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Combining Econometric, Cost–Benefit, and Financial Methodologies in a Framework to Increase Diffusion and to Predict the Feasibility and Sustainability of Irrigation Schemes: A Case Study in Kurdistan, Iraq

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Abstract: This paper applies ex ante econometric, cost–benefit, and financial methodologies to increase participation in an irrigation project and predict its financial feasibility and social sustainability in Shahrazoor, Kurdistan, Iraq. I investigated the socio-economic, psycho-cultural, and financial factors that determine participation. The socio-economic part of the econometric analysis showed that the project was appreciated more by poorer and economically weaker farmers who rely on agriculture than by those who rely on livestock activities. The psycho-cultural part of the econometric analysis emphasized that the project was appreciated more by literate farmers who adopt a maximization (rather than habit) approach. The cost–benefit analysis applied to the irrigation project was tailored to poorer and weaker farmers (i.e., costs of the irrigation scheme and benefits from new cultivation patterns were defined with reference to small farms) by including indirect benefits from both irrigation (e.g., flood control) and hydropower (e.g., eliminated GHG emissions), and determined a 7.1% mean internal rate of return; this was affected more strongly by uncertainty in crop prices than by uncertainty in indirect benefits. The financial analysis highlighted values for water prices, financial returns, and loan rates that met government and farmer budgets. A single framework summarized the main relevant social, economic, and financial conditions, and, by including insights from sensitivity analyses, determined the feasibility and sustainability of the irrigation project. Provided that the water price charged to farmers is between 0.32 and 0.57 USD/m^3, and the loan interest rate paid by farmers is smaller than 3.0%, the irrigation project in Shahrazoor is financially feasible for 13.6% of all reliable economic solutions and socially sustainable for 35.8% of the solutions.

Keywords: irrigation project; econometric analysis; cost–benefit analysis; financial analysis; development; Middle-East; Kurdistan; Iraq

1. Introduction

Agricultural policy programs, in general, and technological interventions in agriculture, in particular, should be congruent with farmer priorities (i.e., the problems to be solved) and expectations, and should also be appropriate for the long-term socioeconomic, cultural, and agronomic circumstances of the farmers ([1–3]). Such policies and technologies would have a greater chance of being accepted and practiced sustainably than programs based on temporary incentives or coercive pressures.

Technological interventions ([4–11]), in general, and irrigation projects ([12–19]), in particular, often result in a low level of awareness among the target group and in a low level of successful diffusion of the project (i.e., dissemination of knowledge leading to participation) because farmers are rarely consulted a priori about their specific circumstances, priority problems, and expectations.

Econometric studies of adoption behaviors and cost–benefit and financial studies of the impacts of an intervention should come before the project's costs are incurred. This is because approaches based solely on expert knowledge are likely to be biased due to a lack of information on the socio-economic and psycho-cultural attributes of the farmers, and on how these attributes will affect their decisions.

Among the few ex ante econometric analyses of policy or technology adoption by farmers, Batz et al. [20] used linear regression analysis to predict the speed and future ceiling for a dairy technology adoption in Kenya by assuming that data on past adoption behavior would provide information about likely future behavior. However, they did not account for the psycho-cultural characteristics of the farmers. Bekele [21] applied a multinomial logit model to analyze the impact of various types of intervention and of the problems prioritized by the farmers on the preferences of Ethiopian farmers. However, this study did not analyze the feasible distribution of costs among the farmers. Kondoh and Jussaume [22] applied logistic regression analysis to estimate the relative impacts of social networks and life experiences on the willingness of farmers in Washington State (USA) to adopt genetically modified organisms. However, they did not consider the psycho-cultural characteristics of the farmers or the technological features of the proposed interventions. Jaek and Lifran [23] performed a choice experiment to estimate the monetary value attached by farmers in France to six relevant attributes associated with rice cultivation practices, in order to design targeted contracts according to farmer preferences and to persuade the majority of rice growers to adopt environmentally friendly practices. However, they did not perform a financial analysis to implement an effective policy based on differentiated payments.

The purpose of the present paper was to solve these problems by applying ex ante econometric, cost–benefit, and financial methodologies within a single framework to increase diffusion and predict the financial feasibility and social sustainability of an irrigation project in Shahrazoor, Kurdistan, Iraq. To do so, I assessed the socio-economic, psycho-cultural, and financial factors that determine participation in order to identify the target farmers, to adjust the project to meet their needs and desires, and to properly distribute the project costs between this audience, the government, and society as a whole. In other words, the objective was to develop and demonstrate a methodological approach in which the results of the econometric analysis (which identifies the major socio-economic and psycho-cultural factors that influence participation decisions by farmers) affect the cost–benefit analysis (for example, by identifying the target group or the project features). In turn, the financial analysis (which specifies water prices and loan rates charged to farmers) is based on the results of the cost–benefit analysis by assuming that these water prices must be smaller than the economic value of water (otherwise, farmers would pay for benefits that accrue to other people) and that these loan rates must be smaller than the internal rate of return (IRR) of the project (otherwise, farmers would pay for the inefficiency of the irrigation project).

Note that this is unlike more usual contexts, in which farmers receive irrigation deliveries in return for some form of payment (in cash or in kind) after an irrigation scheme has been built ([24]; [25]). This paper refers to the future decision (at an individual farm level) to participate in a hypothetical program: the conceptual framework is similar to that for technology adoption, in which farmers decide to begin using a new production method or device; in this context, predicting participation in the project means anticipating future adoption by many farmers.

2. Review of the Econometric Literature

This section will identify the main variables applied in the econometric literature to explain technology adoption in agriculture.

I reviewed the literature to determine the key temporal factors. Batz et al. [20] showed that the perceived characteristics of technologies, such as the relative investment, risk, and complexity, were significant. Moreover, Burton et al. [26] applied a duration model in the U.K. to identify the economic and non-economic determinants of the adoption of organic horticultural technology; they found that gender, attitudes to the environment, and sources of information were important factors. Finally, Fuglie and Kascak [27] applied a duration model in the U.S. to estimate the long-term trends in the adoption and diffusion of technologies designed to reduce environmental externalities from agriculture. Long lags in the adoption of a technology turned out to result from differences in land quality, farm size, farmer education, and regional factors.

Similarly, I reviewed the literature to reveal spatial factors. Adesina and Chianu [28] used a logit model to assess the determinants of farmer decisions to adopt and adapt alley farming technology in Nigeria by considering both farmer and village characteristics. They found that farmer origins, previous contacts with agricultural extension agents, the number of years of experience with agro-forestry, land pressures, erosion intensity, and the distance from urban centers were all statistically significant factors. Moreover, Swinton [29] applied both random-effects regression models and spatial auto-regression models in Peru, using time lags in the choice of keeping some fields fallow as the dependent variable, to depict the impacts of household agricultural management practices on the decisions of neighbors. A spatial structure was evident, and the two models provided nearly identical results; thus, random-effects regression could largely eliminate the spatial dependency if the farmers were stratified according to the landscape characteristics. Finally, Abdulai and Huffman [30] employed a duration function to explain the increased use of crossbred cows in Tanzania; they found that proximity to other users of these cows, the level of schooling, access to credit, and previous contacts with extension agents positively affected adoption of these cows.

Among other studies, De Souza Filho et al. [31] applied duration analysis in Brazil to identify the determinants of the probability that a farmer would adopt a certain technology at time t, given that it had not already been adopted by that time. They found that the integration of farmers with farmer organizations, awareness of the negative effects of chemicals on health and the environment, reliance on family labor, being located in an area with better soil, and declining output prices were significant positive determinants for adoption, whereas the farm size and increasing input prices were significant negative determinants. Moreover, Kondoh and Jussaume [22] showed that, apart from a previous lack of experience with farming or with current organic farming practices, gross incomes, market strategies, and education levels positively affected adoption, whereas whether farmers obtained information about farming practices from other farmers, from cooperative personnel, or from both was not significant. Finally, Baerenklau and Knapp [32] developed a dynamic model of technology adoption in California (USA) by incorporating the age of the technology, whether the investment was reversible, variable inputs and outputs, and stochastic prices, and showed that the optimal decision rule was affected by the age of the technology that was currently adopted, by uncertainty due to variability in input and output prices, and by the irreversibility of the adoption decision. In the present study, these factors were disregarded because irrigation projects are new in the study area. Note that Bekele [21] combined the characteristics of the farm and the farmer with the personal costs and benefits expected by the farmer.

Table 1 summarizes the main independent variables used in the econometric literature, based on the arrangement of factors affecting irrigation adoption that was suggested by Alcon et al. [33]. I disregarded papers that relied only on one or two independent variables that have been used in subsequent studies. See Pardey et al. [34] for a broader analysis of innovation and technical change in agriculture.

Table 1. Independent variables used in the literature. Boldfaced items in the list of variables are associated with boldfaced X's in the body of the table. FF, farmer features; EF, economic factors; FC, farm characteristics; IF, institutional factors; FP, farmer perceptions; TF, technology features.

	Independent Variable	**F&K (2006)**	**BAeA (2003)**	**BUeA (2003)**	**A&C (2002)**	**A&H (2005)**	**DeA (1999)**	**K&J (2006)**	**B&K (2007)**	**B (2006)**	**SeA (2000)**	**D (2010)**	**W&Y (2007)**	**M&B (2006)**
FF	Farmer age	X			X		X							
	Farmer gender			X										
	Farmer origins				X									
	Farmer education level/literacy status	X				X		X		X				
EF	Gross income							X						
	Per capita economic consumption											X		
FC	Farm size						X				X			
	Land tenancy										X			
	Land quality/Soil erosion	X			X		X							
	Stated yields of the main crops	X												
	Livestock income (proportion of total)												X	
	Family labor/Family size						X							
IF	Market access/Market strategies				X			X						
	Distance from urban centers				X									
	Information from other farmers			X		X		X						X
	Membership in a cooperative				X		X	X						X
	Credit access					X				X				
	Extension contacts			X	X	X								X
FP	Declining output prices						X		X					
	Increasing input prices						X		X					
	Health or environmental impacts			X			X							
	Rankings of agricultural problems									X				
TF	Investment size		X											
	Technology risk		X						X					
	Technology complexity		X											
	Technology age								X					

Notes: A&C (2002), [28]; A&H (2005), [30]; B (2006), [21]; B&K (2007), [32]; BAeA (2003), [20]; BUeA (2003), [26]; DeA (1999), [31]; F&K (2006), [27]; K&J (2006), [22]; SeA (2000), [35]; D (2010), [36]; W&Y (2007), [37]; M&B (2006), [38].

3. The Study Area and Data Collection

The Iraqi Ministry of Water Resources is planning to implement several irrigation programs, already defined at the end of the 1970s, by revising the original projects in order to achieve an equitable and sustainable use of regional water resources. The goals were to take into account the development of more competitive markets and a more open society, and to integrate water engineering construction with environmental conservation. The present study focuses on the Qara Ali dam and irrigation project that will be implemented in the Shahrazoor basin of Kurdistan (Figure 1).

The Shahrazoor irrigation area is located in northwestern Iraq, within the highlands of the Kurdistan Mountains in Sulaymaniyah Governorate ([39]). The project area is located at an altitude of approximately 560 m a.s.l., and the land drains toward the Derbendikhan reservoir: this reservoir is assumed to be unaffected, although there might be some positive interactions for flood control, and negative interactions for tourism activities. The proposed Qara Ali dam (crest level = 605 m a.s.l.; dam height = 35 m) and reservoir (full storage capacity = 86 × 10^6 m^3; water area = 6.9 km^2; total yearly inflow = 177.9 × 10^6 m^3; annual losses due to evaporation = 11.14 × 10^6 m^3) are located within the Tanjero River valley, near the point of origin of the Shahrazoor basin. Construction of the dam is planned upstream of the village of Qara Ali. The irrigation project area is located downstream of the dam, along the right bank of the Tanjero River. This is an important project for the future development of the Suleymaniyah Governorate and the Shahrazoor region. The original development study for the area began during the 1970s, and was completed during the 1980s. The overall irrigation scheme (based on open irrigation canals) was originally designed to be larger than the one that was ultimately selected. The present urban development within the valley, water availability, and socio-economic reasons were the driving factors for the selection of the present layout for both the dam and the attached irrigation project.

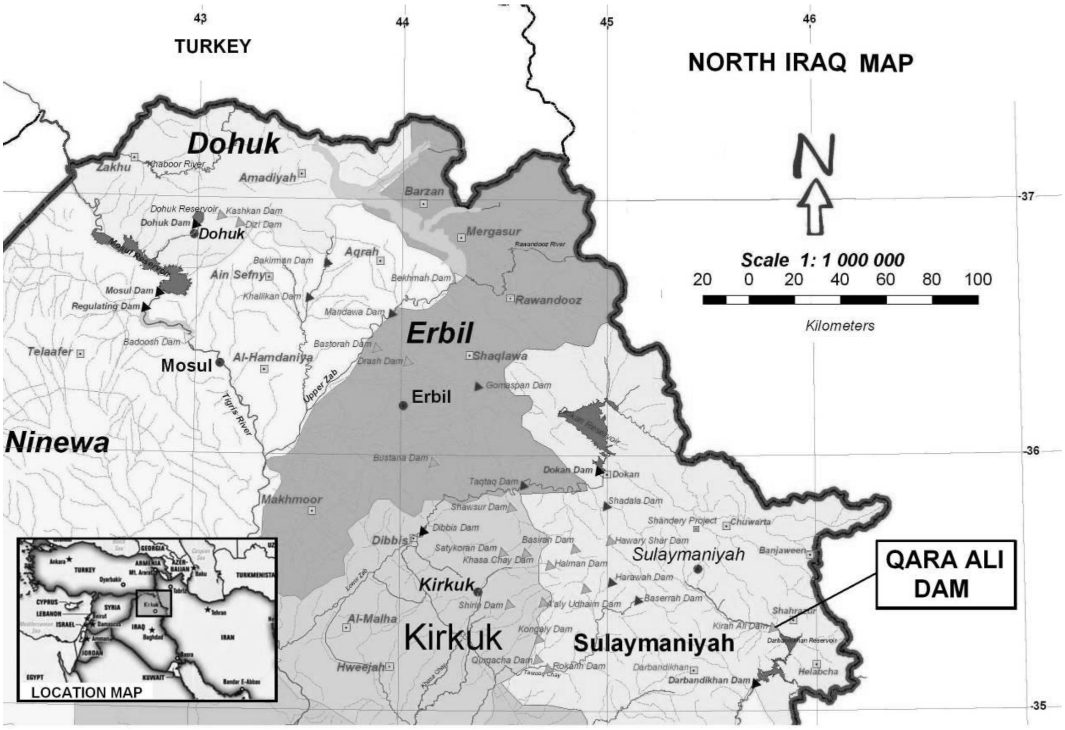

Figure 1. Location of the project area.

The data used in the present analysis were obtained from face-to-face interviews with farmers in the region affected by the project: these individuals were randomly chosen from a list provided by local representatives of the Ministry of Water Resources. The irrigation project will directly affect 15 villages: these are quite similar in terms of irrigation opportunities that might be perceived by farmers (e.g., close to input and output markets, near credit markets). Official statistics ([40]) report that 315 farmers lived in this area in 2011, and specify the land area exploited by each owner and the proportions of rain-fed and irrigated agriculture. Because of time and budget constraints, I only interviewed 46 farmers (15% of the total) in 12 villages (Alan, Daq, Daskara, Hasil-Kanikawa, Jolana, Kani-Bardina, Malwan, Qalawza, Qara-Gol, Shekh-Hasan, Zarayan and, Yakhshi) in April 2012. I initially stratified the population into three farm-size classes and two tenancy classes. I then modified the initial sample plan to account for the actual proportions of farm size and types of tenancy that I observed in the field (Table 2).

Table 2. The revised survey population, stratified according to the actual types of tenancy and farm sizes determined by the survey.

Type of Tenancy	Farm Size (ha)			
	<5	5–10	>10	Total
Owner	—	—	9	9
Share-cropper	—	1	—	1
Tenant	16	14	6	36
Total	16	15	15	46

Farm size was overestimated in the official data, probably due to division of land among heirs after the original statistics were collected, and the proportion of tenant farmers also appeared to have been underestimated, probably due to subsequent sales of land by farmers. I accounted for these features of the sample in the subsequent econometric analysis. Note that such a distribution of land size (i.e., many small farmers) is quite common in developing countries. Thus, in other developing countries, an irrigation project could also increase total income and reduce income inequality in a given area by targeting small farmers.

The detailed results of my survey are presented in Tables A1 and A2 of Appendix A. Here, I will discuss only the most important results. The average farmer was relatively old (nearly 51 years), with a family structure that included both grandparents and children. Farms averaged around 12 ha in size, and were most often (65%) rain-fed rather than irrigated. All raw data were obtained in donum, a local unit of measure that is equivalent to 0.25 ha, and were converted into hectares. Most farmers were poorly educated or illiterate, and government agencies were their primary source of access to information; other farmers were not a significant source. Twelve crops accounted for most of the region's agriculture, and each farmer typically raised both a small number of cows and goats and a larger number of sheep (a mean of 34 per family). Farmers used a mixture of traditional and modern agricultural techniques, and most used their current methods because they had always done so, and had found them to be effective; few used methods because other farmers or the government had advised them to do so. Most felt that increasing prices for agricultural inputs (including labor) were a major concern, despite increasing sales prices for agricultural outputs.

4. Methodology

4.1. The Econometric Analysis

This section will identify a subset of the feasible variables discussed in Section 2 based on the case study characteristics depicted in Section 3, and will develop an econometric model that includes these variables.

As the dependent variable in the present analysis, I chose a decision to be taken in the future rather than decisions already taken in the past; as a result, temporal and spatial aspects of participation could not be assessed. The resulting dependent variable (i.e., the readiness to adopt irrigated agriculture) will be represented by combining data on willingness to adopt the new approach, access to information, and access to credit into a binary outcome variable (with 1 = ready to participate, 0 = unready); the three criteria were whether the farmer was willing to participate, and whether they had access to at least one source of information and at least one source of credit; in this study, 98%, 91%, and 89% of the survey population met these criteria, respectively. Needless to say, willingness to adopt is different from readiness to adopt in terms of knowledge and financial resources. In particular, among the temporal factors, previous contacts with extension agents have been excluded as a variable because no survey respondents reported receiving information from such sources, and the number of years of experience was not analyzed because the irrigation scheme under consideration is new to the study area. Among the spatial factors, the decisions of neighbors were disregarded because the irrigation scheme is new in the area; land quality and regional factors were not analyzed because of the homogeneous and small agricultural area under consideration; the distance from urban centers was excluded because all farmers live in homogeneously distributed villages; and the proximity of farmers to other users of irrigation was not considered because all farmers lived in villages surrounded by farmland, with little use of irrigation in the study area (i.e., 93% of the study area was non-irrigated land). Moreover, as suggested by my preliminary pilot surveys, gender and environmental concerns were not analyzed because the agricultural society in the study area is heavily male-dominated and sufficiently poor that environmental concerns are not a high priority for residents; and farmer origin was not included in the present analysis because all farmers in the study area come from the same Kurdish culture. Finally, land pressure and erosion intensity were excluded, since these are similar throughout the study area, and the characteristics of alternative technologies have not been considered because a single irrigation scheme is being proposed for the whole study area. Note that some previous studies have assumed full information on the part of the farmers, so that differences in access to information do not lead to different decisions, and have recommended solutions for when this assumption was violated (e.g., [41]). However, since no farmers in the study area knew about the proposed irrigation project before my study, all farmers were assumed to have no knowledge. The economic benefits perceived by the farmers (e.g., [42]) were also not included, because irrigated agricultural management is new in the study area and its benefits are therefore not known to farmers. Similarly, no measures were necessary to correct for selection bias (e.g., [43]) because no farmers were aware of this future irrigation project.

For the independent socio-economic variables, I used the estimated gross income as a linear function of crop yields, with crop prices as weighting factors. Indeed, the relationship between farm size and farm income, which would suggest the need to use income per hectare, is likely to be weak (i.e., the average farm dimension was 7.74 ha, with a standard deviation of only 0.68). Other studies chose alternative proxies for income: the farm size ([35]), the estimated gross income ([44]), the estimated consumption per capita ([36]), or the stated yield for the main crop ([27]). Moreover, I introduced a dummy variable to account for direct access to output markets, thereby omitting the alternative reference to local traders ([28]), and I introduced four dummy variables for prices, with good or fair (but not unfair) as the options for output and input prices ([31]). Finally, I used dummy variables for direct access to bank loans ([45]), thereby omitting the alternative reference to other sources (i.e., cooperatives and other farmers), and for whether the percentage of income from livestock activities was greater than 50% ([37]).

Note that the ex ante a priori nature of the present study made it impossible to highlight the impacts of alternative types of adopters; for example, Zhang et al. [46] estimated a higher influence by early successful adopters on the decisions of others. The relatively small size of the farmer families involved in the present irrigation project suggested that differences in available labor could be disregarded, unlike in the study by Dadi et al. [47]. The ex ante nature of the present study also made it impossible to distinguish non-adopters from alternative types of adopter; for example, Barham et al. [48] identified the most significant differences between non-adopters and early adopters, late adopters, and those who adopted and then abandoned the technology. The small and very small numbers of owners and sharecroppers, respectively, in my sample made it impossible to highlight the impacts of alternative types of tenancy; for example, Soule et al. [35] estimated the influence of land tenure on the adoption of conservation practices. The relatively small area involved in the present irrigation project suggested that differences in available technologies could be disregarded, whereas the water shortage perceived by almost all farmers made it impossible to analyze the possibility of a partial participation in the irrigation scheme.

For the psycho-cultural independent variables, the small sample size suggested that I should distinguish literate from illiterate farmers using a dummy variable ([21]) and that I should rank agricultural problems using dummy variables for access to markets and access to additional water, which were ranked as the most urgent problems, and used access to loans as a residual variable (see Table 3). Based on the perception that water shortages mainly occurred during the summer, I created a third dummy variable for summer water availability (always and never), and used water shortages in winter as a residual variable. Moreover, I introduced two variables to account for attitudes towards innovation. To do so, I counted the number of replies that included "I have always done it this way" as the justification for the current choice of crops, fertilizers, output markets, and irrigation technology, and used this as an indicator of a "habit" (status quo) approach to innovation. I also counted the number of responses that represented a "maximization" approach to innovation, where these respondents justified their current choices as follows: "it offers a better price" for the output market, "they show high profitability" for crops, "they are very effective" for fertilizers, and "it is efficient" for irrigation technology. Finally, I used two dummy variables for attitudes towards the future: one for positive expectations (i.e., for the future, increasing output prices and either increasing or stable input prices), and one for uncertainty (i.e., not in a position to express any expectation). I also introduced dummy variables for membership in a cooperative and access to information on agricultural technologies from governmental agencies, other farmers, or cooperatives ([38]). For the project's potential, I used two dummy variables (changing crops and expanding current crops), since these were ranked as the most significant expectations from the irrigation project (see Table 4). Details on information provided during the interviews can be deduced from the questionnaire, which is available from the author on request.

Table 3. Prioritization of issues by the farmers. Priority 1 is more important than 2, which is more important than 3, and so on.

Priority	Access to (Percent of Responses in Each Ranked Priority)				
	Alternative Agricultural Methods	**Markets**	**Additional Water**	**Credit (Loans)**	**Information**
1	0	39	41	20	0
2	13	28	46	11	2
3	37	15	13	35	0
4	48	15	0	24	13
5	2	2	0	11	85

Table 4. Ranking of project potentials by the farmers. Potential 1 is more important than 2, which is more important than 3, and so on.

Potential	Most important potential (Percent of Responses for Each Ranked Potential)		
	Changing Crop Pattern	**Expanding Current Crops**	**Cultivating Additional Land**
1	94	4	2
2	4	76	20
3	2	20	78

Table 5 summarizes the main statistics for the independent variables used in this study. The dependent variable had a mean of 0.85 (i.e., based on a value of one in 39 out of 46 observations) and a standard deviation of 0.36, with Max and Min at 1 and 0, respectively.

Table 5. Statistics of quantitative independent variables: * indicates a dummy variable, 1 means yes. EE, expected effects on adoption (+ = increase, − = decrease), according to the econometric literature.

Quantitative independent variable	Mean	St. Dev.	Max.	Min.	EE
Gross income (×10^6 Iraqi Dinars)	6.23	7.53	40.93	0.45	+
Farm size (ha)	12.07	76.86	125	1.50	+
Farmer age	50.65	13.56	80	25	−
Family size	7.07	2.92	15	1	+
Dependency ratio (proportion of young (≤14) and old (≥65) family members)	0.33	0.20	1	0	−
Direct access to output markets *	0.07	0.25	1	0	+
Access to fair prices for outputs *	0.39	0.49	1	0	+
Access to fair prices for inputs *	0.41	0.50	1	0	+
Satisfactory access to bank loans *	0.11	0.31	1	0	+
Income from livestock activity greater than 50% of the total *	0.50	0.51	1	0	−
Literacy status *	0.57	0.50	1	0	+
Access to markets as the most urgent problem *	0.39	0.49	1	0	−
Access to additional water as the most urgent problem *	0.41	0.50	1	0	+
Need to cope with water shortages in all seasons *	0.48	0.51	1	0	+
Need to cope with water shortages in summer *	0.35	0.48	1	0	+
Habit approach to innovation [0, 4]	2.50	0.81	4	1	−
Maximization approach to innovation [0, 4]	0.98	0.68	2	0	+
Predict increased output and input prices or increased output and stable input prices *	0.37	0.49	1	0	+
Not in a position to express any expectation *	0.35	0.48	1	0	−
Cooperative membership *	0.83	0.38	1	0	+
Access to suitable information from governmental agencies *	0.85	0.36	1	0	+
Changing crop pattern as the most important project potential	0.94	0.25	1	0	+
Expanding current crops as the most important project potential	0.04	0.21	1	0	+

Binary logistic regression is a standard statistical procedure in which the probability of a dichotomous outcome (in the present case, participation or non-participation) is related to a set of explanatory variables (e.g., [49]). If the responses of farmers in the study region are assumed to be consistent with utility-maximizing behavior, then the irrigation project will be joined by farmers if the net utility obtained from participation exceeds that from non-participation.

The small number of observations suggested that it would be necessary to perform a combined estimation for the socio-economic and psycho-cultural determinants of participation by considering as many variables as possible from among those suggested by the literature. In particular, the probit model to be estimated was:

$$\text{Prob}\ (rea = 1) = \Phi(\alpha + \beta_{se}\, x_{se} + \beta_{pc}\, x_{pc})$$

where *rea* is the binary outcome variable "readiness to adopt", x_{se} and x_{pc} are the socio-economic and psycho-cultural determinants of participation (respectively), and Φ is the cumulative distribution function of the standard normal distribution; the parameters α and β are maximum-likelihood estimates. Note that Moreno and Sunding [50] estimated a nested logit model and showed that the irrigation technology was selected jointly with land allocation, whereas Useche et al. [51] applied a mixed-multinomial logit model to estimate the effects of technological traits and farm and farmer characteristics on adoption outcome. The probit model was appropriate here because the present study considered a single irrigation scheme with no alternative technological traits, and farmers provided only partial information on potential crop choices.

4.2. The Cost–Benefit Analysis

In general, once the econometric results have suggested the need to focus on a specified group of farmers as those who are most likely to adopt an irrigation technology, a cost–benefit analysis should be tailored to this group. In particular, if the suggested focus is on the relatively poor and economically weak farmers, a cost–benefit analysis must be performed by referring to this group when estimating both the costs, since the irrigation scheme must be designed for small farms, and the benefits, since new cultivation patterns must be intended for small farms.

In the survey sample, four of the 46 farmers (8.7%) farmed more than 25 ha, and a similar proportion were potentially interested in the irrigation project. On this basis, I assumed that 290 of the 315 farmers (92%) reported in official statistics ([40]) for the study area would represent the target group. After excluding the four largest farmers, the average farm size in the sample was 7.99 ha. I have rounded this value to 8 ha and used that value as the farm size for the target farmer, and I have divided the overall irrigation area into 692 representative hydraulic units of 8 ha each, which are directly affected by the irrigation project.

I will refer to the target farmer when suggesting alternative cultivation patterns and potential increases in crop yields. In particular, Tables A3–A5 in Appendix B depict suggested innovative cultivation patterns that would be permitted by adopting irrigated agriculture and yields based on a farm size of 8 ha, together with market prices for winter, summer, and perennial crops based on market prices that were current as of 2013. Note that the current cultivation pattern is based on few main crops: the most important crops, based on their percentage of the total cultivated area, are wheat at 26%, barley at 23%, and chickpeas at 8% of the total cultivated area in winter, and watermelon at 3%, sunflower at 3%, and melon at 1% of the total cultivated area in summer (with the remainder of the area mostly left fallow). This pattern produces a gross annual income per hectare of 2.358×10^6 Iraqi Dinars. Farmers were asked to state the qualitative impacts on their gross annual income (i.e., small, medium, large) of fertilizers, hired labor, pesticides, and transport costs, as well as the qualitative impacts of product subsidies. It was not possible to quantitatively assess these responses as percentages due to the high illiteracy level observed in the study population. However, it was possible to assign (post hoc) values of 1, 5, and 10% to small, medium, and large impacts, respectively. By applying these percentages as negative values for costs and as positive values for subsidies to the gross annual income for each farmer, I obtained a net annual income per hectare of 1.862×10^6 Iraqi Dinars. I will use 21% (i.e., $[1 - (1.862/2.358)] \times 100$) as a proxy for the farmer's operating costs to calculate the net additional incomes from the gross additional incomes after irrigation adoption.

Thus, the increases in net income from both agricultural and livestock activities for the target farmer as a result of a changed cultivation pattern or an increased crop yield that will become possible as a result of the irrigation project is estimated to be 5400 USD/ha (at 1 USD = 1250 Iraqi Dinar). Note that the percentages of cultivated area as a result of a changed cultivation pattern do not sum up to 1 because some of the same land is used in subsequent seasons.

Moreover, I will refer to the target farmer when calculating water network costs. In particular, Tables A6–A8 in Appendix B depict the investment and operating irrigation costs for both the government and each farmer, based on a farm size of 8 ha, together with costs for the dam and hydropower station and expenditures for social and environmental features such as flood control, water quality control, and recreational activities (e.g., swimming in the reservoir and catching fish). Note that within the area that will be occupied by the Qara Ali reservoir, there are no settlements; thus, resettlement will not be required. In addition, there are no historic shrines, temples, mosques, churches, or other culturally or religiously significant structures, so reconstruction will not be required.

Finally, I will refer to the target farmer when calculating the project's IRR. In particular, the direct benefits from irrigation can be estimated at 29.894×10^6 USD per year (the total irrigated area of 5536 ha multiplied by the income increase of 5400 USD/ha, where 5536 is based on the assumption of 8 ha per hydraulic unit for the 692 units). In addition, I assumed that the indirect benefits from the irrigation project due to improved environmental management would be 10% of the direct benefits for both the farmers directly affected by the project (692, based on the assumption of 8 ha per hydraulic unit, with one farmer per unit) and those who are indirectly affected (1055, which represents the total affected area of 13,976 ha minus the total irrigated area of 5536 ha, then divided by the hydraulic unit area of 8 ha), for a total of 7.547×10^6 USD; this equals the total number of affected farmers (692 + 1055 = 1747) multiplied by the number of 8-ha hydraulic units (one per farmer) and by 10% of the income increase of 5400 USD/ha. Note that the assumed 10% increase can be justified because the additional amount of water from the project that will be used in agriculture is around 90%. Similarly, the direct benefits from hydropower can be estimated at 0.145×10^6 USD per year; this equals the total energy production, which is estimated at 14.490 GWh/year, multiplied by the energy price of 0.01 USD/kWh. In addition, the indirect benefits from hydropower are assumed to be 0.320×10^6 USD per year due to the certified emission reduction (CER) credits received by eliminating greenhouse gas emissions. Note that this figure relies on the assumption that a heavy-oil-fired power plant is the logical alternative to hydropower in this region, and is based on the following calculations: the average CO_2 emission for oil-fired power generation (i.e., 893 t/GWh) minus the average CO_2 emissions for a large hydropower installation (i.e., 8 t/GWh) is multiplied by the expected price in 2012 (i.e., 25 USD/t) of CER credits and by the expected energy production by the hydropower station each year (14.490 GWh).

4.3. The Financial Analysis

In general, once the cost–benefit analysis has provided scenarios for the average IRR (i.e., *AveIRR*) and the worst-case IRR (i.e., *MinIRR*), financial analysis should refer to these figures as the mean and reliable socio-economic values, respectively. In particular, financial analysis must be performed to identify the financial feasibility of the project (i.e., whether the government can meet its budget constraints in terms of revenues from selling water and returns from investing public funds in irrigation or similar projects, whereas farmers must be able to meet their budget constraints in terms of paid water prices and loan rates). Financial analysis must also be performed to identify the social sustainability of the project (i.e., farmers do not pay for benefits that accrue to other people or for inefficiencies of the irrigation project), if some direct economic benefits from irrigation (e.g., selling water to farmers) or some indirect economic benefits from hydropower (i.e., selling CER credits in international markets) are not monetized or are only partially monetized.

The minimum water price (*wp*) required for the government to break even at an alternative rate of financial return (*fr*) can be obtained by solving the following equations with respect to *wp*:

$$\sum_{t=5}^{54}(1/(1+fr)^t)\,(totlan \times watuse \times wp + dirpowben_t + indpowben_t) -$$
$$\sum_{t=1}^{4}(1/(1+fr)^t)\,(damcos_t + powcos_t + irrcos_t + othcos_t) -$$
$$\sum_{t=5}^{54}(O\&Mdam_t + O\&Mpow_t + O\&Mirr_t)\,(1/(1+fr)^t) - (1/(1+fr)^{34})\,(damcosrep_{34} + powcosrep_{34}$$
$$+ irrcosrep_{34})$$

where *totlan* is the total irrigated land, *watuse* is the water use, $dirpowben_t$ is the direct benefits from selling energy production at time *t*, $indpowben_t$ is the indirect benefits from selling CER credits, $damcos_t$ is the total dam cost, $powcos_t$ is the total power station cost, $irrcos_t$ is the total irrigation cost, $O\&Mdam_t$ is the operating and management costs related to the dam, $O\&Mirr_t$ is the operating and management costs related to the irrigation structures, $O\&Mpow_t$ is the operating and management costs related to the hydropower station, $damcosrep_{34}$ is the replacement costs linked to the dam in year 34, $powcosrep_{34}$ is the replacement costs linked to the hydropower station, and $irrcosrep_{34}$ is the replacement costs linked to the irrigation network.

Note that alternative budgetary scenarios (e.g., a 30-year foreign loan at an interest rate of 1%, a 10-year grace period, a 0.5% commitment fee so that the local government pays 0.5% of the cost to prove their commitment to the project, and a 1% interest rate during construction) could be applied.

Solving the government budget constraint with respect to *wp* provides all couples (i.e., all possible solutions) of financial returns (*fr*) and water prices (*wp*) that characterize the project at the government level: an increasing and convex function *wp*(*fr*), where $wp \geq wp(fr)$ meets the government budget constraint. In particular, if CER credits are sold in international markets, $wp \geq wp(fr, \text{CER})$, whereas if CER credits are not sold in international markets, $wp \geq wp(fr)$, with $wp(fr) > wp(fr, \text{CER})$ for each *fr*. In other words, $wp\ (fr) - wp\ (fr, \text{CER})$ depicts the extra water price to be charged to farmers to meet government budget constraints that result from unsold CER credits for each *fr*. Note that *wp* at *AveIRR* and *wp* at *MinIRR* measure the total economic value of water on average (*AveEVW*) and in the worst-case scenario (*MinEVW*), respectively. Indeed, *wp* at *AveIRR* and *wp* at *MinIRR* measure the economic value of the irrigation project as represented by IRR in terms of water price in the average and worst-case scenarios, respectively. In other words, the economic value of the irrigation project is expressed in terms of *wp*, rather than in terms of IRR, by referring to the government break-even point. See Carson et al. [52] and Ready et al. [53] for contingent valuation and hedonic pricing methodologies (respectively) applied to water evaluation. Note that these are not shadow prices, since they are not based on optimization.

In contrast, the maximum *wp* and the maximum loan rate (*lr*) that can be afforded by the representative farmer can be obtained by solving the following equation (i.e., their budget constraint) with respect to *wp*:

$$\sum_{t=1}^{15} farben_t - O\&Mfar_t - watuse_t \times wp \times farlan - farcos_t\,(1+lr)^t$$

where $farben_t$ is the farmer benefits at time *t*, $O\&Mfar_t$ is the operating and management costs related to farmers, $watuse_t$ is the water use, *farlan* is the irrigated land per farmer, $farcos_t$ is the farmer costs, and we assume 7176 m^3 is the water consumed per ha (based on local data provided by the Ministry of Agriculture) and 8 ha is the average size of a farm for the target farmer (as described previously). Note that alternative budgetary scenarios (e.g., a 6-year loan-repayment period) can be applied.

Solving the farmer's budget constraint equation with respect to *wp* provides all couples (i.e., all possible solutions) of loan rates (*lr*) and water prices (*wp*) that characterize the project at a farm level: a decreasing and concave function *wp*(*lr*), where $wp \leq wp(lr)$ meets the farmer's budget constraint. Note that $wp = wp(lr)$ means that farmers are assumed to be willing to renounce up to 100% of their increase in net income due to the irrigation project during the loan period, whereas $wp < wp(lr)$ is consistent with the observation that the estimated annual value of water per hectare obtained by applying the contingent-valuation method (i.e., based on stated preferences; [54]) turned out to be about half of the estimate obtained using the hedonic price method (i.e., based on revealed preferences; [55]) in a nearby area.

Let us define fr^*, lr^*, and wp^* as the financial return, loan rate, and water price at the intersection between $wp(fr)$ and $wp(lr)$. An irrigation scheme is financially feasible if the following conditions hold simultaneously:

$$wp \geq wp(fr)$$

$$wp \geq wp(lr)$$

Indeed, the water price charged to farmers must allow the government to break even (i.e., meet its budget constraint), although at a financial rate that could be smaller than the IRR, and the water price paid by farmers must allow each farmer to break even, although water and loan charges cannot be larger than the whole irrigation benefits during the loan period.

An irrigation scheme is socially sustainable if the following conditions hold simultaneously:

$$wp(lr) \leq MinEVW$$

$$lr \leq MinIRR$$

where *MinIRR* and *MinEVW* represent the reliable IRR and the reliable EVW, respectively. Indeed, the water price charged to farmers must be smaller than the water price consistent with *MinEVW* (otherwise, farmers would pay for benefits that accrue to other people), and the loan rate must be lower than the minimum IRR (otherwise, farmers would pay for inefficiencies of the project). In other words, one should look for solutions at $lr \leq lr^*$.

Within a graphical framework, the conditions for financial feasibility are measured by the area included between $wp(lr)$ and $wp(fr)$ for $lr \leq lr^*$; mathematically, this is represented by $\int_0^{lr^*}[wp(fr) - wp(lr)]\,dfr$. Moreover, conditions for social sustainability are measured by the area included between $wp(lr)$ and *MinIRR* for $lr > lr^*$ *and* between $wp(fr)$ and *MinEVW* for $wp < wp^*$; mathematically, this is represented by $\int_0^{lr^*}[MinEVW - wp(lr)]\,dlr$ *and* $\int_{wp0}^{wp^*}[MinIRR - wp(fr)]\,dwp$, where $wp0 = wp(fr)$ at $fr = 0$. Finally, the rectangular area identified by a water price wp in [0, *MinEVW*] and a loan rate lr in [0, *MinIRR*] identify all reliable solutions. Thus, it is possible to measure financial feasibility and social sustainability as percentages of all reliable economic solutions.

4.4. Innovative Features of the Suggested Framework

Table 6 summarizes the innovative features of the suggested framework in the form of a flow chart. Note that the suggested framework can highlight some decisional dilemmas: for example, supporting small farmers could increase adoption in terms of farmers (and in terms of land, if there are many small farmers) and social sustainability, but it might imply financial unfeasibility; by contrast, supporting large farmers could increase financial feasibility, but it might imply social unsustainability and a low adoption rate in terms of the number of farmers (although it could ensure a high adoption rate in terms of land area). Next, in contrast with structural and long-run determinants (i.e., which cannot be changed or affected, or can be changed only slightly; these include gender, age, tenancy status, and livestock activity), governmental agencies could use operational and short-run determinants (i.e., which can be changed or affected relatively easily; these include literacy status, membership in a cooperative, access to private credit, good markets, governmental information, and fair input and output prices) to increase adoption or mold adoption (e.g., to balance adoption rates between large and small farmers).

Table 6. Conceptual flow chart of the innovative framework in the present study. Innovative theoretical features are boldfaced. EA, econometric analysis; CBA, cost–benefit analysis; FA, financial analysis; IB, indirect benefits; EVW, economic value of water.

Analysis	Goals of the Analysis		Determinants or Specifications		Strategic Decisions	Outcomes of the Analysis
EA	Identify farmers who are more likely to adopt (%) …	→	… dependent on structural and long-run characteristics such as: • Male/female • Rich/poor • Owner/tenant • With/without livestock • Small/large farm • Young/old	→	State aims, such as to reduce inequality, increase indirect incomes in the area, or maximize the adoption rate in terms of land area or number of farmers	Target farmers
						↓
┌	Identify the costs of the irrigation structures	←	Economists/engineers	←	←	Design the irrigation scheme
	Identify the benefits from the yield increases	←	Economists/agronomists	←	←	
↓						
CBA	Economic values of the project …	→	… including direct/indirect and monetized/non-monetized benefits from, and costs of, irrigation and hydropower	→	→	*AveIRR* *MinIRR*
						↓
┌	Reference values in terms of water prices	←	***wp(AveIRR) = AveEVW*** ***wp(MinIRR) = MinEVW***	←	←	Introduce these values into the government budget
↓						
FA	Financial feasibility …	→	… from government budget $wp \geq wp(fr)$, $wp \geq wp(fr, IB)$ … and from farmer budget $wp \leq wp(lr)$	→	→	**Feasibility (%)**
	Social sustainability …	→	… from farmer budget $wp(lr) \leq MinEVW$ $lr \leq MinIRR$	→	→	**Sustainability (%)**
						↓
■	End of the analysis	←				
↑	If necessary, change target farmers and compare new adoption, feasibility, and sustainability rates (%)	←	Value ranges for *wp* and *lr*	←	Identify acceptable *wp* and *lr* values among the feasible and sustainable values, if any	**Summary for stakeholders to support discussion of all crucial economic and financial values**

In summary, there are four key innovations of the suggested framework: First, it expresses economic values in terms of water prices to be used as constraints for determining the feasibility and sustainability of the project. Second, it measures the financial feasibility and social sustainability as percentages of all reliable economic solutions. Third, it clearly identifies the phases that require involvement by stakeholders (see the column in Table 6 on strategic decisions), where all crucial information to be discussed is summarized simply and intuitively. Fourth, econometric analysis, cost–benefit analysis, and financial analysis are linked together in a decision-making flow (see the arrows in Table 6), with each analysis relying on results from the previous analysis, with the potential to start over if the results are unfeasible, unsustainable, or both. In particular, if an irrigation project turns out to have a high predicted adoption rate but is financially unfeasible or socially unsustainable, one could change the definition of the target farmers, which would, in turn, change the design of the irrigation scheme, its costs and benefits, and other factors. Provided that these new target farmers are still consistent with the stated strategic objectives, the revised project can proceed; if not, the project should not be implemented, and funds should instead be invested in alternative irrigation projects or different projects.

5. Results

5.1. The Econometric Analysis

The small number of observations suggested that it was necessary to avoid variables that could split the sample (land tenancy and farm size), to eliminate from the analysis variables with a low range of variation (age and family size), and to eliminate from the analysis one of each pair of strongly correlated variables (the one with the smallest range of variation), such as based on the relationship of the dependency ratio with gross income, of cooperative membership with government information, and of farm size with gross income. In particular, I did not consider age, since it turned out to be insignificant: 59% of respondents were aged between 40 and 60. Moreover, the small sample size suggested that it was necessary to include all dummy variables as independent variables in order to increase the variability ([26]). Finally, to obtain a more robust estimate of the variance value, I applied the Huber–White sandwich estimator with the type of tenancy as the clustering variable (since tenancy characterizes farmers more significantly than their village of residence due to the agronomic homogeneity of the area) to allow observations that were not independent within clusters (although they must be independent between clusters).

The following variables turned out to be non-significant and were therefore excluded from the estimation: "water shortages in summer" is likely to be embodied in "water shortages in all seasons", since 9% of farmers said they had enough water in the winter, versus 0% in the summer. "The most urgent problem" (39% access to markets, 41% access to additional water, and 20% access to credit) might be irrelevant because it was implicitly represented by other included variables (see Table 4). "The ability to predict trends for output and input prices" might be considered as a precondition for stating positive expectations. "The most important project's potential" is likely to be irrelevant because 94% of farmers expressed a preference to change cultivation patterns rather than to expand the area of current crops (4%) or cultivate additional land (2%) (see Table 5).

The main insights can be summarized as follows (see Table 7). The irrigation project is more likely to be adopted (joined) by: poorer farmers (unlike in [12,16,17,19]), who rely more on agriculture than those who rely on livestock activities (like in [15,25]); farmers who have been informed or trained by governmental agencies (like in [14,18,24]), and who feel that they can obtain fair prices for outputs (like in [13]); literate farmers (like in [12,17]); farmers with positive expectations about the future; farmers who base their decisions on a maximization approach rather than on a habit approach. On the other hand, the irrigation project is less likely to be joined by farmers who feel that they obtain fair prices for inputs (like in [13,14]), who have direct access to product markets, and who have satisfactory access to the private credit (loans) market (similar to [12]). Thus, the irrigation project is appreciated most by poorer and economically weaker farmers. This is consistent with a given potential economic benefit per hectare being perceived to be smaller by larger farmers. In contrast, in an ex post econometric study of the potential factors that determine the adoption of irrigation, Namara et al. [56] showed that the largest proportion of micro-irrigation adopters belonged to the relatively wealthy group of farmers.

In particular, the probability of participation will be 0.9948 for an idealized "target" farmer who may not actually exist (Table 7). Moreover, the probability of acceptance is 0.9931 for a poorer and weaker farmer, who is typically characterized by an illiterate status, a habit approach to innovation, negative expectations about future prices, half the average income in the sample population, no access to fair input and output prices, no access to governmental information, no direct access to product markets, and no access to private credit. Finally, a richer and stronger farmer, characterized by the opposite of these characteristics, will show a probability of participation of 0.4658. Analogously, Harris [57] suggests that inter-sectional analysis (e.g., men vs. women, landless vs. landed) should be carried out in any study of water-related development transformations. In other words, decision-makers in Shahrazoor, Kurdistan, seem to be facing a decisional dilemma: they can propose a financially difficult irrigation scheme that serves the needs of poor farmers, with 99% of the farmers joining it, or a financially easy irrigation project that disregards equity issues, but with only 47% of farmers participating in it.

Table 7. Impacts on adoption probability. * indicates dummy variables.

Independent Variable	Ready to Adopt				
	dΦ/dx	Std. Error	*z*-Statistic	*p*	Mean
Literacy status *	0.00243	0.001	4.28	0.000	0.565
Habit approach to innovation	−0.00297	0.002	−9.31	0.000	2.5
Maximization approach to innovation	0.00585	0.009	1.48	0.138	0.978
Predict increased output and input prices or increased output and stable input prices *	0.00689	0.005	19.46	0.000	0.369
Need to cope with water shortages in all seasons *	0.09075	0.116	3.35	0.001	0.478
Gross income	−0.00167	0.001	−3.28	0.001	6.234
Income from livestock activity greater than 50% *	−0.05688	0.061	−5.12	0.000	0.5
Access to fair prices for outputs *	0.02881	0.013	5.21	0.000	0.391
Access to fair prices for inputs *	−0.40222	0.117	−56.84	0.000	0.413
Access to suitable information from governmental agencies *	0.94105	0.002	13.08	0.000	0.847
Satisfactory access to bank loans *	−0.89236	0.190	−5.44	0.000	0.108
Direct access to output markets *	−0.21421	0.221	−4.26	0.000	0.065

Note: * dΦ/dx represents the discrete change in the dummy variable from 0 to 1. Standard errors were adjusted for clustering as a function of the type of tenancy. Predicted probability at average values of the dependent variables = 0.9948.

In the cost–benefit analysis in Section 5.2, I will focus on the poor farmers and disregard the rich farmers in order to maximize the probability of participation. Choosing this farmer group more than doubles the probability of participation.

Note that all effects have the expected signs according to the econometric literature, including the psychological independent variables (i.e., habit approach, maximization approach, perceived needs) and the policy independent variables (i.e., access to suitable information, literacy status, access to fair prices for outputs, expectations), but excluding gross income, access to fair prices for inputs, satisfactory access to bank loans, and direct access to output markets. This is likely to account for the oligopolistic power of richer farmers who would not be ready to adopt the project, in order to make it fail and maintain their economic and social status. In particular, the potential impacts on the participation probability relate to access to suitable information from governmental agencies, to access to good prices for outputs, to the farmer's positive expectations about future trends for output and input prices, and to the farmer's literacy status (Table 7). Thus, the existing governmental agencies can play a crucial role in project participation in the short-run by providing information and training, and by promoting access to fair output prices. Similarly, He et al. [49] showed that the credit obtained, the technical training received, and the assistance obtained all had significant positive effects on the adoption of rainwater harvesting and supplementary irrigation technologies.

The government can therefore play a crucial role in diffusion of the project in the long run by improving expectations and by reducing illiteracy, which in turn could promote the use of a maximizing approach to innovation instead of a habit approach. In contrast, He et al. [49] showed that the risk preference had no significant influence on the adoption of rainwater harvesting and supplementary irrigation technologies.

5.2. The Cost–Benefit Analysis

Section 5.1 suggested a need to focus on the relatively poor and economically weak farmers. This section describes a cost–benefit analysis that focuses on this farmer group for estimating both the costs, since the irrigation scheme will be designed for small farms, and the benefits, since new cultivation patterns will be intended for small farms.

Thus, applying a standard cost–benefit analysis to the data presented in this section produces an internal rate of return (IRR) of 7.1% with benefits from hydropower, and 7.0% without benefits from hydropower. Wood et al. [58] performed a similar analysis in Australia.

Since the direct benefits from irrigation depend strongly on crop prices, and since the indirect benefits from irrigation were assumed to equal 10% of the direct benefits (Section 4.2), I performed a sensitivity analysis to account for a possible change of 20% for each combination of indirect benefits and crop prices. Table 8 summarizes the impacts of these changes on the estimated IRR. Note that I applied these large changes to account for possible impacts on prices at a local level; indeed, unless the government controls crop markets or fixes price caps, the increase in agricultural production due to the irrigation project is likely to significantly and unpredictably affect crop prices at a local level.

Table 8. Sensitivity analyses for the effects of changing crop prices and changing indirect benefits.

Crop Prices	Internal Rate of Return (%)		
	−20% Indirect Benefits	Reference Value for Indirect Benefits	+20% Indirect Benefits
−20% crop prices	4.6	4.9	5.2
Reference value for crop prices	6.7	7.1	7.4
+20% crop prices	8.6	8.9	9.4

Thus, IRR is more sensitive to crop prices than to indirect benefits. In particular, changes in crop prices produce more than proportional changes in IRR, whereas the opposite occurs for changes in indirect benefits. In other words, a given percentage change in crop prices produces a larger percentage change in the IRR, whereas the same percentage change in indirect benefits produces a smaller percentage change in the IRR. Note that the potential initial or subsequent costs for training farmers are not estimated independently, but are instead included in the indirect benefits from irrigation (i.e., they represent local incomes). However, these costs are unlikely to affect IRR due to the tiny magnitude of these benefits in comparison with the overall investment and operating and management costs for the irrigation project.

5.3. The Financial Analysis

In Section 5.2, I estimated an IRR of 7.1% for the project on average, versus 4.6% in the worst-case scenario. This section will refer to these values as the mean and reliable socio-economic values, respectively.

Figure 2 depicts the main social, economic, and financial features of the Shahrazoor irrigation project at the government and farmer levels. The relationships between *wp* and *fr* from the government break-even budget with and without selling CER credits in the international market (i.e., by monetizing and not monetizing an indirect benefit of hydropower) are depicted by the lower increasing curve *wp*(*fr*, CER) and the higher increasing curve *wp*(*fr*), respectively. The relationships between *wp* and *lr* from the farmer's break-even budget are represented by the decreasing curve *wp*(*lr*). The water prices consistent with a government break-even budget at the average IRR (i.e., 7.1%) and at the minimum IRR (i.e., 4.6%) are depicted by *AveEVW* = 0.92 USD/m^3 and *MinEVW* = 0.66 USD/m^3, respectively.

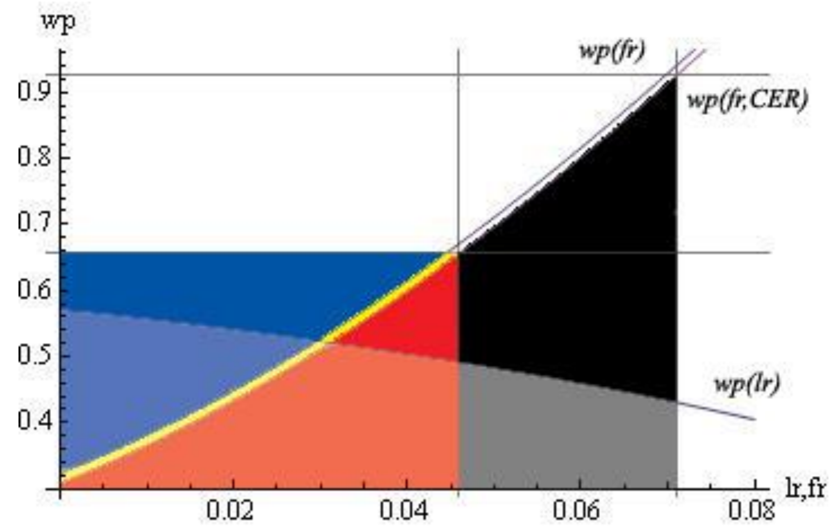

Figure 2. Characterization of a socially sustainable and financially feasible irrigation project. Financial feasibility exists for 13.6% of the reliable economic solutions, versus 35.8% for social sustainability. Black, unreliable solutions, infeasible for farmers and the government; grey, unreliable solutions, feasible for farmers but not for the government; red, infeasible for farmers and for the government; yellow, infeasible for farmers but feasible for the government if it sells CER credits; blue, infeasible for farmers but feasible for the government without selling CER credits; light red, feasible for farmers but not for the government; light yellow, feasible for farmers and feasible for the government if it sells CER credits; light blue, feasible for farmers and for the government without selling CER credits.

Figure 3 characterizes a hypothetical irrigation project with a lower *EVW* for a given *wp*(*lr*). For example, this may be due to a larger variability observed in the sensitivity analyses performed for other case studies: financial feasibility is then smaller, whereas the project is socially unsustainable, since *wp* is never smaller than *MinEVW*. Figure 4 characterizes a hypothetical irrigation project with a higher *wp*(*fr*, CER) due to a greater inability of the government to monetize the indirect economic benefits that are relevant in other case studies: the project is financially unfeasible because there are no *wp* values that meet both farmer and government budget constraints. Note that IRR − *fr* depicts the differences between economic and financial evaluations linked to indirect benefits from irrigation, whereas *wp*(*fr*) − *wp*(*fr*, CER) depicts the differences between economic and financial evaluations linked to indirect benefits from hydropower.

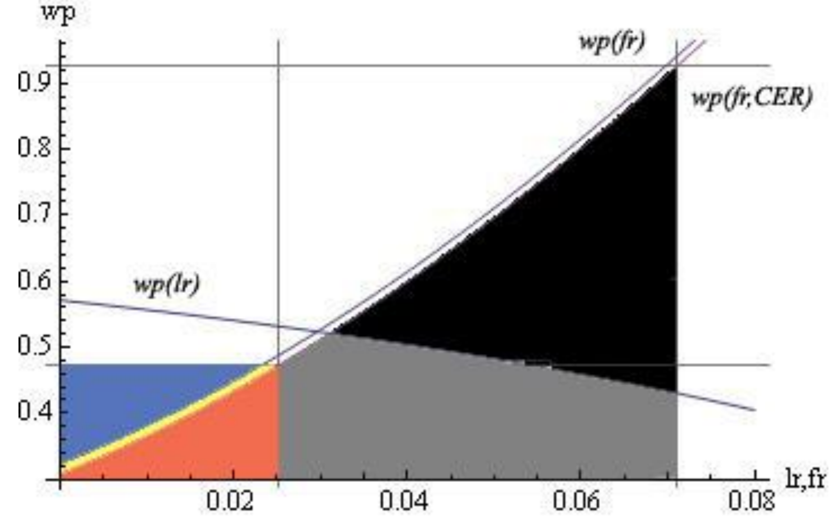

Figure 3. Characterization of a financially feasible but socially unsustainable irrigation project. Financial feasibility exists for 13.3% of the reliable economic solutions but no solution is socially sustainable. Black, unreliable solutions, infeasible for farmers and the government; grey, unreliable

solutions, feasible for farmers but not for the government; light red, feasible for farmers but not for the government; light yellow, feasible for farmers and feasible for the government if it sells CER credits; light blue, feasible for farmers and for the government without selling CER credits.

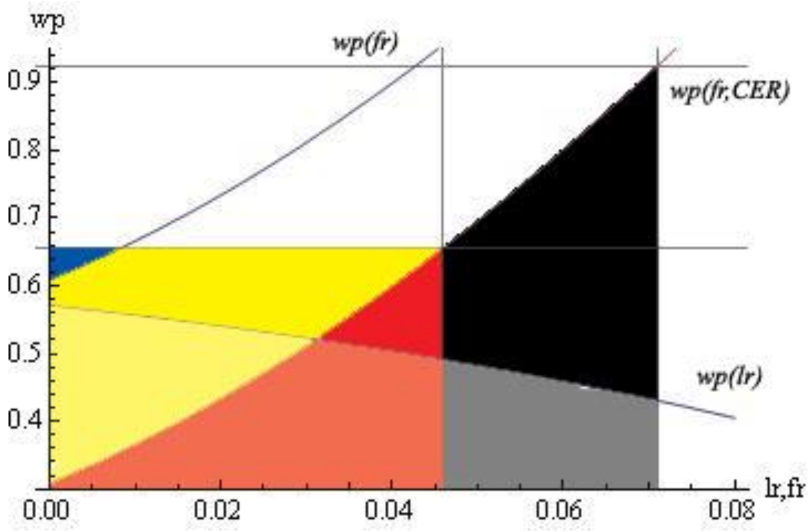

Figure 4. Characterization of a financially infeasible irrigation project. Financial feasibility and social sustainability account for 0% of the reliable economic solutions. Black, unreliable solutions, infeasible for farmers and for the government; grey, unreliable solutions, feasible for farmers but not for the government; red, infeasible for farmers and the government; yellow, infeasible for farmers but feasible for the government if it sells CER credits; blue, infeasible for farmers but feasible for the government without selling CER credits; light red, feasible for farmers but not for the government; yellow, infeasible for farmers but feasible for the government if it sells CER credits; light yellow, feasible for farmers and feasible for the government if it sells CER credits.

Figure 2 shows that the irrigation project in Shahrazoor is feasible and sustainable if *wp* is between 0.32 and 0.57 USD/m^3, the loan rate is smaller than 3.0%, and it is not necessary to sell CER credits in international markets. On this basis, all financially feasible scenarios are socially sustainable, with 13.6% of all reliable economic solutions financially feasible and 35.8% socially sustainable. Indeed, the area including all couples of IRR ≤ *MinIRR* and *wp* ≤ *wp(MinIRR, CER)* represents the economic value of the irrigation project, whether in IRR terms or in *wp* terms or both, whereas the area including all couples of IRR and *wp* within the curves *wp(fr)* and *wp(lr)* represents the financial feasibility of the irrigation project; as a result, the ratio between these areas depicts the extent to which the project is financially feasible. Similar reasoning applies to the ratio of the area representing social sustainability (i.e., *wp*(*lr*) ≤ *MinEVW*, *lr* ≤ *MinIRR*) to the area representing the economic value of the irrigation project (i.e., IRR ≤ *MinIRR* and *wp* ≤ *wp(MinIRR, CER)*). Note that the government could accept a financial return smaller than the *MinIRR* if social benefits (e.g., a smaller degree of income inequality, reduced conflict among farmers) are expected but not included in the present estimates.

5.4. Application of the Suggested Framework to the Kurdistan Case Study

Table 9 summarizes the results of the Iraqi case study within the framework of the flow chart introduced in Table 6. Note that targeting poor and small farmers produced a decisional dilemma: project managers can achieve 99% expected adoption by small farmers combined with an acceptable financial feasibility (at a calculated 13.6%) or 47% expected adoption by large farmers combined with a good financial feasibility (at an assumed 100%). As is the case in many developing countries, Kurdistan has many farmers with small farms; targeting these poor and small farmers will reduce income inequality and increase total income in the area.

Table 9. The conceptual flow chart of the innovative methodological procedure. EA, econometric analysis; CBA, cost–benefit analysis; FA, financial analysis; ID, Iraqi Dinars; CER, certified emission reduction.

Analysis	Goals of the Analysis		Determinants or Specifications		Political Decisions	Outcomes of the Analysis
EA	Identify farmers who are more likely to adopt (99%)	→	as dependent on structural and long-run characteristics: Rich/poor Small/large Literate/illiterate	→	Reduce inequality and maximize adoption rate by farmers	Target farmers: illiterate, small (<7.7 ha), poor (<1861 ID)
						↓
┌	Identify the costs of the irrigation structures	←	Economists/engineers	←	←	Design the irrigation scheme for an average farm size of 8 ha
	Identify the benefits from the yield increases	←	Economists/agronomists	←	←	
↓						
CBA	Economic value of the project	→	including indirect non-monetized benefits from irrigation (flood, recreation) and from hydropower (CER)	→	→	*AveIRR* = 7.1% *MinIRR* = 4.6%
						↓
┌	Reference values in terms of water prices	←	*AveEVW* = 0.92 USD/m^3 *MinEVW* = 0.66 USD/m^3	←	←	Introduce these values into the government budget
↓						
FA	Financial feasibility…	→	from the government budget $wp \geq wp(fr)$, $wp \geq wp(fr, CER)$ and from the farmer budget $wp \leq wp(lr)$	→	→	Feasibility 13.6%
	Social sustainability…	→	from the farmer budget $wp(lr) \leq 0.66$ $lr \leq 4.6$	→	→	Sustainability 35.8%
						↓
■	End of the analysis	←	*wp* must be in [0.32, 0.57 USD/m^3] *lr* must be in [0, 3%]	←	Identify acceptable values for *wp* and *lr*	Figure 2

6. Discussion

To reduce the frequency of decisions to reject an innovation as a result of dissatisfaction with its performance, an ex ante study by Karami [59] suggested using the analytical hierarchy process (AHP) with a panel of experts to help four homogenous target groups of farmers (i.e., small farm and young farmer, small farm and old farmer, medium farm, and large farm) make a rational decision when adopting three new irrigation methods (i.e., border, basin, sprinkler). This was based on applying cluster analysis using 11 variables (i.e., future plans, contact with information sources, attitude towards water-saving technologies, knowledge of irrigation methods, level of farm technology, education, farm size, land slope, land fragmentation, loan obtained, soil texture). Karami's comparison of actual decisions by farmers regarding the adoption of irrigation methods in four Iranian provinces, using the AHP results to appraise the appropriateness of their decisions regarding the choice of irrigation method, revealed that 74% of the farmers made an appropriate decision (16% by adopting and 58% by not adopting sprinkler irrigation), but the remaining 26% made an inappropriate decision (14% by adopting and 12% by not adopting sprinkler irrigation). In particular, the appropriateness of the decision was explained better by farm size than by irrigation method; 100% appropriate adoption was only estimated for large farms.

Karami's [59] analysis has some features in common with the present study. His decision appropriateness is similar to the present financial feasibility results at the farmer level, and his expert assessments about decision appropriateness are similar to the present financial analysis at the farmer level, but the approaches and insights are different. In particular, Karami [59] looked for target groups of farmers for a given irrigation method by suggesting sprinkler irrigation for large farms. In contrast, I designed the irrigation scheme (i.e., for a target farm size of 8 ha) and I identified the economic incentives (i.e., water prices and loan rates) to increase adoption of the project among poor and weaker farmers (i.e., adoption success was measured in terms of the number of farmers rather than the total area). I also considered the social feasibility (i.e., costs not charged to farmers) and the social sustainability (i.e., benefits that accrue to non-farmers) of the irrigation project. In short, by departing from a long history of irrigation projects in which wealthy farmers become richer and poor farmers receive fewer financial benefits, the present study shows that the irrigation scheme could be tailored to the needs of poor farmers, thereby increasing participation and decreasing income inequality ([60]). In addition, wealthy farmers are likely to join the irrigation project once it has been built ([61]).

In the present paper, significant results were obtained despite relying on a relatively small sample of farmers. The approach combines the main contributions of economists and sociologists by using variables that measure limitations on the available information and thought processes as well as variables that describe the institutional contexts, and by using variables that measure farmer perceptions of irrigation schemes and communication frameworks. In Shahrazoor, if the irrigation project is tailored to the needs of poorer and economically weaker farmers, it turns out to be socially sustainable and financially feasible.

Although I considered a range of potential economic and social determinants of adoption of the project in the present study, I disregarded some important aspects that might be relevant in alternative contexts, as Weick and Walchli [62] have discussed. Torkamani and Shajari [63] showed that farmer-specific relative risk premiums have a positive and significant effect on the decision to adopt new irrigation technologies. Governmental agencies should stress the biological benefits of moving away from outdated and inefficient agricultural management practices (see also [64]). Ersado et al. [65] also showed that the number of days of illness and the opportunity costs that arise from caring for sick family members are significant factors in the adoption of land-enhancing technologies such as irrigation. Governmental agencies should therefore not disregard indicators of well-being when they estimate the potential for successful adoption of a project.

In addition, I did not consider the complexity of the innovation, together with issues of knowledge transfer, with respect to the ability of farmers to understand and use the technology, nor did I consider opportunities for farmers to observe the technology and discuss it with other farmers ([42]). Governmental agencies should therefore organize training courses to explain all the technical details so that farmers can best exploit the innovation (e.g., [66]), by taking into account the costs of administering this training and monitoring its effectiveness. I also disregarded the environmental sustainability of the new cultivation patterns, which is clearly an important criterion ([26,27,47]). Governmental agencies should therefore evaluate the potential impacts of the alternative cultivation patterns by means of agronomic and ecological studies. Lastly, I did not consider problems associated with the viability and longevity of irrigation projects. Governmental agencies should therefore develop or promote the development of management institutions, including guidelines and rules, to solve the collective-action dilemma; should organize training courses to improve irrigation management, thereby ensuring that the project remains viable; and should budget for repairs and replacement right from the start, thereby ensuring that the project has longevity ([67–69]).

7. Conclusions

In the present study, I tackled common assessment issues in agricultural policy programs, in general, and technological interventions in agriculture, in particular. The analyzed project was characterized by both economic and financial characteristics and by both direct and indirect aspects. For the irrigation scheme, direct effects on agricultural production (which are relatively difficult to monetize) and indirect effects on flood control and water quality (which are difficult to monetize) must be estimated. For the hydropower station, direct effects on energy selling (easy to monetize) and indirect effects on eliminated emissions CO_2 (relatively easy to monetize) must be evaluated.

Combining the econometric, cost–benefit, and financial analyses in the framework described in this paper supports the view that the participation in and success of irrigation projects could be significantly enhanced by accounting for the characteristics of those who will be affected by the project and those who can potentially benefit from irrigation schemes. In Shahrazoor, the current socio-economic factors (i.e., gross income, access to fair input prices, satisfactory access to bank loans, and direct access to output markets) and expected socio-economic factors (i.e., access to fair output prices) reduce the probability of acceptance to a greater extent than current psycho-cultural factors (i.e., literacy status) and expected psycho-cultural factors (i.e., a habit approach rather than a maximization approach to innovation, positive expectations about prices), with the former factors possibly correlated with the latter factors.

In particular, as in other ex ante econometric studies of the potential factors that determine participation in the project, providing farmers with suitable information in the short run and a suitable education in the long run will also increase diffusion of the project (in the present study, by around 94% and 0.2%, respectively). Unlike other ex ante econometric studies, the present study highlighted the fact that the probability of acceptance can be maximized by identifying the target farmers (here, poorer and economically weaker farmers devoted more to agricultural than to livestock activities) and by specifying the maximum water prices and loan interest rates (i.e., prices and rates in the case in which the whole additional income from irrigation is used to pay for water or to repay loans) by means of cost–benefit and financial analysis for these farmers (less than 0.57 USD/m^3 and 3.0%, respectively) to the largest possible extent (by around 99% in the present study). To a smaller extent, psycho-cultural aspects (e.g., whether farmers adopt a habit approach or a maximization approach to innovation) could hamper the project diffusion (by around 0.3% in the present study).

Combining social, economic, and financial features in a single framework, as described in this paper, supports the view that both financial feasibility and social sustainability of irrigation projects could be significantly enhanced by focusing on economic benefits that are difficult to monetize and on financial costs that must be charged to the general population. In Shahrazoor, 13.6% of the reliable economic solutions were financially feasible and 35.8% were socially sustainable. In particular, the equilibrium water price (i.e., 0.53 USD/m^3) charged to farmers was around 57% (i.e., 0.53/0.92) of the economic value of water (the equilibrium water price divided by the average economic value of water), whereas the financial return missed by the general population (the interest rate divided by the internal rate of return) was around 42% (i.e., 3.0/7.1).

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Appendix A

Table A1. Additional quantitative variables used to describe the survey population (1 USD = 1250 Iraqi Dinar).

Quantitative Variable	Mean	Total	Standard Deviation
Area of rain-fed irrigation (ha)	11.12	511.25	70.62
Irrigated area (ha)	0.79	36.50	4.87
Children and elderly family members (number)	2.39	110	1.45
Percent increase in output prices perceived to be fair	33.33	—	5.77
Percent decrease in input prices perceived to be fair	37.50	—	7.83
Wheat area (ha)	2.34	98.13	5.53
Wheat yield (kg/ha)	75.30	—	7.72
Wheat price (Iraqi Dinar/kg)	382.74	—	15.11
Barley area (ha)	2.13	82.88	5.55
Barley yield (kg/ha)	61.22	—	14.26
Barley price (Iraqi Dinar/kg)	257.05	—	16.17
Chick pea area (ha)	1.61	19.25	3.82
Chick pea yield (kg/ha)	63.54	—	56.09
Chick pea price (Iraqi Dinar/kg)	258.33	—	153.75
Sunflower area (ha)	1.05	10.50	4.39
Sunflower yield (kg/ha)	72.50	—	2020.11
Sunflower price (Iraqi Dinar/kg)	225.00	—	91.42
Watermelon area (ha)	0.96	11.50	1.63
Watermelon yield (kg/ha)	704.17	—	1822.04
Watermelon price (Iraqi Dinar/kg)	119.58	—	110.77
Melon area (ha)	1.56	6.25	0.54
Melon yield (kg/ha)	956.25	—	111.80
Melon price (Iraqi Dinar/kg)	70.00	—	44.72
Cucumber area (ha)	0.33	3.00	0.50
Cucumber yield (kg/ha)	175.00	—	150.00
Cucumber price (Iraqi Dinar/kg)	255.56	—	16.67
Artichoke area (ha)	1.00	1.00	0
Artichoke yield (kg/ha)	75.00	—	0
Artichoke price (Iraqi Dinar/kg)	250	—	0
Bean area (ha)	0.75	0.75	0
Bean yield (kg/ha)	37.50	—	0
Bean price (Iraqi Dinar/kg)	300	—	0
Tomato area (ha)	0.30	1.50	0.45
Tomato yield (kg/ha)	150.00	—	223.61
Tomato price (Iraqi Dinar/kg)	110	—	22.36
Okra area (ha)	0.25	0.50	0
Okra yield (kg/ha)	125.00	—	0
Okra price (Iraqi Dinar/kg)	400	—	0
Number of sheep	33.60	1445	66.23
Percent of sheep herd sold per year	23	—	0.07
Number of cows	1.53	66	3.34
Cow milk and yoghurt production (kg per cow per day)	2.88	—	0.30
Number of goats	2.69	116	24.30
Percent of goat herd sold per year	40	—	0.20

Table A2. Additional qualitative variables from the survey.

Qualitative Variable	Proportion of Respondents (%)				
Education level	Illiterate	Primary	Secondary		
	43	46	11		
Access to information	None	Governmental agencies	Cooperatives	Other farmers	
	9	85	2	4	
Access to loans	None	Banks	Cooperatives	Other farmers	Other sources
	11	11	54	11	13
Types of fertilizer	Organic	Mineral	Both		
	0	63	37		
Reasons for choosing these fertilizers	I have always done this	They are very effective	I know how to use them	Other farmers suggested them to me	Governmental agencies suggested them to me
	30	70	0	0	0
Reasons for choosing these crops	I have always done this	They show a high profitability	I know how to grow them	Other farmers suggested them to me	There is no choice
	61	6	2	0	31
Proportion (%) of respondents who felt that their fertilizer costs were:	Very high	High	Fair		
	83	15	2		
Proportion (%) of respondents who felt that their labor costs were:	Very high	High	Fair		
	57	39	4		
Proportion (%) of respondents who felt that their pesticide costs were:	Very high	High	Fair		
	24	70	6		
Use of agricultural equipment	Yes	No			
	89	11			
Product buyers	Cooperative	Market	Local traders	Other	
	7	52	41	0	
Reason for choosing these buyers	I have always done this	It offers a better price	I know the market channel	Other farmers suggested the buyer to me	There is no choice
	63	17	0	0	20
Evaluation of output prices	Good	Fair	Unfair		
	37	39	24		
Trend of output prices in the past	Increasing	Stable	Decreasing		
	65	35	0		
Expectation about future output prices	Increasing	Stable	Decreasing	I do not know	
	43	41	0	16	
Perception of input prices	Good	Fair	Unfair		
	9	41	50		
Evaluation of past input prices	Increasing	Stable	Decreasing		
	50	50	0		

Expectation about future input prices	Increasing	Stable	Decreasing	I do not know	
	37	33	0	30	
Proportion (%) of respondents who felt that subsidies on revenues were:	Very high	High	Fair		
	9	67	24		
Proportion (%) of respondents who felt that transportation costs on revenues were:	Very high	High	Fair		
	59	41	0		
Enough water in winter	Yes	Just barely enough	No		
	9	39	52		
Enough water in summer	Yes	Just enough	No		
	0	17	83		
Source of water	Pumped from a well	Pumped from the river	I have a personal reservoir	I am connected to an existing canal	Others
	2	2	0	33	63
Irrigation method	No irrigation/rain-fed	Furrow/surface	Sprinkler	Pivot	Drip
	66	17	17	0	0
Reason for using this irrigation method	I have always used it	It is efficient	I know how to use it	Other farmers suggested this method to me	Governmental agencies suggested this method to me
	96	4	0	0	0
Knowledge of alternative irrigation methods	Yes	No			
	13	87			
Willingness to adopt new irrigation methods	Yes	No			
	98	2			
If no, specify which conditions apply	There is no need to change traditional methods	I have no access to the required information	I have no access to the required loans	It is not applied by other farmers	
	0	0	2	0	
If yes, specify which conditions apply	I already have access to the required information	I already have access to the necessary money			
	13	85			

Appendix B

Table A3. The suggested cultivation patterns, yields, and prices for winter crops.

Winter Crop	Intensity (% of Total Cultivated Area)	Yield (t/ha)	Price (Dinar/kg)
Winter vegetables [a]	5	30	515
Green manure (with supplemental irrigation.)	7	0	0
Persian clover	4	60	0
Barley-vetch (with supplemental irrigation)	4.5	20	244
Barley-vetch (non-irrigated)	8.5	12	244
Lentils	1	2	245
Broad bean	1	2	285
Winter–spring vegetables [a]	5	18	551
Wheat (with supplemental irrigation.)	7	4	364
Wheat (non-irrigated)	7	2	364

Note: [a] Winter vegetables refer to cabbage, turnip, red beet, radish, carrot, and parsley; winter–spring vegetables refer to onion, parsley, radish, carrot, and red beet.

Table A4. The suggested cultivation patterns, yields, and prices for summer crops.

Summer Crop	Intensity (% of Total Cultivated Area)	Yield (t/ha)	Price (Dinar/kg)
Chick pea	4	2	245
Spring barley	10	4	244
Sorghum	5	5	214
Summer vegetables [a]	15	25	1093
Cow-pea (lobia)	10	2	451
Maize	8	6	0
Sunflower	6	3	214
Maize for fodder	5	60	0
Autumn vegetables [a]	5	18	1330

Note: [a] Summer vegetables refer to tomato, watermelon, cucumber, okra, eggplant, sweet and hot peppers, melon, and green beans; autumn vegetables refer to cauliflower, garlic, lettuce, beans, and peas.

Table A5. The suggested cultivation patterns, yields, and prices suggested by agronomists for perennial crops.

Perennial Crops	Intensity (% of Total Cultivated Area)	Yield (t/ha)	Price (Dinar/kg)
Apricot	1.6	20	1425
Peach	3.2	20	1900
Plum	2.9	15	950
Pear	1.9	20	713
Almond	0.8	1	1900
Pistachio	1.1	3	8550
Vineyard (table grape)	3.6	7	1188
Olive	0.9	8	475
Alfalfa	1	35	285

Table A6. Investment costs (USD) (at 1 USD = 1250 Iraqi Dinar).

	Year 1	Year 2	Year 3	Year 4	Total
Dam costs	91,500,000	153,245,000	58,075,000	6,439,000	309,259,000
Hydropower costs	50,000	—	—	8,828,500	8,878,500
Irrigation costs	18,727,390	24,684,008	12,151,961	242,000	55,805,359
On-farm infrastructure costs (per farmer)	—	—	—	10,000	10,000
Environmental measures	4,815,000	2,000,000	2,000,000	815,000	—

Table A7. Replacement costs (USD).

Dam replacement costs	In Year 34	3,080,000
Hydropower station replacement costs	In Year 34	4,941,000
Irrigation project replacement costs	In Year 34	14,140,841
On-farm infrastructure replacement costs	In Year 34	10,000

Table A8. Operating, maintenance and management (O&M) costs (USD).

O&M costs for dam	From Year 5 To Year 54	3,154,190
O&M costs for hydropower station	From Year 5 To Year 54	144,910
O&M costs for irrigation project	From Year 5 To Year 54	1,305,434
O&M costs for on farm (per farmer)	From Year 5 To Year 54	400

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