ECONOMETRIC ANALYSIS OF THE IMPACT OF WATER RESOURCES AND CLIMATE FACTORS ON AGRICULTURAL EFFICIENCY AND THE ADOPTION OF DIGITAL TECHNOLOGIES

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Annotation: In this article, a comprehensive survey among farmers was conducted in a binary format, with 322 respondents participating. In the study, the probit regression model was used as one of the most effective statistical tools, and the influence of some factors was assessed from a probabilistic point of view. In particular, the use of mobile applications created by farms in the field of agriculture, the impact of climate change on yields, their attitude towards groundwater monitoring, and other factors were analyzed.

Keywords: Probit model, digital technologies, mobile application, agriculture, farming, mobile information, irrigation, climate change, water resources, productivity, agricultural technologies, statistical analysis, z-statistics, probability model.

Introduction.

In recent years, the issue of digitalization of agriculture and the application of modern information technologies in farms has become increasingly relevant. Such opportunities for farmers as obtaining information through mobile applications, assessing soil fertility, and receiving recommendations for irrigation and fertilization contribute to increasing yields and the efficient use of resources. In this study, the probability of farmers using digital technologies and the factors influencing it were statistically analyzed using the Probit model. One of the advantages of the probit model is the ability to determine how much each factor influences the probability of independent decision-making based on the marginal effects (effect coefficients) obtained through it. That is, it shows how much the probability of an event occurring changes when one factor changes by one unit, and based on their marginal analysis, a real economic assessment is given. For example, according to FAO data, digital solutions reduce production costs and ensure environmental sustainability by optimizing water and fertilizer consumption. This situation demonstrates the importance of innovative approaches in agriculture.

Research methodology

In this study, the probability of using digital technologies in farms and the factors influencing it were statistically assessed. The research is based on a quantitative approach, using one of the discrete selection models Probit model . The probit model allows estimating probability in cases where the dependent variable is expressed in binary form (0 - no, 1 - yes) and determines parameters based on the maximum probability method.

Discussion and results

Probit model is a statistical model that represents the prediction of a dependent (binary) variable based on probability. This model is usually used to assess the probability of an event occurring. The theoretical expression of this model is written as follows:

$$P(\mathrm{Y}=1|\,X)=\Phi(X\beta)$$

Here: $P(\mathrm{Y}=1|\,X)$ - probability of an event occurring, Φ - cumulative distribution function of the standard normal distribution, X - vector of independent variables (e.g., use of a mobile application, land area, climate impact, etc.), β - vector of coefficients.

The probit model is represented based on the latent variable as follows:

$$Y^{*}=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\varepsilon,\ \varepsilon:\ N(0,1)$$

Here,-unobservable hidden variable (for example, decision-making probability) x_1, x_2, x_3....-independent variables (for example, mobile application, climate, land area) β_0, β_1, β_2, β_3....-respectively regression coefficients, $\varepsilon:\ N(0,1)$-error with standard normal distribution.

As a result, the observed variable Y is denoted as follows:

$$\mathrm{Y}=\begin{cases}1 \text{ if } \mathrm{Y}>0\\ 0 \text{ else}\end{cases}$$

The theoretical formula for the probit formula in the Stata program is:

$$P(Y=1|\,X)=\Phi(\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3....+\beta_kx_k)$$

The Stata program evaluates regression parameters based on this model using the maximum probability method.

In our study, the factors influencing the use of digital technologies by farmers were studied through a questionnaire, and the following results were obtained.

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Iteration 0:   log likelihood = -191.71889
Iteration 1:   log likelihood = -159.17993
Iteration 2:   log likelihood = -158.80147
Iteration 3:   log likelihood = -158.80102
Iteration 4:   log likelihood = -158.80102

Probit regression                               Number of obs     =        322
                                                LR chi2(8)        =      65.84
                                                Prob > chi2       =     0.0000
Log likelihood = -158.80102                     Pseudo R2         =     0.1717
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Sizot_suvlari_sathi_haqida_malu	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Yer_bal_bonitetingiz_mobil_ilova	.3091325	.1714446	1.80	0.071	-.0268927	.6451576
Mobil_telefondan_foydalanib_ferm	.3280381	.1639505	2.00	0.045	.0067012	.6493751
Fermerlik_bilan_bogliq_bolmaga	.0623459	.165689	0.38	0.707	-.2623987	.3870904
Fermer_xojaligingiz_sugoriladi	.7016384	.1702475	4.12	0.000	.3679593	1.035317
Iqlim_ozgarishi_hosil_olishingi	.6849732	.1682083	4.07	0.000	.355291	1.014655
Sizot_suvi_sathi_doimiy_kuzatuv_	.8164423	.1679114	4.86	0.000	.487342	1.145543
Paxta_va_bugdoy_uchun_qancha_mi	.4733005	.1647095	2.87	0.004	.1504758	.7961251
Davlat_tomonidan_raqamli_texnolo	.341625	.1786544	1.91	0.056	-.0085311	.6917812
_cons	-1.30676	.2883518	-4.53	0.000	-1.871919	-.7416004

Figure 1. Probit model in Stata 16[1]

According to the analysis results, the Probit regression equation, which determines the probability of having information about the groundwater level, has the following form:

$$Y = -1,30676 + 0,3091x_1 + 0,3281x_2 + 0,0623x_3 + 0,7016x_4 + \\ +0,6849x_5 + 0,8164x_6 + 0,4733x_7 + 0,3416x_8.$$

Here, Y - the hidden (latent) level of access to information about the groundwater level; x_1 - the assessment of land quality through a mobile application; x_2 - conducting farming activities using a mobile phone; x_3 - the presence of non-farming activities; x_4 - the location of the farm on irrigated land; x_5 - the impact of climate change on yields; x_6 - constant monitoring of the groundwater level; x_7 - how much land is allocated for cotton and wheat; x_8 - the introduction of digital technologies by the state.

In the probit model, the probability of receiving groundwater level information through this hidden variable is determined as follows:

$$P(Y=1) = F(Y^*).$$

[1] Based on the author's calculations in Stata 16

Here, $F(Y^*)$ - is the cumulative function of the standard normal distribution.

The standard error in the probit regression results shows how accurately the estimate of each coefficient was calculated. If the standard error is small, the result will be more reliable. If the standard error is large, the value of the coefficient becomes uncertain, and the statistical significance of the result decreases.

Table 1.

Probit Model[2]

Variable	*y*
Does the land rating increase as a result of using the mobile application	0.309 (1.80)
Do you get the necessary information for farming as a result of active mobile phone use?	0.328* (2.00)
Do you have income not related to farming	0.0623 (0.38)
Does the irrigated area of the farm's land exceed 80% and does the groundwater affect your harvest?	0.702*** (4.12)
Does climate change affect crop yields?	0.685*** (4.07)
Do you think that changes in the groundwater level should be constantly monitored?	0.816*** (4.86)
Do you want to know how much water and fertilizers are needed for cotton and wheat?	0.473** (2.87)
Are you satisfied with the government's support for digital technologies for farms?	0.342 (1.91)
Constant value	-1.307*** (-4.53)
Observations	322.

Standard errors are given in parentheses ($p<0.01$; $p^{**}<0.05$; $p^{***}<0.001$)

In the model, the probability of connection is expressed through the reserve variable *y* , which represents the probability of the farmer using information through digital technologies (in particular, a mobile application). Below, each factor is analyzed based on the results of this modeling. Here, the statistic *z* is used, and the statistic *z* is used for models evaluated by the maximum probability method (probability of large data), such as Probit, Logit. In these models, with a large sample size, the coefficients are distributed normally. Therefore, they do not need to use *the* t-distribution, but can use z-statistics based on the standard normal distribution.

Increased land score bonitet and depending on the use of the mobile application. The value of the coefficient for this indicator is equal to 0.309, and the

[2] Based on the author's calculations in Stata 16

statistic z1.80. This result indicates that the use of the mobile application has a positive impact on the assessment of land fertility. Although the result is only 10% significant , this variable indicates that farmers have access to land quality data through a mobile application.

Do you receive the necessary information for farming as a result of active use of a mobile phone?. The coefficient of this variable is 0.328 and it is z-statistic=2.00 at a significance level of 5% significant. This result means that farmers have the opportunity to receive the necessary information (for example, market prices, weather forecasts, agronomic recommendations) through mobile phones. These figures underscore the need for more effective application of mobile technologies in agriculture.

The availability of non-farm income sources. The coefficient 0.0623, the statistic *z* is insignificant in the model with 0.38 . This means that non-farm income does not significantly affect the likelihood of using digital technologies. Therefore, this factor cannot be considered one of the main determinants.

Irrigated land area (more than 80% and is groundwater affecting your harvest). The coefficient of this variable is 0.702, the z-statistic is 4.12, and it is 1% significant. This means that farms with large irrigated areas strive to obtain higher yields and use digital technologies. This reflects the need for digital solutions for efficient water resource management.

Impact of climate change on productivity. Coefficient 0.685, *z*-statistic 4.07 , this variable is also 1% significant. This result means that farmers who feel the risks associated with climate change are turning to digital information sources. Farmers are trying to get real-time weather and climate information.

The need to monitor changes in the groundwater level. The highest influence power belongs to this variable - coefficient 0.816, *z* - statistic 4.86, which is very significant at the level of 1%. This means that through water level monitoring, farmers can plan their water supply, and digital technologies are crucial for such monitoring.

Desire to determine the amount of water and fertilizer. The coefficient for this variable is 0.473, z-statistic 2.87, and it is significant at a level of 5%. This result indicates that farmers strive to obtain individual recommendations on the norms of water and fertilizers. This means that digital applications should be integrated with agricultural services.

State support for digital technologies. Coefficient 0.342, z-statistic 1.91, which is significant at a level of 10%. This result indicates that farmers consider the state's efforts to implement digital technologies sufficient, but additional work is still required.

Constant value of the model (constant). Constant value -1.307, *z*-statistic -4.53, which indicates a significant statistical result in the model. This indicator means that the likelihood of using digital technologies is low when other factors are neutral.

The model was evaluated based on 322 observations. Standard errors are listed in parentheses.

Model results show that the state of water resources, climate change, irrigation area, and the need for information have a significant impact on farmers' adoption of digital technologies.

In the probit model, the marginal effect of variable x_j is given by the following formula:

$$\frac{\partial P(X=1|X)}{\partial X_j} = \Phi(X\beta)\cdot\beta_j$$

Here, $\Phi(X\beta)$ is the probability density function of the standard normal distribution, β_j is the corresponding coefficient of variable x_j and $\frac{\partial P(X=1|X)}{\partial X_j}$ represents the marginal effect of x_j on the probability. In other words, the impact of each β_j value is stronger near the center of the sigmoid-shaped probability function and weaker at the extremes.

Table 2

Marginal analysis

Variable	***Y* (1)**

Does the land rating increase as a result of using the mobile application?	0.0860, (1.83) *
Do you get the necessary information for farming as a result of active use of mobile phones?	0.0912** (2.04)
Do you have income not related to farming	0.0173, (0.38)
Is the irrigated area of the farm's land more than 80%?	0.195*** (4.42)
Does climate change affect crop yields?	0.191*** (4.37)
Do you think that changes in the groundwater level should be constantly monitored?	0.227*** (5.46)
Do you want to determine how much water is needed for cotton and wheat, and how much fertilizer is needed accordingly?	0.132** (2.97)
Do you approve of the government's policy of supporting digital technologies for farms?	0.0950* (1.94)
Observations	322.

($p<0.01$; $p^{**}<0.05$; $p^{***}<0.001$)

Marginal effects obtained from the Probit regression model were calculated . Marginal effects represent the percentage change in the dependent variable *(y=1,* i.e., the probability of using digital technologies) when the value of each independent variable changes. Below is an analysis of these results:

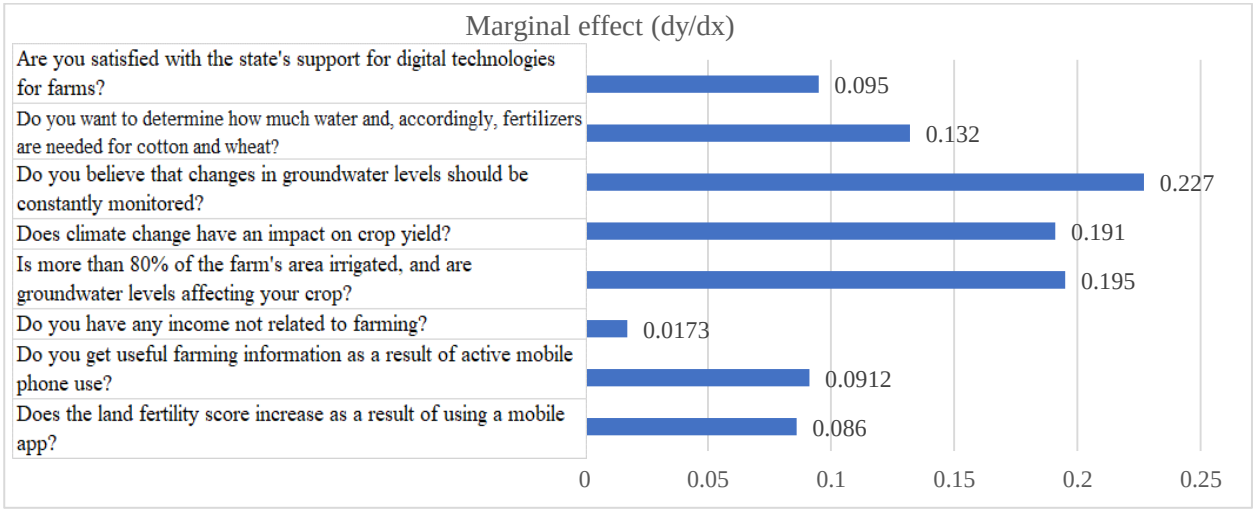


Figure 2. Marginal analysis

Do land bonitet scores increase as a result of using a mobile application: Marginal effect 0.0860, which means that if a farmer uses a mobile application and this leads to an increase in land fertility, then the probability of using digital technologies increases by 8.6 percent. z-statistic 1.83, this result is significant at a 10 percent level . This situation indicates that digital technologies play an important role in land quality monitoring.

Active use of mobile phones: The marginal effect for this factor is 0.0912, that is, farmers who actively use mobile phones are 9.1% more likely to use digital applications. z-statistic is 2.04 , the result is 5 percent significant. This result confirms the availability of data exchange and access to services via mobile devices.

The presence of income not related to farming: The marginal effect of this variable 0.0173, z-statistic 0.38, i.e., is not statistically significant. This result means that other sources of income have no direct impact on the likelihood of adopting digital technologies.

Whether the irrigated area of the farm is more than 80 percent and the impact of groundwater on your harvest: Marginal effect 0.195, which is a very noticeable result, z-statistic is 1 percent significant with 4.42 . This indicator also affects the yield if the farm is larger and irrigated, and the probability of using digital technologies increases by 19.5 percent. This indicates the high role of digital technologies in water resource management.

The presence of the impact of climate change on yield: Marginal effect 0.191, z-statistic 4.37, which is also 1 percent significant. Farmers sensitive to climate change feel the need for real-time information, which increases their likelihood of turning to digital technologies by 19.1%.

Need to monitor changes in groundwater level: This variable has the greatest marginal effect (0.227) . This means that if the farmer believes that it is necessary to constantly monitor the groundwater level, then the probability of using digital technologies increases by 22.7 percent. z-statistic is 5.46 , and the result is very significant at 1 percent. The need for digital solutions for water resource monitoring has a reliable statistical basis.

Want to know the water and fertilizer standards for cotton and wheat: Marginal effect 0.132, z-statistic 2.97, which is significant at 5%. This indicates that farmers want to receive specific agrotechnical recommendations, and the probability of using digital technologies for this will increase by 13.2%.

Attitude towards the state's policy of supporting digital technologies: Marginal effect 0.0950, z-statistic 1.94, which is significant at a 10 percent level . This result

indicates that if farmers evaluate government policy positively, their likelihood of using digital technologies increases by 9.5 percent.

Marginal analysis results show that the following factors have a significant positive impact on farmers' likelihood of adopting digital technologies:

Table 3

Marginal analysis result indicators in percentage

Area of irrigated land	19.5
Climate change	19.1
Necessity of monitoring the groundwater level	22.7
Use mobile phone	9.1
Land bonitet	8.6
Satisfaction with government policy	9.5
Desire to receive agricultural recommendations	13.2

Conclusion

This analysis shows that water and climate risk management, access to information, and public policy are important factors in the wider adoption of digital technologies. These results will serve as a basis for the development of strategic approaches to planning digital transformation in the future. According to Jierong Wang et al., "if farmers have a low level of knowledge and skills, when they encounter large amounts of data arising from the development of digital technologies, farmers will not be able to verify and process this data." Farmers' ability to use the Internet effectively to increase overall agricultural productivity depends on their digital literacy and programming skills.

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