with among the main deviations of the CVM (Hausman, 2012). The embedding effect refers to the fact that the same public goods are valued at a lower level as part of more inclusive public goods than they are individually (Kahneman and Knetsch, 1992), or that there is little difference in valuation between the public goods and the more inclusive public goods (Ronald and Glenn, 1995), or that different investigations of the same public goods result in widespread changes in the WTP (Hausman Hausman, 1994). The respondents usually have no experience in the selection of public goods to be estimated, so they are more likely to be affected by the embedding effect in non-use value assessment (Schulze et al., 1998). The National Oceanic and Atmospheric Administration (NOAA) recommends internal consistency tests be performed to assess the validity and reliability of CVM studies (Kerry et al., 1996). The scope test is a standard method to examine the existence of an embedding effect (Arrow, 1993).

At present, the research results on embedding effects mainly focus on explaining or verifying the phenomenon of embedding effects from the aspects of diminishing marginal utility (Pinto et al., 2016), survey design or execution ability defect (Ojea and Loureiro, 2010), substitution effect, income effect (Jorgensen et al., 2013), etc. From the existing typical cases of embedding effect research, there are many achievements in selecting rivers, wetlands, natural parks, and forests as research objects (Grammatikopoulou and Olsen, 2013; Giguere et al., 2020). At present, existing studies on the WTP for agricultural resources and the environment based on the CVM mainly focus on rural tourism, cultural industry, forestry, and other aspects (Tonin, 2019), while the research on the WTP for the improvement of agricultural resources and environment based on the green energy industry is obviously lagging behind. Moreover, no research result is found on the embedding effects of choosing the willingness of the green energy industry to pay for the improvement of agricultural resources and the environment as the research object.

In general, an area where a green energy industry is located will not only promote the improvement of local agricultural green resources and the environment but will also benefit its nearby areas. The radiation degree decreases with the length of this distance. When the improvement of agricultural resources and the environment in the region where the green energy industry is located is valued as a component of the improvement of resources and the environment in a larger region, due to factors such as saturation degree, diminishing marginal utility, or substitution effect, the embedded-effect phenomenon occurs such that the valuation result is lower than the individual valuation result or the sum of the independent valuation results exceeds the overall valuation result.

Therefore, a reasonable analysis and test of farmers' WTP for the photovoltaic industry to improve agriculture and green production resources and the environment and the embedding effect can better fill the gap in the existing literature and provide a reference value for relevant empirical research. This study chooses Ningxia Province, a typical representative province of the photovoltaic industry in China, as the study case. Using the double-bound dichotomous CVM model (Changlin et al., 2016), which can reduce the WTP bias caused by market distortions, we used a C-optimal design to revise the bidding value of the payment scheme (Kim, 2009), combined the double-bound dichotomous CVM with embeddedness effect research, and conducted a study on farmers' WTP for the photovoltaic industry to improve agricultural green resources and the environment. At the same time, analysis of the substitution effect, convergence effect, and influencing factors in different regions, in order to promote the development of the photovoltaic industry in different regions according to local conditions, effectively improves the utilization rate of the photovoltaic technology and increases the radiation benefits of a new energy industry to agricultural green production and environmental improvement. It is expected to provide an empirical and theoretical basis for cost-benefit analysis of agricultural green resources. It also provides an empirical reference for the compensation and subsidy measures for farmers in the development of the photovoltaic industry and other new energy industries.

Materials and methods

Theoretical basis

Double-bound dichotomous CVM

According to the stochastic utility maximization principle, the data on double-bound dichotomous CVM are analyzed by referring to the stochastic utility function model established by Hanemann (1989). The stochastic utility function model estimates the utility function through the bid value and its answer response data.

Assuming that the state of obtaining and maintaining the improved value of agricultural production resources and the environment changes from Q_0 to Q_1, the measured equivalent surplus value is used to evaluate the cost paid by farmers to obtain the value. If the answer to a respondent's WTP is "Yes," it means that he is willing to pay a given price for obtaining and maintaining the sustainable existence (existence value), future generations' use (bequest value), and his own use (option value) of the photovoltaic industry for the improvement of agricultural production resources and the environment.

The income of the interviewee is M, and the indirect utility function of the interviewee is composed of two parts: the observable part V and unobservable part ε. Then, the utility function is $U = V(Q, M) + \varepsilon$. The observable utility difference is denoted by ΔV. When the bid value given to the respondent is T yuan, the probability of the respondent answering "Yes" is $P[Yes] = [1 + e^{-\Delta V}]^{-1}$. For the observable utility difference ΔV, respondents may be affected by their socioeconomic characteristics and bid value. The linear function of ΔV is expressed as follows: $\Delta V = \alpha + \beta x_i + \gamma T$.

The core question of the double-bound dichotomous CVM first provides an initial bid value of R_i to the respondents and asks them whether they are willing to pay. If the respondents answer "Yes," another higher bid value of R_i^u is provided to them. Otherwise, they are offered another lower bid value of R_i^d. Therefore, there are four possibilities of the answers of respondents: "Yes/Yes," "Yes/No," "No/Yes," and "No/No." d_i^{YY}, d_i^{YN}, d_i^{NY}, and d_i^{NN} are dummy variables corresponding to the answer results of respondents "Yes/Yes," "Yes/No," "No/Yes," and "No/No," respectively. If the respondent's answer is "Yes/Yes," then $d_i^{YY} = 1$; then, other d_i^{YN}, d_i^{NY}, and d_i^{NN} are all 0.

Parameters α, β, and γ are estimated by maximum likelihood estimation. The expression of its likelihood estimation function is as follows:

$$\ln L = \sum_{i=1}^{n} \left[d_i^{YY} \ln P_{YY} + d_i^{YN} \ln P_{YN} + d_i^{NY} \ln P_{NY} + d_i^{NN} \ln P_{NN} \right]. \quad (1)$$

The mean value of the WTP is calculated as follows:

$$WTP_{mean} = \int_0^{T\max} \frac{dt}{1 + \exp(-\alpha - \beta \bar{X} - cT)} \quad (2)$$

where α is a constant, γ is the regression coefficient of the bid value, $\bar{X}$ is the average value of socioeconomic characteristic variables, and β is the regression coefficient of socioeconomic characteristic variables.

Embedding effects

According to the consumption theory, the individual preference utility function is constructed. Suppose the initial supply level of the public goods is S_0, y is the disposable income and $U(S_0, y) = U(S_0 + a, y - WTP_a)$. It is assumed that the whole a of the public goods to be estimated consists of a first increase part b and a second increase part c, so a+b = c. At independent valuation, the WTP of a, b , and c is WTP_i^n (i is a, b, and c, and n is the number of independent valuations). Then, the utility function of the first increased part of the public goods to be estimated is $U(S_0, y) = U(S_0 + b, y - WTP_b)$. In the case of b already being possessed, the WTP for c is $WTP_c|b$. Due to possible substitution and/or income effects (Whitehead, 2016), the utility function of c, the second additional part of the public goods to be evaluated is $U(S_0 + b, y - WTP_b) = U(S_0 + b + c, y - WTP_b - WTP_c|b)$. In field experiments, the income effect usually cannot be adjusted, so there is $U(S_0 + b, y) = U(S_0 + b + c, y - WTP_c|b)$.

If there are four cases of ① $WTP_a \le WTP_b + WTP_c|b$; ② $WTP_c|b = WTP_a - WTP_b \le WTP_c$; ③ $WTP_a \approx WTP_b$; and ④ $WTP_i^1 \ne WTP_i^2 \ne \cdots \ne WTP_i^n$ in the total test and partial test, it indicates the existence of an embedding effect. Considering the possibility and accuracy of the experiment, the scope test is usually carried out mainly to test whether there are two cases (③ and ④) (Kahneman and Knetsch, 1992; Boyle et al., 1994; Whitehead, 2016; Baron, 2017).

NOAA recommends the scope test as the standard method for assessing the internal consistency of CVM results. The scope test is a construct validity test based on the basic principle of the "more goods are better than less" consumption theory (Arrow, 1993; Borzykowski et al., 2018), which is usually divided into the internal scope test and external scope test (Carson and Mitchell, 1995). The internal scope test is to measure the WTP change of the same respondent under different ranges of public goods to be estimated, corresponding to the paired sample. The external scope test measures the WTP changes of different respondents in different ranges of public goods to be estimated, corresponding to sub-samples (Carson et al., 2001; Bateman et al., 2004). The internal scope test and the external scope test are complementary (Ndambiri et al., 2017).

Methods

Sample selection

In terms of green energy development, the Ningxia Hui Autonomous Region has high-quality natural conditions and is the country's first comprehensive demonstration area for new energy. As of August 2022, the installed PV capacity of the province was 14.36 million kW. New energy generation accounted for 23% of the province's total power generation, ranking second in the country. Ningxia is also the first province in China to combine solar photovoltaic technology with a facility agricultural greenhouse. As one of the earliest counties in Ningxia to develop a photovoltaic industry, Pingluo County has made outstanding contributions to the development of the clean energy industry and the improvement of green resources and the environment in the agricultural industry. Until now, the total installed capacity of clean energy industries in Pingluo County accounts for 49.6% of the total installed capacity of photovoltaic and wind power in the city. In conclusion, this study selects Pingluo County in Ningxia Province for agricultural technology development, construction, and management of the business of the photovoltaic industry. Four research sites are selected within the county for sampling, such as the photovoltaic industry area (Gaozhuang), two adjacent photovoltaic industry areas (Huang Quqiao and Touzha), and away from the photovoltaic industry area (Chonggang) (Figure 1), as a case study of farmers' WTP for the photovoltaic industry to improve agricultural green resources and the environment.

Research design

Bid value design of the double-bound dichotomous CVM

The double-bound dichotomous CVM can simulate market transactions realistically, accurately describe the false market, reduce the bias caused by market distortions, and find a more realistic WTP for respondents (Changlin et al., 2016). In the given virtual situation, this study directly asked respondents about the WTP (Ressurreio et al., 2012; Fitzpatrick et al., 2017) of maintaining the existing photovoltaic industry to improve the state of agricultural green resources and the environment without decreasing (Ramdas and Mohamed, 2014) so as to ensure the sustainable existence (existence value) of these resources and the environment, the use of future generations (bequest value), and their future use (option value). As a means of eliciting WTP, the double-bound dichotomous CVM for each volunteer designs three bid values: a higher bid value (R_i^u), a lower bid value (R_i^d),

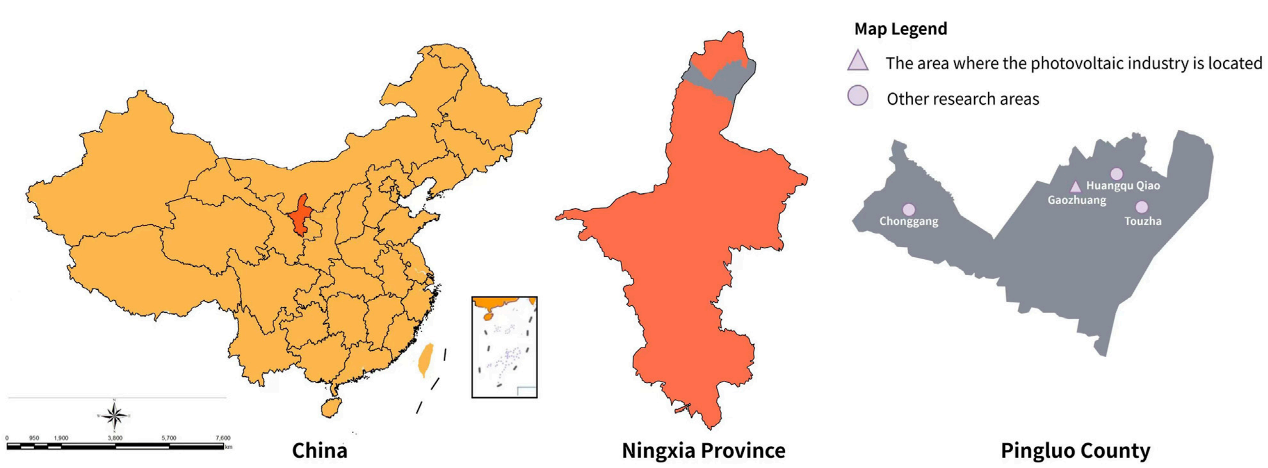

FIGURE 1
Study area map.

and the initial bid value (R_i); according to the respondents' bid value, there are four answers: (Yes, Yes), (Yes, No), (No, Yes), and (No, No). Based on the functional relationship between the probability of acceptance by the respondents and the bid price, the WTP of the respondents is derived (Whan et al., 2013).

In order to avoid the problem of bias in the bid value range in the double-boundary dichotomous CVM questionnaire, this study selects the C-optimal design based on Anna (1995), Pukelsheim (2007), and Kim (2009) to correct the bid value design, correctly estimate the bid value range, and reduce the bias due to inclusion of low bid values.

Suppose there is one and only one bid value scheme, then the initial value of the bid is equal to the median of the WTP derived from the pre-survey. The higher bid value and the lower bid value are distributed about the axis of symmetry of the initial bid value. Asymptotic variance minimization of the WTP median is the essence of the C-optimal design (Kim, 2009).

Based on the model construction of the double-bound dichotomous CVM, using maximum likelihood estimation, set $\theta = (\beta, \sigma)$. $\exp(\mu)$ is set as the estimated median value of the WTP in this study, and $\exp(\mu)$ and μ have the same monotonicity. Then, the asymptotic variance expression of μ is

$$Asy.Var(\hat{\mu}) = \frac{I_{\mu\mu}}{Det\left[I(\mu, \sigma)\right]} = \frac{4\sigma^2 (1 + e^w)^2}{N(-1 + 4e^w + e^{2w})}. \tag{3}$$

N is the sample size, and the bid value is calculated according to the principle of asymptotic variance minimization and the expression: $w = (\log(R_i^d) - \mu)/\sigma = -(\log(R_i^\mu) - \mu)/\sigma$.

Embedded effect verification scheme design

Referring to the research results on the value evaluation of embedded public goods and serial public goods, this study adopts the exclusive list method (Bateman et al., 2001; Bateman et al., 2004); information disclosure adopts advanced disclosure design (Powe and Bateman, 2003); and the sequence of valuation questions adopts a combination of top–down and bottom–up methods (Carson and Mitchell, 1995; Halvorsen, 1996; Hanley et al., 2003; Mcdaniels et al., 2003). Research on the embedded effects of farmers' WTP for resource and environmental improvement has been carried out.

From the perspective of the quantitative scope embedding effect, five groups of independent sub-samples were designed, and each group of independent sub-samples was designed with 1–3 core valuation questions about farmers' WTP for the photovoltaic industry to improve agricultural resources and the environment. The region where the photovoltaic industry is located (Gaozhuang) is the core component of farmers' WTP. Therefore, this study selected Gaozhuang, Huang Quqiao, Touzha, and Chonggang as the four research points, respectively, as the variation of the quantitative scope (Table 1).

The upper corner marks "1–3″ represent the serial number of the payment value within the sub-sample. AS represents the WTP for the improvement of resources and the environment, and $AS = gr + hr + tr + cr$ and gr、hr、tr、cr represent the resources and environment to be improved in Gaozhuang, Huang Quqiao, Touzha, and Chonggang, respectively. $gr + hr$, $gr + hr$, and $gr + cr$ represent the resources and environment to be estimated in the pairwise combination of the region where the photovoltaic industry is located (Gaozhuang) and the rest of the survey area.

According to the design ideas of the verification scheme of quantitative scope embedding effects in Table 1, this study proposes the null hypothesis of the external quantitative scope embedding effect test and the internal quantitative scope embedding effect test of farmers' WTP for the photovoltaic industry to improve agricultural production resources and the environment.

TABLE 1 Design ideas of the verification scheme for the quantitative scope embedding effects.

S-sub-sample I	S-sub-sample II	S-sub-sample III	S-sub-sample IV	S-sub-sample V
AS_{I}^{1}	AS_{II}^{1}	AS_{III}^{1}	AS_{IV}^{1}	AS_{V}^{1}
-	gr_{II}^{2}	hr_{III}^{2}	tr_{IV}^{2}	cr_{V}^{2}
-	-	$(gr+hr)_{\mathrm{III}}^{3}$	$(gr+tr)_{\mathrm{IV}}^{3}$	$(gr+cr)_{\mathrm{V}}^{3}$

Note: The lower corner "I ~ V″ represents the serial number of the payment value between sub-samples.

The null hypothesis of the external quantitative scope embedding effect test is as follows:

① $ex-H_1$: $WTP[AS_{\mathrm{I}}^{1}] = WTP[AS_{\mathrm{II}}^{1}] = WTP[AS_{\mathrm{III}}^{1}] = WTP[AS_{\mathrm{IV}}^{1}] = WTP[AS_{\mathrm{V}}^{1}]$,
② $ex-H_2$: $WTP[gr_{\mathrm{II}}^{2}], WTP[(gr+hr)_{\mathrm{III}}^{3}] \leq WTP[AS_{\mathrm{I}}^{1}]$,
③ $ex-H_3$: $WTP[hr_{\mathrm{III}}^{2}], WTP[(gr+tr)_{\mathrm{IV}}^{3}] \leq WTP[AS_{\mathrm{II}}^{1}]$,
④ $ex-H_4$: $WTP[tr_{\mathrm{IV}}^{2}], WTP[(gr+cr)_{\mathrm{V}}^{3}] \leq WTP[AS_{\mathrm{III}}^{1}]$,
⑤ $ex-H_5$: $WTP[cr_{\mathrm{V}}^{2}] \leq WTP[AS_{\mathrm{IV}}^{1}]$,
⑥ $ex-H_6$: $WTP[gr_{\mathrm{II}}^{2}] \leq WTP[(gr+hr)_{\mathrm{III}}^{3}], WTP[(gr+tr)_{\mathrm{IV}}^{3}], WTP[(gr+cr)_{\mathrm{V}}^{3}]$.

The null hypothesis of the internal quantitative scope embedding effect test is as follows:

① $in-H_1$: $WTP[gr_{\mathrm{II}}^{2}] \leq WTP[AS_{\mathrm{II}}^{1}]$,
② $in-H_2$: $WTP[hr_{\mathrm{III}}^{2}] \leq WTP[(gr+hr)_{\mathrm{III}}^{3}] \leq WTP[AS_{\mathrm{III}}^{1}]$,
③ $in-H_3$: $WTP[tr_{\mathrm{IV}}^{2}] \leq WTP[(gr+tr)_{\mathrm{IV}}^{3}] \leq WTP[AS_{\mathrm{IV}}^{1}]$,
④ $in-H_4$: $WTP[cr_{\mathrm{V}}^{2}] \leq WTP[(gr+cr)_{\mathrm{V}}^{3}] \leq WTP[AS_{\mathrm{V}}^{1}]$.

Questionnaire design and survey implementation

In this study, the double-bound dichotomous CVM question format was used to design the questionnaire, and the 15 guiding principles of the non-use value assessment proposed by NOAA were referenced (Arrow, 1993). On the basis of fully understanding the development status of the photovoltaic industry in Pingluo County, the main contents and methods of the questionnaire were determined through expert consultation. In order to improve the quality of the survey, field training was conducted for the investigators, and a pre-survey was organized in the sampled areas. Finally, according to the pre-survey results, the survey scheme was improved and the bidding value of the questionnaire was revised to improve the content and quality of the questionnaire design. In order to ensure the truth and accuracy of the data, this survey adopts the form of a one-on-one interview. Residents of the village and non-residents of the village were selected as the main respondents affected by the sample sampling. Farmers living in the villages of each survey site (Gaozhuang, Huang Quqiao, Touzha, and Chonggang) were the main sources of the sample of residents. The sampling frequency of farmers interviewed at home was higher. The main sources of non-village residents were farmers in the core blocks of each survey site and those participating in the market.

① Deviation control: Control the hypothetical bias by explicitly reminding respondents of budget constraints, adding additional costs and alternatives, and using anonymity (Johnston, 2006) and strictly training investigators. Control information deviation through pre-information disclosure and pre-investigation (Spash, 2002; Bateman et al., 2004). Adopt a payment card-based guidance method to ease the cognitive burden of respondents on the improvement of agricultural resources and the environment (Ressurreio et al., 2012). N initial bid values will correspond to N payment schemes. This study sets N+2 bid values in the questionnaire design, combined with the C-optimal design, to determine the final bid value of the questionnaire, reduce the deviation, and truncate lower bid values.

Based on the previous research, the random utility model is calculated in the double-bound dichotomous CVM model, assuming that the WTP obeys the logistic distribution, and the bid value is calculated: $(R_i^d, R_i^u) = [\exp(\hat{\mu} - 1.09861\hat{\sigma}), \exp(\hat{\mu} + 1.09861\hat{\sigma})]$, so $(\hat{\mu}, \hat{\sigma}) = (3.364, 1.836)$. Combined with the C-optimal design method, the final calculation is $(R_i^d, R_i^u) = (3.849, 217.437)$. Considering the research basis of the existing value evaluation and the design of the bid value in the existing CVM research and taking into account the actual research situation and the truncation of the bid value, the final bid value is determined as $R_i^d = 5$ and $R_i^u = 2009$ (Table 2).

② Questionnaire structure: This study classifies the socioeconomic characteristics of farmers. In addition to the personal characteristics of farmers' gender, age, and degree of education, it also covers farmers' family characteristics (management type, labor force, and acreage), family property (household incomes per capita, home value, value of cultivated land, and household savings), and social capital (family members or friends serve as village cadres), which enhances the accuracy of calculating the WTP. Furthermore, this study measures the influencing factors of subjective environmental behavior

TABLE 2 Design scheme before and after bid value revision.

Payment plan	Before correction			After correction		
	Initial bid value (R_i)	Higher bid value(R_i^u)	Lower bid value(R_i^d)	Initial bid value(R_i)	Higher bid value(R_i^u)	Lower bid value(R_i^d)
A	1	3	-	10	30	5
B	5	10	3	30	50	10
C	10	20	5	50	75	30
D	20	35	10	75	100	50
E	35	55	20	100	125	75
F	55	80	35	125	150	100
G	80	110	55	150	200	125

TABLE 3 WTP distribution of the double-bound dichotomous CVM.

Payment plan	YY	YN	NY	NN	Protest	Efficient
	Proportion (%)	Proportion (%)	Proportion (%)	Proportion (%)	Questionnaire (copies)	Questionnaire (copies)
A	62.7	13.7	15.7	0	26	313
B	43.8	12.5	14.6	12.5	48	293
C	40.4	17	19.1	6.4	48	289
D	40.8	14.3	14.3	14.3	48	299
E	37.8	11.1	11.1	31.1	26	275
F	22.4	16.3	14.3	22.4	73	299
G	8.5	8.5	12.8	51.1	55	288
Total	36.9	13.1	14.6	19.3	3 24	2056

assessment of farmers' WTP for the photovoltaic industry to improve the agricultural production environment from three aspects: cognitive degree (know the impact of the photovoltaic industry on the environment), pay incentive (the photovoltaic industry is beneficial to the improvement of agricultural green resources and the environment), and behavior attitude (to support the photovoltaic industry in some way to improve the agricultural production environment), as shown in Table 3.

The survey questionnaire adopts the combination of the double-bound dichotomous CVM and an embedded scheme. There are seven payment schemes for the bid value in the questionnaire and nine bid values for WTP. A total of five independent sub-sample questionnaires were designed.

The key question of the double-bound dichotomous CVM is that, according to the revised payment standard in Table 2, respondents are asked whether they are willing to pay relative to the initial payment price R_i if the price is set to increase to R_i^u (or decrease to R_i^d).The key question of the embedded scheme takes "S-sub-sample III" in Table 1 as an example, and then, the core valuation question about AS_{III}^1, hr_{III}^2, and $(gr + hr)_{\text{III}}^3$ is "in order to support the development of the local (Pingluo County/ Huang Quqiao County/Gao Zhuang and Huang Quqiao County) photovoltaic industry and make full use of photovoltaic resources into agricultural production and farmers' lives so that it can be sustainable and used by future generations or their own future use; it is envisaged to establish a development and protection fund if the fund is in the fundraising stage. Would you like to support this agricultural production environmental protection activity through a one-time donation, and would you like to pay yuan?" The questionnaire is shown in Supplementary Material.

Descriptive statistical analysis

Zero payment for protest.

During the survey period, 2056 valid questionnaires were interviewed, and the reasons for no WTP, such as being

TABLE 4 Respondents' socio-demographic and willingness to pay statistics.

Variable type	Variable	Assignment	Frequency (%)	Willing to pay (%)
Personal characteristics	Gender (G)	Male = 1	46.3	64.1
		Female = 2	53.7	65.5
	Age (A)	29 and under = 1	4.9	69.1
		30–39 = 2	36.5	68.9
		40–49 = 3	46.6	64.2
		50–59 = 4	10.3	59.3
		60 and over = 5	1.7	50.2
	Degree of education (E)	No schooling = 1	3.0	50.0
		Primary school education = 2	13.7	47.2
		Junior high school education = 3	31.2	65.9
		High school education = 4	45.6	69.0
		College education and above = 5	6.7	70.2
Family characteristics	Management type (MT)	Pure agriculture = 1	11.3	69.1
		Agriculture is mainly engaged in other activities = 2	27.3	70.2
		Non-agricultural mainly = 3	54.6	65.1
		Non-agricultural = 4	6.8	64.3
	Labor force (LF)	1–2 people = 1	70.3	63.2
		3–5 people = 2	28.5	57.0
		6–8 people = 3	0.4	50.4
	Acreage (Ac)	0–5 mu = 1	0.8	60.7
		6–10 mu = 2	20.2	65.3
		11–15 mu = 3	63.2	65.2
		16–20 mu = 4	14.5	66.3
		21 mu and over = 5	1.2	69.3
Family property	Household incomes per capita (HI)	0–5,000 yuan = 1	10.3	64.2
		5,001–10,000 yuan = 2	49.6	65.1
		10,001–15,000 yuan = 3	37.2	57.8
		15,001–20,000 yuan = 4	2.2	56.6
		20,001 yuan and over = 5	0.7	69.8
	Home value (HV)	0–100,000 yuan = 1	10.3	49.2
		100,001–150,000 yuan = 2	39.6	53.4
		150,001–200,000 yuan = 3	37.2	60.4
		200,001–300,000 yuan = 4	10.2	70.3
		300,001 yuan and over = 5	2.7	76.2
	Value of cultivated land (VL)	0–5,000 yuan = 1	0.3	59.7
		5,001–10,000 yuan = 2	29.3	64.3
		10,001–15,000 yuan = 3	53.2	65.1
		15,001–20,000 yuan = 4	10.5	63.2
		20,001 yuan and over = 5	6.7	62.1
	Household savings (HS)	None = 1	2.3	55.4
		Less than 20,000 yuan = 2	35.6	57.2
		20,000–50,000 yuan = 3	47.2	68.3
		50,001–80,000 yuan = 4	13.2	76.5
		80,001 yuan and over = 5	1.7	79.5

(Continued on following page)

TABLE 4 (*Continued*) Respondents' socio-demographic and willingness to pay statistics.

Variable type	Variable	Assignment	Frequency (%)	Willing to pay (%)
Social capital	Family members or friends serve as village cadres (VC)	Yes = 1	35.2	82.1
		No = 2	64.8	59.2
Cognitive degree	Know the impact of the photovoltaic industry on the environment	Strongly disagree = 1	2.3	58.7
		Disagree = 2	20.7	63.3
		Generally = 3	40.7	64.6
		Agree = 4	34.2	63.2
		Strongly agree = 5	2.1	64.1
Pay incentive	Photovoltaic industry is beneficial to the improvement of agricultural green resources and environment	Strongly disagree = 1	1.3	58.7
		Disagree = 2	30.7	62.2
		Generally = 3	30.4	63.5
		Agree = 4	33.2	62.1
		Strongly agree = 5	4.4	63.9
Behavior attitude	To support the photovoltaic industry in some way to improve the agricultural production environment	Strongly disagree = 1	1.6	56.6
		Disagree = 2	26.7	57.3
		Generally = 3	42.4	60.2
		Agree = 4	13.2	61.1
		Strongly agree = 5	16.1	64.1

uninterested in WTP or resource protection, rejecting donations or fund forms, and having nothing to do with oneself, were identified as protest zero payment (Dziegielewska and Mendelsohn, 2007; Lo and Jim, 2015; Khan et al., 2019b) in the protest payment questionnaire. There are 324 questionnaires, and the positive payment rate of these questionnaires is 84.2%. Residents and non-residents of the village samples accounted for 70.67% and 29.33%, respectively.

The valid data collected by the survey were classified and sorted, and the responses to the core questions in the double-bound dichotomous CVM questionnaire were obtained, as shown in Table 4.

According to the respondents' answers to the core questions of the CVM questionnaire, we found that the respondents' responses to the survey area followed the increasing bid value, and the probability of answering "No" also gradually increased.

Relationship and influence between the socio-demographic statistics and willingness to pay

Furthermore, the original continuous variables (acreage, household incomes per capita, home value, and value of cultivated land) were designed according to their quintiles or three quantiles (labor force) to form ordinal variables, to analyze the individual social attribute variables of the respondents in the valid questionnaire, and to increase the relationship and influence between the socio-demographic statistics of the respondents and their environmental behavior of the WTP for the improvement of agricultural resources and the environment, as shown in Table 4.

It can be seen that the difference in gender, age, and education degree has little influence on the WTP. However, farmers with a lower age and a higher education degree have a stronger awareness of ecological and environmental protection and could better understand and accept the importance of the photovoltaic industry to improving agricultural green resources and the environment, and have a higher WTP. If farmers rely more on agricultural production, they will pay more attention to the improvement of agricultural resources and the environment, and they will be more willing to invest. When the acreage of farmers increases, they can feel the impact of optimization and upgrading of resources and the environment on agricultural production more personally. Therefore, farmers with more acreage are more willing to pay. Household savings and home values are both positively correlated with WTP. Social capital has a strong positive impact on the WTP. Although the overall proportion of farmers with social capital, as defined in this study, is not high, they have the highest proportion of the WTP. To some extent, social capital provides a convenient way for farmers to access agricultural production policies and technological updates. As for the subjective factors affecting the WTP, from the perspectives of cognition, behavior, and attitude, most people are not active in the photovoltaic industry's

TABLE 5 Significance tests of socio-demographic differences.

Variable type	Variable	Parametric test	Non-parametric test
		One-way ANOVA (*p*-values)	Kruskal–Wallis test (*p*-values)
Personal characteristics	Gender (G)	0.162	0.162
	Age (A)	0.516	0.779
	Degree of education (E)	0.699	0.668
Family characteristics	Management type (MT)	0.590	0.762
	Labor force (LF)	0.589	0.651
	Acreage (Ac)	0.588	0.557
Family property	Household incomes per capita (HI)	0.405	0.668
	Home value (HV)	0.351	0.453
	Value of cultivated land (VL)	0.627	0.780
	Household savings (HS)	0.701	0.773
Social capital	Family members or friends serve as village cadres (VC)	0.315	0.479
Cognitive degree	Know the impact of the photovoltaic industry on the environment	0.690	0.563
Pay incentive	Photovoltaic industry is beneficial to the improvement of agricultural green resources and the environment	0.547	0.519
Behavior attitude	To support the photovoltaic industry in some way to improve the agricultural production environment	0.326	0.538

improvement of the agricultural environment, showing an "indifferent attitude." The possible reason is that farmers in western China are in a relatively backward area and have no understanding of clean energy. It has not realized the promotional benefits of new energy for the promotion of agricultural industry technology and environmental improvement. However, it can be seen that the more the farmers tend to "agree" with the photovoltaic industry on the improvement of the agricultural environment in behavioral attitude and emotional cognition, the higher their WTP is. This analysis provides the basis for the following empirical analysis.

The significance test of the socio-demographic characteristic difference

Multiple independent-sample parametric one-way ANOVA and multiple independent-sample non-parametric Kruskal–Wallis test (Christie, 2001; Norinder et al., 2001) were used to test the significance of the differences in the socio-demographic characteristics in five independent subsamples (Khan et al., 2022). The results are shown in Table 5. From the test results, a significance level of 0.05 indicates that there is no significant difference in socio-demographic characteristics among the five independent subsamples, indicating that the questionnaire design and survey process are reliable.

Empirical results and discussion

Willingness to pay estimation

Using the data from the double-bound dichotomous core question to sort out the dependent variable data, the respondent's personal social attribute variable is set as the independent variable and Logit regression is used to obtain the relationship expression between WTP and influencing factors as follows:

$$\log(WTP_{mean}) = \beta_0 + \beta_1 G_i + \beta_2 A_i + \beta_3 E_i + \beta_4 MT_i + \beta_5 LF_i + \beta_6 Ac_i + \beta_7 HI_i + \beta_8 HV_i + \beta_9 VL_i + \beta_{10} HS_i + \beta_{11} VC_i + \beta_{12} R_i.$$

TABLE 6 Estimated results of WTP for respondents of the double-bound dichotomous CVM.

Variable	Coef.	St.Err	Sig.	95% confidence interval		Variable mean
				Lower limit	Upper limit	
R_i	−0.019	0.003	0.000	0.975	0.987	
Labor force	−1.034	0.209	0.000	0.236	0.535	2.418
Acreage	0.053	0.022	0.017	1.010	1.102	14.286
Management type	0.425	0.200	0.034	1.033	2.263	2.459
Home value	0.033	0.012	0.006	1.009	1.058	19.339
Household savings	0.464	0.180	0.010	1.118	2.265	1.3216
Village cadres	−0.817	0.386	0.034	0.207	0.942	1.234
Intercept	2.562	0.848	0.003			

TABLE 7 Estimation results of the mean WTP.

Variable	Original mean/yuan	OLS mean/yuan	IR mean/yuan
$WTP[AS_{I}^{1}]$	85.66	113.34(94.53)	107.49(85.83)
$WTP[AS_{II}^{1}]$	86.16	115.53(90.24)	108.78(80.67)
$WTP[AS_{III}^{1}]$	80.18	107.41(54.64)	98.97(49.96)
$WTP[AS_{IV}^{1}]$	87.46	115.90(67.39)	108.81(62.26)
$WTP[AS_{V}^{1}]$	79.57	105.42(74.77)	101.08(69.94)
$WTP[gr_{II}^{2}]$	65.62	98.11(66.64)	90.43(57.92)
$WTP[hr_{III}^{2}]$	50.72	85.16(59.69)	78.99(55.85)
$WTP[tr_{IV}^{2}]$	57.59	89.70(65.13)	84.16(60.57)
$WTP[cr_{V}^{2}]$	52.92	82.29(75.46)	82.02(66.41)
$WTP[(gr+hr)_{III}^{3}]$	65.93	98.78(67.46)	91.03(61.56)
$WTP[(gr+tr)_{IV}^{3}]$	67.16	104.11(56.34)	90.95(51.72)
$WTP[(gr+cr)_{V}^{3}]$	65.80	99.64(56.85)	94.03(50.38)

Note: The meaning of each symbol is shown in Table 1; the values in brackets are robust standard errors.

On the basis of obtaining the average value of each variable and the coefficient of each variable, the average WTP of respondents under the dichotomous guidance technique can be obtained. According to the sorted survey data, the forward: LR method is used to gradually regress the model, and after eliminating the insignificant variables, the regression analysis (Table 6) can be obtained.

In this study, a Hosmer–Lemeshow goodness-of-fit test was conducted on the model, and the survey data were randomly divided into 10 groups. The Sig of the display test was 0.772 > 0.5, so the model could fit the data well.

According to the regression results, in the WTP model, social capital, household savings, labor force, acreage, management type, and home value have a positive and significant impact on respondents' WTP. According to the results of this analysis, the WTP increased with the number of family members working as village officials and the amount of savings. Household savings have a positive and significant impact, while household per capita income has not passed the significance test. It can be seen that savings among the influencing factors can better reflect the wealth level of respondents in the survey area.

In comparing the literature on the WTP for solar industry development and environmental protection (Jin et al., 2019; Ali et al., 2020; Khan et al., 2020b; Haque et al., 2022), the wealth benefits (income, house-ownership appear, etc.) of the respondents have a significant positive effect on the WTP, which is consistent with this study. However, education, as the main influencing factor in some literature reports, has not passed the test in this study. This is due to the fact that the education level of rural households in western China is generally lower than that of other regions, especially that of urban residents, and their awareness and acceptance of resource and environmental protection and green energy utilization are lower (Khan et al., 2019a; Khan et al., 2020a). Compared with most literature reports that take urban residents as the research object,

TABLE 8 Results of internal scope tests.

Hypothesis test	Non-parametric test	Parametric test			
		Z/Chi-square	Asymp. sig.	t	Sig.
$in-H_1$	$WTP[gr^2_{II}] = WTP[AS^1_{II}]$	−7.068	0.000	−4.457	0.001
$in-H_2$	$WTP[hr^2_{III}] = WTP[(gr+hr)^3_{III}] = WTP[AS^1_{III}]$	33.736	0.001		
	$WTP[(gr+hr)^3_{III}] = WTP[AS^1_{III}]$	−5.917	0.000	−3.037	0.000
	$WTP[hr^2_{III}] = WTP[(gr+hr)^3_{III}]$	−3.296	0.007	−2.039	0.068
	$WTP[hr^2_{III}] = WTP[AS^1_{III}]$	−6.093	0.001	−4.755	0.003
$in-H_3$	$WTP[tr^2_{IV}] = WTP[(gr+tr)^3_{IV}] = WTP[AS^1_{IV}]$	20.898	0.000		
	$WTP[(gr+tr)^3_{IV}] = WTP[AS^1_{IV}]$	−4.116	0.003	−2.078	0.049
	$WTP[tr^2_{IV}] = WTP[(gr+tr)^3_{IV}]$	−3.031	0.021	−3.473	0.037
	$WTP[tr^2_{IV}] = WTP[AS^1_{IV}]$	−3.411	0.001	−2.647	0.000
$in-H_4$	$WTP[cr^2_{V}] = WTP[(gr+cr)^3_{V}] = WTP[AS^1_{V}]$	44.729	0.000		
	$WTP[(gr+cr)^3_{V}] = WTP[AS^1_{V}]$	−5.018	0.002	−4.705	0.001
	$WTP[cr^2_{V}] = WTP[(gr+cr)^3_{V}]$	−3.751	0.007	−2.199	0.023
	$WTP[cr^2_{V}] = WTP[AS^1_{V}]$	−7.416	0.003	−4.020	0.000

this study chooses the influencing factor which is different from urban research and has agricultural characteristics like acreage and management type. At the same time, social capital, which has a significant impact on farmers' behavior and moral hazard, is included in the consideration scope to further reduce the regression error. The results show that these variables pass the regression test.

In addition, this study uses OLS regression and interval regression (Cameron and Huppert 2006; Stefania, 2018) to calculate the willingness of respondents to pay for the improvement of agricultural production resources and the environment in the photovoltaic industry again and analyze the embedded effects. Due to the limitation to sample size (a total of 2,056 valid questionnaires divided into five independent subsamples), this study introduced dummy variables into OLS and IR (Henrik 2000) to consider the differences in socio-demographic characteristics and payment preferences between residents non-residents of the village. The WTP in this study is based on the C-optimal design of the bid value and other deviation control. OLS regression is suitable for estimation of the dependent variable with established boundaries (Cheng et al., 2022). It also avoids excessive correction that may distort the regression results. In order to better retain more information and robust regression results and improve the comparison effect, this study chooses IR regression, which is more suitable for the double-bound dichotomous CVM, and takes the payment interval as the dependent variable for regression. Three kinds of WTP estimation results are combined to improve the robustness and effectiveness of subsequent embedding effect analysis.

Table 7 shows the original mean, OLS mean, and IR mean of the 12 kinds of farmers' WTP for the improvement of agricultural production resources and the environment.

It can be seen that the five groups of independent sub-samples estimated the WTP (AS^1_I; AS^1_{II}; AS^1_{III}; AS^1_{IV}; AS^1_V) of farmers to protect the agricultural production resources and environmental improvement of the photovoltaic industry in the same area, and the original mean, OLS mean, and IR mean of WTP were relatively stable. The maximum difference in WTP among the five independent sub-samples of the three valuation methods was all less than 4%. At the same time, the change direction of the original mean, OLS mean, and IR mean of each WTP is consistent with the change direction of the quantitative scope; the WTP mean of the largest range > the WTP mean of the middle range > the WTP mean of the smallest range.

This study draws on the practice of Cameron and Huppert (2006) and Tonin (2019) and adopts OLS and IR regression to estimate WTP. Due to the limitation to sample size (a total of 2056 valid questionnaires divided into five independent subsamples), this study introduced dummy variables into OLS and IR (Henrik 2000) to consider the differences in socio-demographic characteristics and payment preferences between residents non-residents of the village (related contents have been added to the survey implementation and descriptive statistics in the article). Therefore, OLS and IR regression are more suitable for the research content of this study. Second, the WTP is based on the C-optimal design of the bid value and other deviation control, which reduces the error caused by the

TABLE 9 Results of external scope tests.

Hypothesis test	Non-parametric test	Parametric test			
		Z/Chi-square	Asymp. sig.	t/F	Sig.
$ex-H_1$	$WTP[AS_{I}^{1}]=WTP[AS_{II}^{1}]=WTP[AS_{III}^{1}]=WTP[AS_{IV}^{1}]=WTP[AS_{V}^{1}]$	3.032	0.059	0.049	0.886
$ex-H_2$	$WTP[(gr+hr)_{III}^{3}]=WTP[AS_{I}^{1}]$	-2.487	0.170	2.238	0.370
	$WTP[gr_{II}^{2}]=WTP[AS_{I}^{1}]$	-3.461	0.021	2.159	0.306
$ex-H_3$	$WTP[(gr+tr)_{IV}^{3}]=WTP[AS_{II}^{1}]$	-1.689	0.338	1.492	0.814
	$WTP[hr_{III}^{2}]=WTP[AS_{II}^{1}]$	12.874	0.061	2.375	0.255
$ex-H_4$	$WTP[(gr+cr)_{V}^{3}]=WTP[AS_{III}^{1}]$	-1.850	0.448	1.894	0.545
	$WTP[tr_{IV}^{2}]=WTP[AS_{III}^{1}]$	-1.805	0.084	1.893	0.738
$ex-H_5$	$WTP[cr_{V}^{2}]=WTP[AS_{IV}^{1}]$	-1.909	0.527	2.652	0.235
$ex-H_6$	$WTP[gr_{II}^{2}]=WTP[(gr+hr)_{III}^{3}]$	-2.157	0.306	1.129	0.097
	$WTP[gr_{II}^{2}]=WTP[(gr+tr)_{IV}^{3}]$	-2.343	0.325	-1.793	0.507
	$WTP[gr_{II}^{2}]=WTP[(gr+cr)_{V}^{3}]$	-2.836	0.194	-1.056	0.156

inclusion of a low bid value and also reduces the degree of data dispersion in regression analysis (Kim, 2009). Compared with the Tobit model that requires the explained variable to be "Left censor" and/or "Right censor," OLS regression is more suitable for estimation of the dependent variable with established boundaries in this study (Cheng et al., 2022). It also avoids excessive correction that may distort the regression results. OLS regression is chosen to highlight the comparative results of WTP estimation. Compared with other regression methods, OLS is primitive and simple (Cameron and Huppert 2006; Cheng et al., 2022). It selects the midpoint value of each interval as the true WTP of the respondents as the dependent variable. Therefore, in order to better retain more information and robust regression results and improve the comparison effect, this study chooses interval regression, which is more suitable for the double-bound dichotomous CVM, and takes the payment interval as the dependent variable for regression. Three kinds of WTP estimation results are combined to improve the robustness and effectiveness of subsequent embedding effect analysis.

Analysis of scope test results

Internal scope test

This study uses two paired sample parametric t-tests and two paired sample non-parametric t-tests. The Wilcoxon signed-rank test compares two sets of paired samples. Using multiple paired sample non-parametric test in the Friedman test pair, three groups of paired samples were compared.

External scope test

This study uses a two independent sample parametric t-test and a two independent sample non-parametric Mann–Whitney U test to compare two independent samples (Khan et al., 2022). Multiple independent-sample parametric one-way ANOVA and multiple independent-sample non-parametric Kruskal–Wallis test (Christie, 2001; Norinder et al., 2001) were used to compare three independent samples and four independent samples. Due to the possible existence of the phenomenon of the "over-embedding effect" (Powe and Bateman et al., 2004; Heberlein et al., 2005; Frontuto et al., 2017), this study uses a two-tailed test for comparison between pairs, and the test results are shown in Table 8 and Table 9.

According to the results of the scope test of embedding effect verification, the comparison between farmers' WTP for the improvement of agricultural resources and the environment in the Huang Quqiao area and farmers' WTP in the photovoltaic industry location (Gaozhuang) and Huang Quqiao area ($WTP[hr_{III}^{2}]=WTP[(gr+hr)_{III}^{3}]$) fails to pass the internal scope test of two paired samples. WTP comparisons of null tests for other hypotheses passed both internal scope parametric and non-parametric tests (Table 7).

By comparing the WTP for the improvement of agricultural production resources and the environment (AS_{I}^{1}; AS_{II}^{1}; AS_{III}^{1}; AS_{IV}^{1}; AS_{V}^{1}) of farmers in the same region surveyed by different independent sub-samples, the WTP results for the maximum range of the five independent sub-samples were stable, which passed the external scope test, proving the reliability of the questionnaire design, survey implementation, and estimated WTP results. The comparison of farmers' WTP for the improvement of agricultural resources and the environment between the location of the photovoltaic industry (Gaozhuang) and Pingluo County as a whole ($WTP[gr^2_{II}] = WTP[AS^1_{I}]$) has passed the non-parametric test of external scope. The WTP comparisons of null tests for other hypotheses did not pass the external scope parametric and non-parametric tests (Table 8). It can be seen that respondents can perceive the changes in the internal or external quantitative scope of the photovoltaic industry improving agricultural resources and the environment, and the direction of the change in the WTP size is consistent with the direction of the change in the quantitative scope size (see following equations).

① Comparison of WTP for internal quantitative scope changes

$$in - H_1: WTP[gr^2_{II}] \xrightarrow{19} WTP[AS^1_{II}]$$
$$in - H_2: WTP[hr^2_{III}] \xrightarrow{6} WTP(gr + hr)^3_{III}] \xrightarrow{10} WTP[AS^1_{III}]$$
$$in - H_3: WTP[tr^2_{IV}] \xrightarrow{19} WTP[(gr + tr)^3_{IV}]$$
$$in - H_4: WTP[cr^2_{V}] \xrightarrow{6} WTP[(gr + cr)^3_{V}]$$

Note: The number on the arrow is the marginal WTP, which is the same as follows.

② Comparison of each WTP for external quantitative scope changes (0–1–4)

$$ex - H_2: WTP[gr^2_{II}] \xrightarrow{18} WTP[AS^1_{I}]$$
$$ex - H_3: WTP[hr^2_{III}] \xrightarrow{32} WTP[AS^1_{II}]$$
$$ex - H_4: WTP[tr^2_{IV}] \xrightarrow{18} WTP[AS^1_{III}]$$
$$ex - H_5: WTP[cr^2_{V}] \xrightarrow{32} WTP[AS^1_{IV}]$$

Note: 0, 1, and 4 represent the number of sample areas, which is the same as follows.

③ Comparison of each WTP for external quantitative scope changes (0–2–4)

$$ex - H_2: WTP\left[(gr + hr)^3_{III}\right]$$
$$ex - H_3: WTP\left[(gr + tr)^3_{IV}\right]$$
$$ex - H_4: WTP\left[(gr + cr)^3_{V}\right]$$

④ Comparison of each WTP for external quantitative scope changes (0–1–2)

$$ex - H_6: WTP[gr^2_{II}] \xrightarrow{1} WTP\left[(gr + hr)^3_{III}\right]$$
$$ex - H_6: WTP[gr^2_{II}] \xrightarrow{0} WTP\left[gr + tr)^3_{IV}\right]$$
$$ex - H_6: WTP[gr^2_{II}] \xrightarrow{3} WTP\left[(gr + cr)^3_{V}\right]$$

The primary economic question for the quantitative scope test is the degree of saturation (Bateman et al., 2004). Whether WTP increases depends on the saturation degree of the respondents to the supply level of the photovoltaic industry to improve agricultural production resources and the environment (Chilton and Hutchinson, 2000). From the comparison of the results of each WTP, the increased marginal WTP value of the internal quantitative scope changes was low (①). The marginal WTP increase in the quantitative scope changes is also low (②, ③, and ④). At the same time, the willingness of farmers to pay for the photovoltaic industry to improve agricultural production resources and the environment shows a marginal decline, and the utility of respondents tends to be saturated. Combined with previous studies, this study has shown that saturation degree (Hutchinson and Hutchinson 2003) and diminishing marginal utility (Veisten et al., 2004; Desvousges et al., 2012) are the main factors affecting the magnitude and range sensitivity of marginal WTP added value of agricultural green resources and environmental quantitative scope changes.

In Pingluo County, farmers' WTP for the photovoltaic industry to improve agricultural production resources and the environment has convergence and substitution within the region and between the same external regions. The WTP of farmers in the location of the photovoltaic industry (Gaozhuang) and its adjacent sample areas (Huang Quqiao and Touzha) on the external quantity range of the photovoltaic industry to improve agricultural production resources and the environment is 1 and 0, respectively. Pairwise WTP comparison shows a substitution effect (④). Thus, combined with previous studies, the substitution effect (Nunes and Schokkaert, 2003; Desvousges et al., 2017) is the main factor affecting the magnitude of the marginal WTP increase and range sensitivity of quantitative scope changes. Farmers in the regions where the photovoltaic industry is located and radiation areas have a high awareness of the photovoltaic industry and an urgent desire to improve agricultural industry technology and production environments by using photovoltaic industry technology.

Conclusion, recommendations, limitations, and future directions

1) This study uses a combination of the double-bound dichotomous CVM and an embedding scheme to measure the farmers' WTP for the photovoltaic industry to improve agricultural resources and the environment. After estimating the WTP for the improvement of agricultural resources and the environment of farmers in the four survey sites (gr^2_{II}; hr^2_{III}; tr^2_{IV}, and cr^2_{V}), the sum of WTP is 304 yuan. For the overall valuation of farmers' WTP in the four regions, the mean WTP

of the five independent sub-samples (AS_{I}^{1}; AS_{II}^{1}; AS_{III}^{1}; AS_{IV}^{1}, and AS_{V}^{1}) was 99.8 yuan, that is, in order to obtain and maintain the local photovoltaic industry to improve the agricultural production resources and environment, the average willingness of each respondent was to pay 99.80 yuan per year, respectively. The sum of the independent estimates of the four areas is 3.04 times the mean value of the overall estimates of the four areas. In addition, the resource endowment of farmers has a significant impact on their WTP, and the higher the social capital and financial capital of farmers, the more obvious the positive effect on the WTP.

2) In this study, five independent sub-sample questionnaires, including seven bidding value payment schemes, were designed, and four internal range tests and six external range tests were designed. The results of the range test show that the comparison of the WTP for the improvement of agricultural resources and the environment among different independent sub-samples in the same region has passed the external quantitative scope test, and the hypothesis $ex - H_1$ has passed, indicating that the questionnaire design, survey implementation, and WTP estimation results of the double-bound dichotomous CVM in this study are reliable. The comparison of WTP results with other external quantitative scope tests showed differences, indicating that the respondents were sensitive to changes in the external quantity scope of the photovoltaic industry for the improvement of agricultural production resources and the environment but did not reach statistical significance. Except for part of the internal scope test ($in - H_2$), all the other tests passed, indicating that the respondents were sensitive to the changes in the internal scope of the improvement of agricultural production resources and the environment to be estimated and reached statistical significance.
3) When the quantity range changes, the utility of respondents tends to saturate and marginal utility rapidly decreases. At the same time, there are substitutions between the WTP of farmers in some research areas, which accelerates the decline of the marginal WTP added value. The degree of saturation, diminishing marginal utility, or substitution effect are the main influencing factors of the magnitude change of the marginal WTP added value, which provides the basis for the external and internal quantitative scope tests to fail to reach statistical significance. Therefore, the range test should not be used as the only criterion to judge the validity of CVM research. The improvement of the photovoltaic industry to the agricultural green production environment and the effective use of photovoltaic technology in the optimization of agricultural green production technology are inseparable from the promotion of the government. When developing the photovoltaic industry, the local government should fully consider the substitution effect and convergence effect between different regions and comprehensively consider the saturation degree and diminishing marginal utility. Support policies for the photovoltaic industry should be formulated according to local conditions and be in line with the needs of agricultural green production so as to maximize the radiation benefits of green energy for the improvement of agricultural production resources and the environment.
4) Affected by factors such as saturation degree, diminishing marginal utility, and substitution effect, the overall valuation result of farmers' WTP for the local photovoltaic industry to improve agricultural production resources and the environment is more reliable in cost-benefit analysis. According to the calculation results, it is suggested to choose 99.80 yuan in cost-benefit analysis. According to the farmers' WTP, it provides an empirical reference for the development of photovoltaic industry compensation and subsidy measures for farmers to help increase farmers' awareness of the photovoltaic industry's improvement of agricultural green production resources and environment, increase farmers' enthusiasm to support the development of the photovoltaic industry, and promote the input and utilization of photovoltaic technology in agricultural production. This conclusion also applies to the valuation of public goods in a complex environment.

Embeddings are broader economic phenomena, and failure to meet the range test should not be used as a preliminary basis for rejecting CVM studies, and the results of the range test should be considered more carefully. Scope insensitivity may be a problem with any assessment method, but current research has focused on the context of declarative preferences dominated by the CVM domain.

Further research may focus on the following discussions:

1) Research design is a key factor in determining the validity and reliability of the non-use valuation results of complex public goods. When designing the questionnaire, it is recommended to use the independent list method to evaluate the public goods to be estimated.
2) It may focus on the affective, cognitive, attitude, and behavior of social psychological theory factors on the embedding effect. The relationship between the warm glow and the embedding effect is controversial at present and is worth discussing in the future.
3) By breaking the limit of sample size, the embedded-effect problem of different resident characteristic samples was examined separately by increasing the sample size. Other types of embedding effects, such as the classification range embedding effect and geographic range embedding effect, are considered.

4) At present, the relationship between social psychological factors, warm glow, and the embeddedness effect is a hot and frontier direction in the research of CVM validity and reliability, which needs further exploration and study.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Northwest A&F University. The patients/ participants provided their written informed consent to participate in this study.

Author contributions

JL: conceptualization, formal analysis, investigation, software, methodology, data curation, writing—original draft, and writing—review and editing. AK: investigation, software, methodology, and writing—review and editing. SK: methodology and writing—review and editing. MA: data curation and writing—review and editing. JL: funding acquisition, project administration, and supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.1029568/full#supplementary-material

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