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A contingent valuation of smallholder farmers' willingness to pay for improved irrigation water supply in Egypt

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Abstract

This study employs a double-bounded dichotomous choice contingent valuation experiment to investigate the willingness to pay (WTP) of 313 Egyptian smallholder farmers in the Nile Delta region for improved irrigation services. The results from probit and bivariate probit models reveal an inverse relationship between water price and WTP, underscoring the importance of carefully considering farmers' affordability thresholds in water pricing strategies. The probability of smallholder farmers' agreeing to pay for an improved irrigation scheme is positively associated with agricultural income, farm size, distance to the irrigation canal, trust in water institutions and attitudes towards investing in an improved water supply. Conversely, the probability of WTP is negatively associated with farming experience, perceptions and psychological distance. Overall, the empirical findings underscore the need for integrated and holistic approaches that account for the influence of various factors on farmers' decision-making processes and thus design effective water-resource management strategies.

Highlights

- Farmers are willing to pay around 7% of their average annual income per feddan for improved access to irrigation water.
- An inverse relationship exists between water price and WTP, highlighting the importance of careful consideration of farmers' affordability thresholds in water pricing strategies.
- Farmers' WTP depends on a suite of socioeconomic, technological, biophysical, institutional and psycho-behavioural factors.
- WTP is positively associated with agricultural income, farm size, distance to the irrigation canal, trust in water institutions and attitude towards investing in an improved water supply.
- WTP is negatively associated with farming experience, perceptions and psychological distance.

KEYWORDS

contingent valuation, Egypt, irrigation water, smallholder farmers, willingness to pay

1 | INTRODUCTION

Physical and economic water scarcity presents a major global development challenge, while approximately 2.4 billion people worldwide are affected by water-stress conditions, and an estimated 3.2 billion people reside in agricultural regions facing severe water shortages (FAO, 2024). These figures are projected to rise because of population growth and the escalating effects of climate change (United Nations, 2024). Agricultural sectors are among the most profoundly affected by water scarcity, as agriculture is the largest consumer of freshwater resources globally, with about 70% of global water withdrawals and over 90% in some low- and middle-income countries (LMICs) (FAO, 2020). Reduced water availability for agricultural sectors directly limits crop production, reduces yields, affects farm incomes and often leads to rural unemployment and out-migration (Le Mouël et al., 2023). Consequently, this drives food price inflation and exacerbates hunger and malnutrition, particularly in regions heavily reliant on agriculture for livelihood and sustenance. Moreover, water shortages can ignite socio-political unrest and escalate regional conflicts (Emile et al., 2022). Therefore, achieving the United Nations Sustainable Development Goals (SDGs) related to water access (SDG6) and food security (SDG2) critically depends on how water resources are allocated, managed and conserved (Balasubramanya et al., 2022).

The Middle East and North Africa (MENA) region is the most water-scarce area in the world, where challenges related to water scarcity and irrigation shortages are most pronounced (SIWI & UNICEF, 2023; World Bank, 2017). On the one hand, MENA countries face pressure from a growing population with changing dietary preferences; on the other hand, renewable freshwater resources are rapidly diminishing in both quantity and quality (Abu Hatab et al., 2024). Projections suggest that by 2030, annual per capita water availability in this region will fall below the absolute scarcity threshold of 500 cubic meters per person (de Waal et al., 2023). Compounding this critical situation are issues such as soil degradation in irrigated areas, groundwater depletion, water pollution, degraded ecosystems and inefficient water use encouraged by subsidies and misaligned incentives (Zekri & Al-Maamari, 2020). Moreover, outdated agricultural techniques, poor water management and inadequate response mechanisms across the food value chain exacerbate scarcity challenges, which are further intensified by rising temperatures and increased drought frequency because of climate change (Al-Taani, Nazzal, & Howari, 2021).

Research on irrigation water scarcity in MENA countries typically focuses on physical and environmental factors—such as climate change, droughts and groundwater depletion—and their effects on agricultural productivity and rural vulnerability (e.g., Darvishi Boloorani et al., 2024). Technological solutions, including improved irrigation techniques, rainwater harvesting and water recycling, are also commonly explored (El-Rawy, Wahba, & Fathi, 2024). In addition, existing literature assesses the socioeconomic impacts of water scarcity, particularly its effects on livelihoods, poverty and migration patterns (e.g., AlEmadi, 2021; Tinazzi, 2024). Recently, there has been a growing emphasis on policy and governance issues, such as water allocation policies and institutional roles in effective water management (de Waal et al., 2023). However, there remains limited research addressing farmers' adaptive behaviours and willingness to pay (WTP) for water-resource management initiatives. In particular, insights from WTP studies can also guide equitable pricing policies that avoid disproportionately burdening small-scale or low-resource farmers and enhance overall water efficiency (Biswas & Venkatachalam, 2015; Young & Loomis, 2014). Examining WTP for irrigation water provides also insights on how farmers value additional or reliable water supplies, which can inform water pricing mechanisms that reflect scarcity and provision costs, encourage water conservation and promote sustainable water use (Gebretsadik & Romstad, 2020).

Against this backdrop, the present study surveyed 313 smallholder farmers in Egypt's Nile Delta from November to December 2022, using a contingent valuation method to elicit their WTP for improved irrigation access. The study makes two main contributions to the literature. First, it provides empirical results on farmers' WTP for irrigation services in Egypt—a highly water-scarce LMIC facing severe challenges related to irrigation water scarcity that are emblematic of those encountered throughout the MENA region. This enhances the value and relevance of our empirical findings, making our insights applicable to other MENA countries facing similar water scarcity challenges. Policymakers and stakeholders in these countries can draw on our findings to inform water management strategies tailored to the needs and behaviours of smallholder farmers.

Second, previous studies on WTP for irrigation innovations in LMICs have tended to emphasize sociodemographic, biophysical and technological factors. While these factors are important, this focus has often overlooked the significance of institutional and psycho-behavioural factors in shaping farmers' decision-making processes. In our study, we incorporate variables such as governance, policy trust, perceptions of water scarcity, conservation attitudes and psychological distance from water issues to provide a more holistic view of the determinants of WTP. This comprehensive approach not only fills a critical gap in the literature but also offers practical insights for policymakers and practitioners, enabling the development of targeted interventions that are more likely to gain acceptance among farming communities.

The remainder of this paper is structured as follows: Section 2 provides a contextual background on irrigation water scarcity in Egypt. Section 3 outlines the survey design and methodology employed in our study. Section 4 presents the empirical results and discusses the main findings. Finally, Section 5 summarizes the paper and offers policy recommendations.

2 | WATER SCARCITY AND SMALLHOLDER FARMERS' ACCESS TO IRRIGATION SERVICES EGYPT

Egypt faces inherent challenges with limited freshwater resources because of its arid climatic conditions (FAO, 2016). Approximately 90% of the country's water supply originates from the Nile River, with an annual allotment of around 55 billion cubic meters that has remained unchanged since 1954 (NWRP, 2017). This fixed supply has left Egypt in recent years with a significant annual water deficit exceeding 50 billion cubic meters (MPED, 2021). Annual per capita water availability has fallen over the past few decades below 600 cubic meters, well under the international standard of 1000 cubic meters per person. This concerning trend is compounded by rapid population growth, urbanization, economic development and the adverse impacts of climate change—all of which increase water demand across domestic, industrial and agricultural sectors (El Bedawy, 2014). Further straining Egypt's water supply are uncoordinated upstream projects along the Nile, such as the Grand Ethiopian Renaissance Dam (Molle, 2018).

Agriculture, which accounts for about 75% of Egypt's total water usage and over 85% of freshwater withdrawals (NWRP, 2017), is particularly impacted. Efforts to boost agricultural output for the country's fast-growing population—growing at 2.1% annually and reaching 100 million in 2020 (CAPMAS, 2017)—are hindered by declining irrigation resources. Over the past two decades, rising temperatures, heat stress and decreasing rainfall have exacerbated these challenges, especially in the Nile Delta region, which produces around 60% of Egypt's food (Badreldin, Abu Hatab, & Lagerkvist, 2019). This has led to Egypt becoming heavily reliant on food imports, which satisfy about 45% of the country's domestic food demand. Such dependence on global markets to meet the food requirements of Egypt's expanding population makes the country highly vulnerable to price volatility and disruptions in international food markets (Abu Hatab & Hess, 2021; Gabr (2023).

Over the years, successive Egyptian governments, along with their development partners, have implemented numerous initiatives aimed at enhancing water management, upgrading water infrastructure and promoting sustainable irrigation practices (Abu Zeid, 2020). In 1998, Egypt adopted its first comprehensive water policy strategy, which emphasized maximizing water-use efficiency and fostering collaboration with Nile Basin countries for the development and optimal utilization of water resources (Eldardiry & Hossain, 2021). A second national water-resource plan, covering the period 2017–2037, was introduced in 2017, outlining strategies to diversify water sources through desalination in coastal areas, groundwater extraction, water recycling and the adoption of advanced irrigation technologies to improve water efficiency (MWRI, 2017). More recently, the government launched a water management strategy for 2050, which includes initiatives such as canal rehabilitation, transitioning from flood to drip irrigation and implementing programs for climate adaptation and rainwater harvesting (Abdelzaher & Awad, 2022). A central aspect of these strategies is the acknowledgement that enhancing water-use efficiency requires more than just top-down government measures; it also demands active participation from farmers and stakeholders (Luo et al., 2020). A recurring focus in Egypt's water development projects has been on water pricing and cost recovery (Molle et al., 2019). Recent irrigation initiatives, for example, have encouraged farmers to contribute financially to ensure project sustainability and improve water-use efficiency (El-Agha, Closas, & Molle, 2017). In 2013, the Ministry of Water Resources and Irrigation (MWRI) emphasized that "it has become essential for farmers to pay for irrigation services to promote the rational use of irrigation water and establish sustainable drainage techniques" (OOSKAnews, 2013).

To develop effective water pricing schemes, policymakers and stakeholders need accurate insights into the economic value of water as perceived by smallholder farmers. This information is crucial for effective water allocation, particularly in public projects requiring fair distribution among multiple user groups (Jaghdani & Brümmer, 2016). In addition, understanding farmers' WTP can assist in determining compensation for reduced water access and diminished water rights (Winpenny, 2012). Despite its importance, to the best of the authors' knowledge, no study has specifically investigated the WTP of Egypt's smallholder farmers for improved irrigation access. This research is essential for developing strategies that not only enhance water-use efficiency but also ensure sustainable agricultural practices, thereby safeguarding farmers' livelihoods and strengthening national food security amid intensifying water scarcity. The present study addresses this gap.

3 | MATERIALS AND METHODS

3.1 | Study area

The survey was conducted in Fayoum Governorate, lying between latitudes 29° 10′ and 29° 30′ N, and longitudes 30° 20′ and 31° 10′ E, and located in Egypt's Western Desert (SIS, 2023). The governorate is divided into six administrative centres: *Senorus*, *Ebshoway*, *Tamya*, *Atsa*, *Yusuf El-Sideq* and *Fayoum* (Figure 1). Covering a total area of 6068.7 km^2, Fayoum is home to around 4 million people, over 70% of whom live in rural areas and are engaged in agriculture (CAPMAS, 2017). The total cultivated land in Fayoum spans approximately 400 thousand feddans (DoA, 2021), with the average farm size being 1.7 feddans (0.71 ha). Smallholder farmers dominate the agricultural landscape, cultivating a variety of crops such as horticultural products, medicinal and aromatic plants and staple grains including wheat, cotton, rice, corn and sugar beet (Abd-Elgawad et al., 2013).

Due to the low annual rainfall of just 7.2 mm, irrigated agriculture is the primary method of farming in the region. The Nile River serves as the main source of irrigation water (Khairy et al., 2022). However, in recent years, Fayoum has faced significant challenges related to irrigation water availability and management. These challenges include increasing demand and competition for water between agricultural and non-agricultural sectors, inadequate infrastructure, outdated irrigation systems, inefficient water management practices and a lack of institutional support. In addition, illegal water practices by farmers have worsened water scarcity issues (Abdelhaleem et al., 2021; Zaky et al., 2022).

3.2 | Survey design and participants

Participants in this survey were randomly selected from smallholder farmers across the six municipalities in the Fayoum governorate. A sample size of 313 was determined based on practical constraints, including resource limitations, accessibility and farmers' willingness to

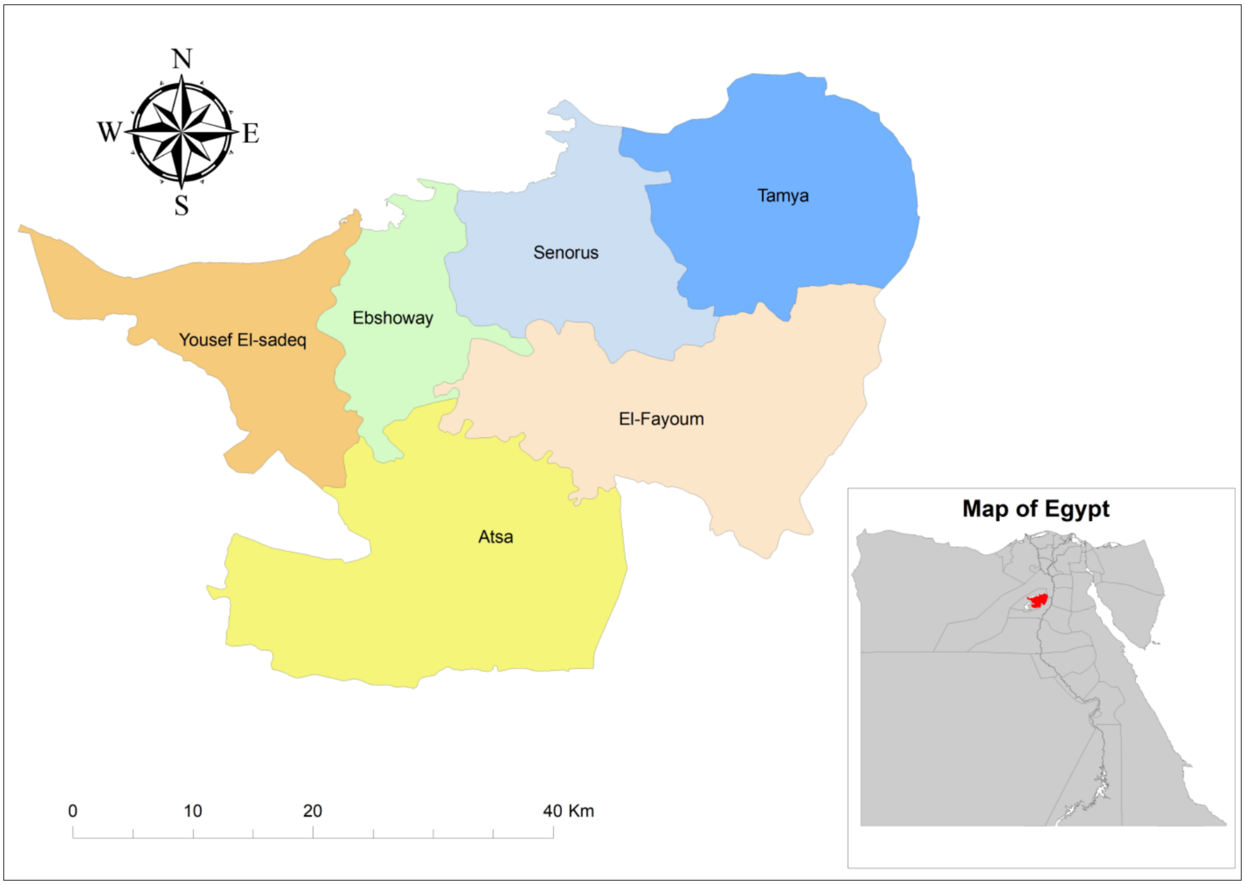

FIGURE 1 Map of the Fayoum governorate and study area.

participate in the study. To ensure representativeness, the sampling was proportional to the size of the cultivated area in each municipality relative to the total cultivated land in the governorate. This proportion ranged from 8.4% in *Ebshoway* to approximately 25% in *Atsa*. The distribution of the sample across the six municipalities is detailed in Table S1 (Supplementary Material 1). Previous studies with similar objectives have achieved significant results using comparable sample sizes (e.g., Bogale, 2015; Getnet, Tassie, & Ayele, 2022).

The questionnaire was developed by the research team in collaboration with local experts, farmer organizations and representatives from the Ministry of Irrigation and Water Management and the Ministry of Agriculture and Land Reclamation in the target areas. It was translated into Arabic and pre-tested through interviews with two selected farmers in each municipality to evaluate question clarity, logical flow and respondent comprehension. The final questionnaire gathered data on farmers' sociodemographic characteristics, farm attributes and irrigation systems. It also included a hypothetical scenario with bid designs to assess farmers' WTP for improved irrigation services. Additionally, the questionnaire explored farmers' perceptions and attitudes towards irrigation water scarcity, their psychological distance from the issue, trust in water management authorities and their information-seeking behaviour and communication regarding water-related topics (see Supplementary Material 2 for further details). The survey was conducted during the period November–December 2022, with each interview lasting around 30 minutes. Prior to commencing the interviews, participants were provided with a concise overview of the study objectives and were requested to provide their consent for participation.

Table 1 shows that approximately 60% of the respondents had over 15 years of farming experience indicating their substantial knowledge and familiarity with water resource issues and practices in the governorate. Half of the surveyed farmers had no formal education or education below the primary level. Two-thirds of the farmers reported monthly earnings ranging between 2000 and 5000 EGP, which is a moderate-income level. Furthermore, approximately 62% of the respondents had diversified their livelihood, having an additional off-farm income. About two-thirds of the respondents operated small farms spanning less than 30 *kirats*. Surface water emerged as the primary water source for the surveyed farms, with 64% of farmers utilizing surface water alone or in combination with groundwater (22%). The dominant irrigation system employed by the majority (64.9%) of farmers was flood irrigation with a pump, while the remaining third relied on flood irrigation without a pump.

3.3 | Contingent valuation method

Treating water as an "economic" good is rooted in fundamental economic principles, which aim to allocate scarce resources efficiently to

TABLE 1 Sample characteristics (n = 313).

Characteristics	Categories	% of the sample
Education	Illiterate or below primary	49.8
	Completed primary school	11.2
	Completed secondary school	1.6
	Technical qualification	26.2
	University degree	9.9
	Higher degree, MSc/PhD	1.3
Farming experience (Years)	<5	1.6
	5–10	8.3
	10–15	30.3
	>15	59.7
Off-farm income	Yes	62.3
	No	37.7
Total household monthly income (EGP*)	<1200	11.8
	1200–2000	14.4
	2000–3000	25.9
	3000–4000	27.2
	4000–5000	10.2
	5000–6000	3.2
	>6000	7.3
% of agriculture in total household income	<20%	32.3
	>20 to < 50%	24.0
	50%	14.4
	>50% to < 75%	12.1
	>75% to < 100%	17.0
	100%	0.3
Farm size (kirats**)	<30	62.6
	31–70	23.0
	71–100	6.71
	>100	7.7
Type of irrigation water used	Surface water	64.0
	Groundwater	0.6
	Surface and groundwater	22.0
	Other, including reuse of waste water	13.4
Irrigation system utilized	Flood irrigation system without pump	35.1
	Flood irrigation system with pump	64.9

*1 USD = 24.77 EGP in December 2022.
**1 ha = 57.14 *kirats*.

meet both current and future demands. However, determining an appropriate price for irrigation water, as an economic good, has long posed empirical challenges (Lazaridou & Michailidis, 2020). Non-market valuation methods provide effective tools for estimating the value of water and assessing farmers' WTP for water access and use (Bozorg-Haddad et al., 2016). Nevertheless, studies on water resources reveal significant variability in WTP estimates derived from different valuation techniques (Jaghdani, Brümmer, & Barkmann, 2012). Consequently, the choice of valuation method is critical and should align with the study's objectives—whether to evaluate the overall value of the entire irrigation system or to analyse the value of its specific attributes and components (Hynes, Campbell, & Howley, 2011).

Consistent with the objective of the present study, we employed the Contingent Valuation Method (CVM) to assess the economic value of system improvements aimed at enhancing access to irrigation water from the perspective of smallholder farmers. Specifically, we adopted the Double-Bounded Dichotomous Choice (DBDC) approach, which involves presenting respondents with two sequential bids. If a respondent accepts the first bid, a higher second bid is offered; if they reject the first bid, a lower second bid is presented (Bateman et al., 2002; Hanemann, Loomis, & Kanninen, 1991). This method provides a robust framework for estimating the value of non-market goods, such as irrigation water, particularly in developing countries where traditional market mechanisms often fail to adequately capture the social and economic significance of resources like water (Beavor et al., 2024).

Beyond its direct impact on agricultural productivity, improved access to irrigation water offers additional benefits, such as mitigating risks associated with rainfall variability and enhancing livelihoods. The CVM is particularly effective in capturing these often-unpriced attributes. Moreover, CVM surveys can be customized to align with the specific socio-economic and cultural contexts of farming communities, ensuring that the scenarios presented are both realistic and relatable. For instance, in Egypt, where agriculture is heavily dependent on irrigation, reliable access to irrigation water is crucial for boosting agricultural output. However, water is frequently underpriced or mismanaged because of systemic inefficiencies and financial limitations. By employing the CVM, we can estimate the economic value that farmers assign to improved irrigation water access. This information can then inform the design of cost-recovery strategies, investment priorities and policies that accurately reflect the true demand and payment capacity of farming communities.

While recent literature suggests that CVM approaches may be outperformed by other valuation techniques, such as discrete choice experiments (DCEs), which provide more robust frameworks for eliciting preferences (Alcon et al., 2014; Bell, Shah, & Ward, 2014; Guerrero-Baena et al., 2019), we chose to employ CVM in this study because of its alignment with our research objectives and contextual constraints. Several factors informed this decision. First, to the best of our knowledge, this is the first study to examine smallholder farmers' WTP for irrigation water in Egypt. As a result, neither the enumerators nor the respondents have prior experience with surveys based on valuation methods. The simplicity of CVM ensures that respondents can easily understand and accurately respond to valuation questions (Ferreira & Marques, 2015). In addition, the CVM framework mirrors farmers' everyday market decisions, where they typically choose to purchase or decline based on a proposed price (Merino-Castello, 2003). This straightforward approach to estimating the monetary value of non-market goods makes CVM particularly suitable for regions with lower literacy levels and limited familiarity with complex survey instruments. Second, conducting a DCE requires extensive pre-testing to design choice sets and determine attribute levels, which is both time-consuming and resource-intensive. Given the logistical and budgetary constraints of our study, CVM emerged as a more feasible option while still providing valuable insights into farmers' WTP. Third, although DCEs excel at capturing preferences across multiple attributes, our primary objective was to estimate the monetary value of a single, well-defined improvement—enhanced access to irrigation water. Introducing multiple attributes and levels, as required in DCEs, would have added unnecessary complexity without commensurate benefits for our specific research question. Furthermore, the cognitive burden associated with DCEs can lead to "choice inconsistencies," particularly among populations unfamiliar with such survey formats (Colombo et al., 2022).

To address common critiques of CVM—such as starting bid effects, format bias, embedding effects, ordering problems and the free-rider problem (Cuccia, 2020)—we implemented several measures to enhance the reliability and validity of our results. We utilized a dichotomous choice format with follow-up questions to refine WTP estimates, thereby reducing biases inherent in open-ended questions. A pilot survey was conducted to ensure that the valuation scenarios were both realistic and comprehensible, improving the reliability of responses. To mitigate starting bid effects, four starting bids were randomly assigned to respondents (Bronowski & Goldsmith, 2023). To address potential free-riding behaviour, respondents were explicitly informed that farmers who did not pay the irrigation fee would be excluded from benefiting under the new scheme (Tietenberg & Lewis, 2018). Finally, to minimize information bias, the hypothetical valuation scenario included a detailed description of the proposed irrigation scheme and the payment mechanism (an irrigation fee). These measures collectively strengthen the credibility and applicability of our findings.

3.4 | The hypothetical valuation scenario and bid design

The hypothetical scenario used to implement the CVM was designed to align with the regional government's proposed irrigation water expansion and modernization project to provide farmers with improved access to irrigation water (see Supplementary Material 2). The CVM scenario explicitly detailed the project's characteristics to ensure clarity and context, stating that the project will rehabilitate irrigation canals and upgrade the irrigation system, ensuring an additional 30% annual irrigation water supply at the farm level, which reduces variability across cropping seasons. The improved system is expected to benefit over 66 000 households, irrigating approximately 400 000 feddans of agricultural land for the next 20–30 years.

Farmers were informed that the government would oversee the project construction, which is expected to be completed within 2–3 years. Following the completion, all villagers would have access to the improved irrigation water through an equitable canal system, regardless of farmland location. However, because of the project's high costs and the limited financial capacity of the regional government, farmers were required to share the construction and maintenance costs based on their landholdings. The financial contribution would involve an annual payment adjusted upwards by 8% to account for loan interest over a 10-year period. Farmers were also informed that non-contributors would face taxation and would not benefit from the improved irrigation water supply. The scenario emphasized that the project would only proceed if more than half of the farmers agreed to participate. A budget reminder was also included at the end of the text.

The surveyed farmers were then given an initial bid, asking if they were willing to pay for the described improvement in their irrigation water availability, with values ranging from 600 EGP/feddan/year to 2100 EGP/feddan/year (Table 2). An example of an initial bid question was: "Are you willing to pay if the surcharge is 900 EGP per annum per feddan?" Depending on the response to this initial bid, farmers were asked a follow-up bid that was either lower (600 EGP) or higher (1200 EGP) than the initial bid. Six bid levels (600, 900, 1200, 1500, 1800, 2100 EGP) were used across four different questionnaire versions that differed in their initial bid (Table 2). Notably, in dichotomous choice CVM studies, bid vectors need to be carefully selected to ensure that bids are realistic and acceptable to respondents (Johnston et al., 2017). While there is no valuation study specifically focusing on farmers' willingness to pay for cost recovery of water services in Egypt, the determination of the bid values was done in consultation with local experts from academia and governmental and non-governmental organizations. These values were further refined and validated during the pre-testing of the questionnaire.

A set of follow-up questions was included to gauge participants' understanding and engagement and assess the clarity of the scenario. For those who were willing to pay, additional questions probed the certainty of their payment decision and their primary motivations. Conversely, those unwilling to pay were asked to provide reasons in order to distinguish protest zeros from true zeros (Yu & Abler, 2010).

3.5 | Econometric model and specification

A smallholder farmer i's profit is determined by the difference between farm-specific revenues R_i and costs C_i. Suppose the farmer maximizes profits by managing the cultivated area (X_i). The maximum feasible profit depends on exogenously given input and output prices (P_i), farm-specific characteristics (S_i) and irrigation water supply (w_i). Hence, we can express the problem of profit maximization as:

$$\max \check{\pi}_i = R_i(X_i) - C_i(X_i) = \check{\pi}_i * (P_i, S_i, w_i) \quad (1)$$

In equation (1), $\check{\pi}_i$ and $\check{\pi}_i *$ represent profit and maximum feasible profit for given input and output prices (P_i), farm-specific characteristics (S_i) and irrigation water supply (w_i).

TABLE 2 Bid design for assessing smallholder farmers' WTP (values are in Egyptian pounds).

Bid sets	Initial bid value	Lower follow-up bid	Higher follow-up bid
S1	900	600	1200
S2	1200	900	1500
S3	1500	1200	1800
S4	1800	1500	2100

Note: During the survey period, 1 USD = 24.77 EGP.

We suppose that p_i, X_i, S_i are fixed. Furthermore, we assume that improved irrigation water supply positively affects profits (e.g., the profit function's first derivative is larger or equal to zero).

$$\frac{\partial \check{\pi}_i *}{\partial q_i} \geq 0 \quad (2)$$

According to equation (2), for an improvement in irrigation water supply from level w_0 to w_1, for all $w_0 < w_1$, there is a positive willingness-to-pay WTP_i. We defined WTP as the maximum amount of income a smallholder farmer in our sample would pay in exchange for an improved supply of irrigation in order to be indifferent between two levels w_0 and w_1.

$$\check{WTP}_i = \check{\pi}_i *(p_i, S_i, w_0) - \check{\pi}_i *(p_i, S_i, w_i) \quad (3)$$

We are interested in $\check{WTP}$ per feddan (roughly 0.42 ha) in our survey. Therefore, we need to divide $\check{\pi}_i *$ and $\check{WTP}_i$ by the amount α of irrigation water in the feddan the farmer uses. This can be written as $WTP_i = \frac{\check{WTP}_i}{\alpha}$ and $\pi_i^* = \frac{\pi_i}{\alpha}$. The applicable formula for willingness to pay per feddan with this straightforward transformation is as follows:

$$WTP_i = \pi_i^*(p_i, S_i, w_0) - \pi_i^*(p_i, S_i, w_1) \quad (4)$$

When being asked about their willingness to pay, respondents were confronted with two choices: maintaining the current situation with an existing level of irrigation water w_0 (the status quo) or opting for an increased irrigation water supply w_1. As previously described, respondents were then asked if they were ready to forgo a predetermined amount t (bid value) for a better irrigation water supply, which they could reject or accept. In the subsequent question, respondents were given a lower price if they rejected the initial proposal and a higher price if they accepted the initial offer.

In equation (3), WTP indicates that it could not be calculated directly in this format. However, we can observe that either farmers' WTP is greater or smaller than t. In a formal way, the improved scenario with w_1 is selected if:

$$\pi_i^*(P, S_i, w_1) - \pi_i^*(P_i, S_i, w_0) + t = \Delta\pi(P_i, S_i, w_0, w_1, t) > 0 \quad (5)$$

To simplify, we suppose the change in profit $\Delta\pi$ to be linear in its justification and exclude P_i, as we have not collected any information on prices.

$$\Delta\pi(S_i, w_0, w_1, t) = \alpha + \beta S_i + \gamma t + \epsilon \quad (6)$$

In equation (6), α, β and γ are parameters, and ϵ shows the profit function's unobserved and random elements. Here, γ needs further justification. The amount t that farmers are willing to forego in exchange for a better irrigation water supply would incur an opportunity cost because this amount cannot be used for any other purpose. Therefore, we can say γ is the marginal profit that was lost as a result of giving up the opportunity to invest for any other purpose. Similar to the utility theory, we can also interpret γ as the change in profit from one more unit of money. Alternatively, profits will rise by γ if the farmer has one additional unit of money. This interpretation allows us to determine willingness to pay as:

$$WTP_i = \frac{\alpha + \beta S_i}{\gamma} \quad (7)$$

Here, we need to make assumptions about the profit function's stochastic part in order to measure the parameters of $\Delta\pi$. We can express the probability of answering with a no, for example, not willing to pay for an efficient and improved irrigation water supply as:

$$Prob(w_0) = Prob(\alpha + \beta S_i + \gamma t + \epsilon < 0) = Prob(\epsilon > \alpha + \beta S_i + \gamma t) \quad (8)$$

Furthermore, the probability of answering with a yes can be expressed as:

$$Prob(w_1) = 1 - Prob(w_0) \quad (9)$$

Now, suppose ϵ has a normal distribution, then the cumulative distribution function (CDF) is as follows:

$$Prob(w_0) = \Phi[\alpha + \beta S_i + \gamma t] \quad (10)$$

Equation (10), which depicts the probit model, can be calculated using the method of maximum likelihood. There are two equations to be estimated, corresponding to two bids. There is a likelihood that the error terms ϵ of these two equations are correlated because the follow-up bid is dependent on the first bid. In particular, the unobserved components of the first and the second bid, which can be incorporated into a bivariate probit model, are correlated. The Newton–Raphson approach could be used to optimize the associated log-likelihood function.

3.6 | Variable selection and definition

In the estimated probit and bivariate probit models, the dependent variable is a binary indicator (yes/no) that captures whether a smallholder farmer in our sample is willing to pay a monetary amount for improved access to irrigation water. The bid amounts offered to farmers ranged from 600 to 2100 EGP. Specifically, the variable *BID1*, representing the initial bid in our DBDC elicitation format, could take on values of 900, 1200, 1500 or 1800 EGP, depending on the version of the questionnaire used during the interview. The follow-up bid variable, *BID2*, could take any of the six bid values between 600 and 2100 EGP, based on the respondent's answer to the initial bid.

In the initial phases of our empirical analysis, we incorporated a wide array of candidate variables from the survey (see Supplementary Material 2) into the econometric models (Table 3). The inclusion of these variables was guided by the recent literature on farmers' WTP in LMICs as shown in the examples provided in the following paragraphs. These variables encompassed five broad dimensions that previous studies have identified as predictors of smallholder farmers' WTP: sociodemographic, biophysical, technological, institutional and psycho-behavioural factors. The final model specification was determined by selecting a subset of variables from the initial candidate set, based on their statistical significance, their ability to enhance the model's explanatory power and their representation of the five categories influencing the premiums that smallholder farmers were willing to pay.

For the sociodemographic characteristics, we included farming experience, education level and the share of agricultural income in the total household income (Olum et al., 2020; Tang et al., 2022). Biophysical and technological factors included farm size, type of irrigation system used, distance from the farm to the irrigation canal and the cost of irrigation (Knapp et al., 2018). Institutional factors consisted of trust in government authorities, measured as the level of confidence that farmers place in institutions responsible for governing water resources. Two other variables were included to capture farmers' knowledge about irrigation water issues and their networks, measured by their membership in farmer and water-user associations (Biswas & Venkatachalam, 2015; Deh-Haghi et al., 2020).

The psycho-behavioural variables incorporated farmers' attitudes towards improving irrigation water and perceptions about the impacts of irrigation water scarcity on farm operations and productivity (Lasram et al., 2018). In addition, we included a variable on psychological distance, which has been identified in recent behavioural studies as an important influencing factor concerning farmers' environmental behaviours (Abu Hatab et al., 2022). These psycho-behavioural variables (attitude, perception, knowledge and psychological distance) were derived from a principal component analysis (PCA) using statements from the corresponding sections of the questionnaire. The use of PCA helped reduce the dataset into fewer uncorrelated components while minimizing information lost (Jolliffe & Cadima, 2016). As shown in Table S2 in Supplementary Material 1, the Cronbach alpha (α) values for attitudes, perceptions, knowledge and psychological

TABLE 3 Description of the variables included in the econometric analysis.

Variable	Definition	Type	SD
Experience	Number of years in the farming business	Categorical (Less than 5 years: 1 - More than 15 years: 4)	3.09
Education	Level of education	Categorical (No formal Schooling: 1 - MS/PhD: 6)	1.59
Agricultural income	Share of income from agriculture in total income	Categorical (Just a small part: 1 - All: 5)	1.48
Farm size	Total farm size in *kirat**	Continuous	54.28
Irrigation system	Farm irrigation system	Categorical (Flood irrigation without pump: 1, Flood irrigation with pump: 2)	0.48
Cost of irrigation	Irrigation cost per/kirat in 2021	Continuous	186.58
Farm location	Distance from the farm to the irrigation canal	Categorical (Beginning: 1, Middle: 2, End: 3)	0.76
Membership	Membership of water-user associations	Binary (Yes: 1, No: 0)	0.31
Trust	The level of farmers' trust in government irrigation organizations	Categorical (Strongly disagree: 1 - Strongly agree: 5)	1.27
Attitude	Farmers' attitudes towards irrigation water/services	PCA-derived	1.92
Perception	Farmers' perceptions about changes in quality and availability of irrigation water and their impacts on farming activities	PCA-derived	1.85
Knowledge	Familiarity with water-resource challenges	PCA-derived	1.58
Psychological distance	The extent to which a farmer perceives events of water shortages across dimensions of time and geographic location.	PCA-derived	1.18

*1 kirat = 0.0175 ha.
Source: Survey data.

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distance were 0.77, 0.74, 0.69 and 0.76 respectively, which indicate that our PCA-derived variables are adequately reliable and effectively capture the underlying variation in the data.

To assess potential multicollinearity issues among the explanatory variables included in the Probit and bivariate Probit models, we conducted Variance Inflation Factor (VIF) diagnostics. All VIF values were below 2, indicating that multicollinearity is not a significant concern in the model (Table S3 in Supplementary Material 1). Moreover, pairwise correlation coefficients among the independent variables were examined, and no excessively high correlations were observed (Table S3 in Supplementary Material 1).

4 | EMPIRICAL RESULTS AND INTERPRETATION

4.1 | Descriptive analysis of farmers' WTP for improved access to irrigation water

By and large, the results indicate that the majority of surveyed farmers are willing to pay for improved access to irrigation services, although the specific amounts they are willing to pay vary (see Figure 1 in Supplementary Material 1). Specifically, the relationship between the randomly assigned initial bids and the percentage of farmers accepting those bids forms a downward-sloping curve. When an initial bid of EGP 900 was offered, approximately 75% of the farmers responded positively, whereas only 20% responded positively to an initial bid of EGP 1800. Despite historical government subsidization of agricultural water leading Egyptian smallholder farmers to expect free water provision (Molle et al., 2019), these findings suggest that farmers are increasingly aware of the severity of irrigation water scarcity and recognize that their financial contribution is necessary. The results align with existing empirical literature, which consistently shows that smallholder farmers in developing countries are willing to pay for enhanced access to irrigation water (e.g., Angella, Dick, & Fred, 2014; Gebretsadik & Romstad, 2020; Knapp et al., 2018).

To further understand farmers' perspectives on irrigation water pricing, we asked them to provide reasons for their positive or negative responses regarding their WTP. The primary reason cited by those willing to pay was their recognition that water scarcity is a critical issue requiring timely action (74%), along with the importance of stable access to irrigation water for maintaining their farming activities (24.5%). They justified their WTP by advocating for the active involvement of farmers in the implementation of such projects and emphasizing that responsibility for irrigation projects should not rest solely with the government but should be shared among various stakeholders. Conversely, among the farmers who rejected the bids, financial constraints were the primary reason for their unwillingness to pay (61.1%). Other factors included uncertainty about how the funds would be utilized (13.6%), the perception that the problem is not an urgent priority (20.6%) and the belief that the proposed change is insignificant (4%). Previous research has shown that past experiences of inconsistent service delivery and inadequate maintenance have led Egyptian farmers to distrust the government's ability to provide reliable and high-quality irrigation services, even if they were to pay for them (Molle et al., 2019).

4.2 | Econometric estimates of smallholder farmers' WTP for improved access to irrigation water

Table 4 presents the results of the estimated probit and bivariate probit models regarding the factors influencing smallholder farmers' WTP for improved access to irrigation water. To avoid potential

TABLE 4 Probit and bivariate probit estimation results.

Variables	Probit model	Bivariate probit model
Response to bid 1	−0.0017*** (0.0002)	−0.0015*** (0.0002)
Farming experience	−0.0659** (0.0304)	−0.0640** (0.0299)
Level of education	−0.0807 (0.0603)	−0.0777 (0.0597)
Agricultural income	0.1630** (0.0676)	0.1550** (0.0683)
Farm size	0.0036* (0.0019)	0.0039** (0.0019)
Irrigation system	0.0243 (0.2180)	0.0460 (0.2170)
Cost of irrigation	−0.0001 (0.0005)	−0.0001 (0.0005)
Location of the farm from the irrigation canal	0.2630** (0.1240)	0.2690** (0.1240)
Membership of water user associations	0.9000*** (0.3450)	0.9500*** (0.3440)
Trust in government	0.2170** (0.0857)	0.2160** (0.0842)
Attitude	0.1860*** (0.0557)	0.1920*** (0.0555)
Perceptions	−0.1340** (0.0603)	−0.1350** (0.0602)
Knowledge	−0.0630 (0.0631)	−0.0664 (0.0627)
Psychological distance	−0.2860*** (0.0900)	−0.2870*** (0.0892)
Constant	1.5120* (0.8330)	1.2150 (0.8180)
Athrho		−0.5420*** (0.1680)
Log lik. (Null)	−215.61	
Log lik.	−163.25	−333.83
Chi-squared	104.71	97.32
Observations	313	313

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$
Source: Econometric model estimates. Standard errors in parentheses.

biases, as recommended by Bateman et al. (2001), the probit model excludes the second bid, ensuring the accuracy and reliability of the results. In contrast, the bivariate probit model incorporates both the first and second bid responses, providing a broader perspective on farmers' decision-making. The goodness-of-fit measures indicate robust model performance, with highly significant chi-squared values for both the probit model ($\chi^2 = 104.71$) and the bivariate probit model ($\chi^2 = 97.32$), confirming their suitability for analysing our DBDC experimental data. The results further reveal consistency in the sign and magnitude of the estimated coefficients across both models, underscoring their reliability. Notably, the athrho (ρ) parameter in the bivariate probit model is statistically significant, confirming a correlation between the error terms of the two equations. This finding underscores the appropriateness of employing the bivariate probit model over two independent probit models, as it accounts for unobserved factors influencing responses to both bid questions.

As presented in Table 4, the coefficients for the bid variable, which represents the proposed payment for upgrading the irrigation system, are negative and highly statistically significant ($p < 0.01$). This result aligns with theoretical expectations, which predict that higher costs reduce the probability of participation. Specifically, as the proposed payment increases, the perceived benefits of the irrigation improvements become less favourable compared to the cost, leading to a decline in smallholder farmers' WTP. This outcome is consistent with findings from prior studies on WTP for enhanced irrigation services in developing countries. For instance, Angella, Dick, & Fred (2014), Gebretsadik & Romstad (2020) and Kanda & Lutta (2022) report that higher bid amounts are associated with a reduced likelihood of payment, as the increased financial burden diminishes the perceived value of the intervention. Therefore, the results highlight the importance of carefully calibrating payment schemes to align with the financial capacities and perceived benefits of smallholder farmers, ensuring that proposed improvements remain attractive and feasible for target communities.

Table 5 summarizes the mean WTP values (in EGP) per feddan (approximately 0.42 ha) derived from the probit and bivariate probit models. According to the probit model results, the estimated mean WTP per feddan is EGP 1215.66, while the bivariate probit model estimates it slightly lower at EGP 1206.01. The overlap of the confidence intervals suggests that the difference between the two estimates is statistically insignificant. Overall, the mean WTP for improved access to irrigation water ranges from approximately EGP 1111 to EGP 1311 per feddan. Comparing these values to recent statistics from the Economic Affairs Sector of the Egyptian Ministry of Agriculture and Land Reclamation (MALR, 2021) regarding the average per feddan income in the Fayoum governorate, our estimated mean WTP represents approximately 7% of the average annual income per feddan. A comparable study by Kidane, Wei, & Sibhatu (2019) on the WTP of Eritrean smallholder farmers found that farmers were willing to pay an amount equal to 5% of their average farm income to gain improved access to irrigation water. Overall, our findings indicate that smallholder farmers in our sample perceive the importance of this investment for their agricultural activities and are willing to allocate a significant portion of their income to enhance their access to irrigation water.

4.3 | Factors shaping farmers' WTP for improved access to irrigation water

4.3.1 | Socio-demographic characteristics

The results from both models in Table 4 demonstrate that a farmer's reliance on agriculture as a primary income source positively and significantly influences their WTP. Farmers who depend more heavily on agricultural income may recognize the critical role of irrigation water in enhancing agricultural productivity, leading to a greater willingness to invest in irrigation system improvements (Tang et al., 2022). Contrary to many previous studies, our findings indicate that the level of education among farmers exhibits an insignificant negative influence on WTP. Higher levels of education are typically expected to increase awareness and contribute to a higher WTP for irrigation water conservation and development initiatives (Deh-Haghi et al., 2020). However, some studies have reported a negative and statistically significant effect of education on WTP for irrigation water supply (e.g., Lalika et al., 2017). This might be attributed to the notion that education provides farmers with alternative income sources and exit options, potentially reducing their WTP for agricultural investments.

Interestingly, the findings indicate a negative and statistically significant effect (at the 5% significance level) of the number of years a farmer has been practicing agriculture on their WTP. Experienced farmers often encounter challenges and risks throughout their farming careers, which may make them more risk-averse and cautious when considering new or costly initiatives, such as investing in improved access to irrigation (Guerrero-Baena et al., 2019; Knapp et al., 2018). Moreover, accumulated knowledge of past difficulties can influence their decision-making, leading to a reduced WTP. Scepticism about the anticipated benefits of investing in improved irrigation access may also play a role, especially if past interventions did not yield the expected results. Furthermore, farmers with long-standing experience

TABLE 5 Willingness to pay estimates obtained from the probit and bivariate probit models.

WTP estimates	Mean WTP	Lower level	Higher level	p-value
Probit model	1215.66	1110.93	1310.14	0.0000
Bivariate probit model	1206.01	1086.50	1310.73	0.0000
Heckman probit model	1782.62	1585.53	2210.65	0.0000

Source: Econometric model estimates.

often have established farming practices and routines, including specific irrigation methods ingrained in their operations, making them less inclined to adopt changes.

4.3.2 | Technological and biophysical factors

The results reveal a positive and significant impact of the distance between the farm and the water source on a farmer's WTP. Proximity to the irrigation canal directly influences the convenience and accessibility of water supply. Farms located farther from the canal may face challenges in transporting water, leading to increased labour, time and additional expenses. Therefore, farmers with more distant farms may exhibit a higher WTP for improvements that ensure a more reliable and consistent water supply, reduce infrastructure costs and enhance the efficiency of water delivery (Aydogdu & Bilgic, 2016). Similarly, the results show that farm size has a positive and statistically significant influence on farmers' WTP. This finding aligns with the results of Olum et al. (2020), suggesting that farm size reflects a farmer's financial situation, capacity to absorb costs and ability to invest in irrigation infrastructure, leading to a higher WTP for agricultural innovations.

In contrast, both the cost of irrigation and the type of irrigation system used by the farm have the expected signs but show statistically insignificant influences on farmers' WTP. Decena & Pabuayon (2015) attribute similar findings to farmers' distrust in how policies or regulations on water distribution are implemented based on past experiences. This could also be because of the homogeneity of the irrigation systems used by the sample farmers—all of whom use flood irrigation, with approximately 65% using flood irrigation with a pump and 35% without a pump (Table 1). This homogeneity may result in similar costs or a narrow range of cost variation, reducing the statistical power to detect significant differences in WTP based on these factors.

4.3.3 | Institutional factors

Consistent with previous studies, our results show that trust in water management institutions has a significant and positive influence on farmers' WTP for improved irrigation services. As noted by Makwinja, Kosamu, & Kaonga (2019), trust in water management institutions enhances farmers' confidence that the fees they contribute will be used effectively to deliver improvements in irrigation water attributes that meet their expectations. In the same vein, Saldías et al. (2016) point out that institutional credibility plays a critical role in reducing perceived risks associated with payment, as farmers are less likely to commit to a financial contribution if they doubt the ability of institutions to deliver promised outcomes. Furthermore, Abdelhafidh et al. (2021) reveal that corruption, mismanagement or failure to deliver past promises can erode institutional trust and reduce farmers' motivation to contribute financially. Therefore, addressing these institutional challenges by enhancing transparency, promoting inclusivity and strengthening the capacity of water management institutions can be instrumental in increasing farmers' WTP and the success of such interventions.

Similarly, farmers' membership in irrigation water user groups or associations positively influences their WTP. According to Olum et al. (2020), such memberships act as platforms for collective participation in decision-making processes related to the management of irrigation water systems, fostering a sense of ownership and shared responsibility among farmers. These groups also enable better dissemination of information about proposed improvements, creating transparency and increasing farmers' awareness of the benefits associated with improved irrigation systems.

4.3.4 | Psycho-behavioural factors

The results show that farmers with positive attitudes towards improving irrigation water are more likely to demonstrate a higher WTP. Positive attitudes may stem from perceived productivity gains, increased crop yields or environmental sustainability benefits associated with improved irrigation (Deh-Haghi et al., 2020). Moreover, psychological distance emerges as a highly significant determinant of WTP, showing a negative relationship. Psychological distance refers to the extent to which individuals perceive events, such as water shortages, across dimensions of time, social proximity, geographic location and uncertainty (Abu Hatab et al., 2022). This suggests that farmers who perceive irrigation water scarcity as a proximate and concrete issue and an immediate concern affecting them personally are more likely to pay for solutions and invest in improvements.

Surprisingly, farmers' knowledge about the scarcity of irrigation water in their communities was found to have a negative but statistically insignificant effect on their WTP. This contradicts the expectation that greater knowledge and awareness of water scarcity would lead to higher WTP (e.g., Meijer et al., 2015). This finding may be attributable to the nature or quality of information farmers receive. It is possible that the information does not sufficiently highlight the specific benefits of investing financially in improved irrigation resources.

Contrary to previous studies on WTP for irrigation water supply in developing countries (e.g., Kidane, Wei, & Sibhatu, 2019), our results show that farmers' perceptions about changes in the availability of irrigation water are negatively associated with WTP at the 5% significance level. One potential explanation is that farmers may conduct a cost–benefit analysis based on past experiences, evaluating the trade-offs between the required investments and the potential impacts on their farming operations. If they perceive the costs to outweigh the benefits or anticipate minimal positive impacts, they may display lower WTP. A lack of confidence in the effectiveness of interventions can also reduce their willingness to invest. Moreover, farmers may be aware of alternative strategies, such as altering cropping patterns, that are perceived as more cost-effective or suitable for their operations, achieving similar outcomes without additional investment.

4.4 | Robustness check using the two-step Heckman probit model

As a robustness check, we estimated a two-step Heckman probit model to address potential selection bias resulting from non-randomly missing observations related to responses to WTP questions (Heckman, 1979). The two-step Heckman probit model accounts for potential selectivity in the data by first estimating a selection equation for the dichotomous choice contingent valuation question, capturing the factors influencing the likelihood of observing a positive WTP response. In the second step, the outcome equation is estimated, incorporating the selection correction derived from the first step to predict the willingness to pay the amount. This approach aims to mitigate biases arising from the non-random nature of missing observations and enhance the validity and reliability of our findings.

Upon examining the results of the two-step Heckman probit model, presented in Table S5 in Supplementary Material 1, we find that the results from the selection equation generally align qualitatively with those obtained from the probit and bivariate probit models. This consistency indicates reliability in our estimates and suggests robustness in our findings. It strengthens the validity of our results and reinforces confidence in the observed relationships between the explanatory variables and WTP.

5 | SUMMARY AND IMPLICATIONS

The study employed a double-bounded dichotomous choice contingent valuation method to assess the willingness to pay (WTP) of 313 smallholder farmers in Egypt's Nile Delta for enhanced access to irrigation water. The findings offer valuable insights for policymakers and stakeholders in designing interventions and pricing models that align with the needs and financial limitations of farmers, supporting a more effective and sustainable approach to water resource management in agriculture. Specifically, the results reveal an inverse relationship between water price (bid values) and farmers' WTP, underscoring the importance of considering the economic realities and vulnerabilities of smallholder farmers in water pricing strategies. These farmers already face limited incomes and financial constraints, struggling to afford essential inputs. Increasing water costs can further strain their finances, reducing their ability or WTP for improved services. Therefore, water pricing strategies should be developed with careful consideration of farmers' affordability thresholds. To this end, governments of water-stressed LMICs should explore flexible and inclusive pricing mechanisms that reflect the diverse economic conditions of farmers. In addition, implementing differentiated pricing models tailored to the financial capacities of various farmer segments can ensure equitable access to sustainable water use without imposing undue burdens. Strategies such as tiered pricing, flexible payment options aligned with harvest cycles, community-based financing models or providing subsidies for low-income farmers can align water pricing with farmers' economic capacities.

The results highlight that smallholder farmers' WTP for improved irrigation services is shaped by a complex mix of factors, including socioeconomic, technological, biophysical, institutional and psycho-behavioural elements. The significance of these factors, particularly psycho-behavioural factors that have traditionally been overlooked in empirical analyses and policy discussions on irrigation water management in LMICs, emphasizes the need for integrated, interdisciplinary approaches that incorporate social science and psycho-behavioural perspectives to understand farmers' decision-making processes under eater stress conditions. Considering the multifaceted influence of various technological, biophysical, institutional and psycho-behavioural factors can help design policies that are both equitable and efficient, ultimately contributing to the long-term sustainability of irrigation water resources and the resilience of agricultural systems.

The results imply the importance of engaging stakeholders such as extension services, water resource institutions and farmer associations in the design and implementation of irrigation water strategies. These groups can play a key role in fostering positive attitudes and enhancing farmers' perceptions of the value and feasibility of investing in better water supply systems. Training extension workers in behavioural communication strategies, developing messaging that resonates with farmers' values and beliefs and creating feedback mechanisms to ensure policies are aligned with farmers' needs can enhance the effectiveness of irrigation water strategies.

The findings emphasize the strong influence of good governance and trust in service providers on farmers' WTP. A lack of trust in water institutions can exacerbate farmers' concerns regarding the potential misuse or misallocation of funds, corruption or inadequate service delivery. This may erode the sense of collective responsibility and ultimately discourage farmers from actively participating in cost recovery efforts. Promoting transparency in financial management and resource allocation through effective communication and information provision about the governance of irrigation institutions can enhance farmers' understanding of how their financial contributions are utilized. Creating platforms that allow farmers to provide input and have oversight in project planning and decision-making could strengthen their trust in the governance of water institutions and the fairness of cost recovery mechanisms.

Finally, we acknowledge a few limitations of this study, which highlight areas where future research can contribute to a more comprehensive understanding of the factors influencing farmers' WTP for improved irrigation services. First, the CVM scenario used in this study is inherently hypothetical, which may lead to hypothetical bias. While we took measures to ensure the realism of the scenario, such as presenting farmers with detailed descriptions of the proposed project and its potential benefits, responses may still differ from actual behaviour. Future studies could explore the use of alternative valuation methods, such as choice experiments or revealed preference approaches, to validate and complement the findings. Second, the sample size, while sufficient for robust statistical analysis, may limit the generalizability of the results to other regions with different socio-economic, institutional or agro-ecological contexts. Expanding the study to include a more diverse range of regions and farmer groups would allow for a deeper understanding of regional variations in WTP and the factors influencing it. Third, the methodological choices, including the use of probit and bivariate probit models, provide valuable insights but are not without constraints. For example, while these models capture the relationships between WTP and explanatory variables, they may not fully account for unobserved heterogeneity among farmers. Future research could explore alternative econometric models that may better capture this heterogeneity and refine the understanding of farmers' decision-making processes. In addition, the long-term impacts of the proposed irrigation improvements, such as changes in agricultural productivity, household income and community resilience, remain unexplored. Future studies could adopt longitudinal designs to assess these impacts over time and evaluate the sustainability of farmers' WTP commitments.

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DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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