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Editorial office

AGRIS on-line Papers in Economics and Informatics
Department of Economics of FEM CZU Prague
Kamýcká 129, 165 00 Praha-Suchdol
Czech Republic
Phone: +420 224 382 056
E-mail: agrisonline(at)pef.czu.cz

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The Effects of Biofuels on Food Security in Selected Countries

Ebrahim Babakhani, Reza Rostamian, Mostafa Goudarzi

Department of Agriculture Economic, Qaemshahr Branch, Islamic Azad University, Iran

Abstract

Biofuels are produced as replacements for fossil fuels. Nevertheless, these fuels may jeopardize food security. No research has examined the relationship between the production of biofuels and food security in terms of their various dimensions. This study examined the effects of biofuels on food security in several developed and developing countries comprising oil-producing and developed countries. Dimensions of food security were including food availability, food accessibility, food utilization, and food stability. To this end, standard and neo-Malthusian theories combined with the food availability decline (FAD) theory were employed. In addition, the panel generalized method of moments (GMM) was used to estimate the relationships between variables. The results showed that food stability, population growth, and income inequality were measured by the Gini index, and unemployment was significantly higher in developing countries than in developed countries. Conversely, food security, food availability, food accessibility, food utilization, land area, total biofuel production, agricultural credit allocation, and food product prices were higher in developed countries than in developing countries. The increase in biofuel production reduced food security by 0.031%, 0.047%, and 0.064% in all countries, developing and developed countries, respectively. In developing countries, biofuels had a significant impact on food accessibility and food availability. However, biofuels had significant and positive effects on food stability and utilization. In developed countries, biofuels had negative effects on food accessibility, stability, and availability and positive effects on food utilization (0.016%). In conclusion, policies are needed to mitigate the negative effects of biofuels on food security.

Keywords

Biofuels, developing countries, developed countries, food availability, food security.

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Introduction

Historically, nonrenewable fossil resources have driven the development of civilization, where investment growth increased from 4.2% in 2017 to 4.7% in 2018 (Subramaniam, Masron and Azman 2019). However, their applications are restricted due to the emission of air and environmental pollutants (Stolarski et al. 2019). Due to the renewability of the feedstocks, biofuels have been introduced as alternatives to fossil fuels (Brinkman et al., 2020).

Some industrial crops have been used for non-food applications, including fiber production, bioenergy, and industrial products (Jarzebski et al., 2020). Nevertheless, biofuel production necessitates land that can jeopardize food security (Martínez-Jaramillo et. al, 2019). First-generation biofuels are conventional, while subsequent generations are more advanced. However, the third and fourth generations have not yet been commercialized (Mohanty et al., 2021).

Food insecurity is characterized by limited access to safe and nutritious food, whereas food security is represented by all people having physical, social, and economic access to adequate, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (George and McKay, 2019). Indeed, available land and water resources for biofuel production compete with food production (Pachapur et al., 2020). Despite advancements, more than 820 million people are still malnourished, and at least 2 billion fail to receive sufficient nutrients (Ingram, 2020). Moreover, during the 2008 financial crisis, biofuels may have contributed to a 20 to 40% increase in food prices (Mittal, 2008; Sousa et al., 2019). The relationship between population and food supply is one of the most important economic principles. Moreover, the decrease in food security can have destructive effects, health risks, and negative socioeconomic consequences (Abdullah and Akbar 2021).

Some nations, such as those in the Middle East, play a significant role in the global oil and gas market supply. These countries derive most of their income from oil and natural gas resources. However, rapid population growth and changes in zonal climate and the water cycle have increased the need to integrate the planning and design of renewable energy and systems in this area (Nematollahi et al., 2016). It has been reported that water scarcity, drought, and economic growth severely restrict energy production in Middle Eastern nations. This water-food security is primarily impacted by drought, water scarcity, population growth, urbanization, or political unrest (Hameed et al., 2019). On the other hand, natural disasters, such as frequent drought events, water scarcity, and unsustainable intensive agricultural practices, may threaten food security in these nations (Hameed at al., 2020). On the other hand, developed countries are pioneers in producing biofuels. In the United States, ethanol is produced primarily from corn, while in Brazil, it is produced from sugarcane. Moreover, biofuels are mainly obtained from oilseeds in the European Union, particularly in Spain, Germany, and France (Simionescu et al., 2017). In 2016, European countries produced more than one thousand ktoe biofuels (Streimikiene et al., 2019).

The relationship between food security and biofuels has been the subject of numerous studies. A study has evaluated the impact of biofuels on food security in 51 developing countries and found a negative correlation between biofuels and food security (Subramaniam et al., 2020). Other studies have reported a negative correlation between biofuel production and food supply in Colombia (Martínez-Jaramillo et al., 2019), food prices and imports in Ghana (Brinkman et al., 2020), and food security in low- and middle-income countries (Renzaho et al., 2017).

Despite potential food security crises in the Middle East and the global shift toward biofuels, it seemed necessary to investigate the impact of food security and biofuels on food security in oil-producing countries. We were unable to find a study examining the relationship between food security and biofuels on food security in oil-producing and developed countries which considered various food security dimensions. Consequently, the current study examined the relationship between food security and biofuels in the studied countries.

Increased biofuel production increases food prices, resulting in chronic malnutrition (To and Grafton, 2015). Hence, the focus of this study is to further contribute to the literature by empirically analyzing the effect of biofuel production on food security. Another important contribution of this study is that it takes a broader view of the definition of food security. For the reasons stated in the theoretical foundations, this study also aims to separate food security into four dimensions, "food availability"; "food accessibility"; "Food utilization" and "food stability”. Food availability does not rely only on the amount of food within the national borders, which was the main issue of food security in the past, and today it also includes the production (domestic and/or internal supply) and importing the food. Food accessibility refers to physical and economic access to resources in order to provide food items needed by society (Renzaho and Mellor 2010). Food stability mentions the ability to receive food over time. Food utilization is based on the correct use of food. Based on this, the existence of food and access to it does not mean that people's diet is healthy and nutritious (Renzaho and Mellor 2010). Another important issue is comparing the effects of biofuels on food security in different countries of the Middle East and developed countries. The importance of this issue increases when we know that most countries of the Middle East countries have not much attention to this issue due to the abundant sources of fossil fuels.

Materials and methods

In the present study, a standard Malthusian and neo-Malthusian theory emphasizing food insecurity was employed due to the large population compared to the amount of food supply (Malthus et. al., 1992). On the other hand, neo-theory suggests that limited and finite land resources are responsible for insufficient food supply per person. Equation (1) can be utilized to express food security:

$$FS = (POP, AL) \quad (1)$$

Where FS denotes food security, POP represents the population, and AL is arable land.

The Food Availability Decline (FAD) theory was then applied to determine the primary causes of the food shortage (Devereux, 1993). Several studies have found that biofuels impact food supply or production (Ajanovic, 2011; Amigun et. al, 2011; Kgathi et al. 2012) and agricultural credits (Adams and Hunter, 2019). Thus, the equation for this is formulated as follows:

$$FS = (POP, AL, BP, CA, ED) \quad (2)$$

Where *BP*, *ED*, and *CA* are biofuel production, environmental degradation (*ED*), and agriculture credit, respectively.

Food entitlement decline (FED) theory was incorporated to complete the model. The theory is predicated on the set of alternative commodity bundles that a person can command in a society based on the totality of rights and opportunities that individuals face (Devereux, 1993). Therefore, food demand or consumption is determined by variables such as income inequality (Masters et al., 2013), income (Pingali, 2007), price (Campbell et al., 2016; Koizumi, 2015), and unemployment (Etana and Tolossa, 2017; Loopstra and Tarasuk, 2013). Consequently, the complete model is expressed as follows:

$$FS = (POP, AL, BP, CA, ED, IE, GDP, PRI, UNE \quad (3)$$

Where *IE* denotes income inequality, *GDP* is income, *PRI* represents price, and *UNE* is unemployment.

Subsequently, the model can also be presented as follows;

$$FS_{it} = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it} \quad (4)$$

All variables are then transformed into logarithms. Equation (5) can be rewritten as follows:

$$lnFS_{i,t} = \alpha + \beta lnX_{i,t} + \varepsilon_{i,t} \quad (5)$$

For a more precise assessment of food security, each element must be reported in four dimensions and transformed as follows:

$$FS_{element} = \frac{Country\ Index - World\ Minimum}{World\ Maximum - World\ Minimum} \times 100 \quad (6)$$

The maximum and minimum global values were considered for the United States and Sudan, respectively (World Bank, 2018). Calculations of FS were performed in a range of 0-100 based on the above relationship of minimum food security (Sudan) and maximum food security (USA).

Four separate indices were created for each of the four dimensions. This was completed by calculating each dimension's mean of all element indices. The food availability index (FSAVA) consists of five components; consequently, the index is expressed as the weighted average of these five components, as shown in Equation 7:

$$FS_{AVA} = (FS_{element1} + FS_{element2} + \ldots)/5 \quad (7)$$

It is essential to mention, the weight of each dimension is equalized. All dimensions are homogenized in the range of 0 to 100 before averaging.

Consequently, the final equation for food security is as follows:

$$FS = (FS_{AVA} + FS_{ACC} + FS_{UTI} + FS_{STA})/4 \quad (8)$$

Where FS_{ACC}, FS_{UTI}, and FS_{STA} denote food accessibility, food utilization, and food stability indexes, respectively.

Four dimensions were initially calculated and then divided by four (total dimensions) in the current study. The food security index is reported as a value between 1 and 100, where the higher the value, the greater the level of food security. The FAO food security framework is illustrated in Table 1.

Code	Dimension	Source
	Availability	
AV1	Average dietary energy supply adequacy	FAOSTAT
AV2	Average value of food production	FAOSTAT
AV3	Share of dietary energy supply derived from cereals, roots, and tubers	FAOSTAT
AV4	Average protein supply	FAOSTAT
AV5	Average supply of protein of animal origin	FAOSTAT
	Access	
AC1	Gross domestic product per capita (in purchasing power equivalent)	World Bank
AC2	Prevalence of undernourishment	FAOSTAT
AC3	Depth of the food deficit	FAOSTAT
	Stability	
ST1	Food per capita	FAOSTAT
ST2	Percent of arable land equipped for irrigation	FAOSTAT
ST3	Per capita food supply variability	FAOSTAT
	Utilization	
UT1	Percentage of the population with access to improved drinking water sources	World Bank
UT2	Percentage of the population with access to sanitation facilities	World Bank
UT3	Prevalence of obesity in the adult population (18 years and older)	GHO
UT4	Prevalence of anemia among women of reproductive age (15–49 years)	World Bank

Source: Adopted from FAOSTAT

Table 1: The FAO framework of food security.

In addition to the indices reported in Table 1, several additional indices must be defined, as detailed in Table 2.

Code	Definition/Measurement	Source
POP	Population growth per year	World Bank
ED	CO2 emission based on tonne/metric	World Bank
AL	Land area (total land %)	World Bank
GDP	Gross production in the year 2010 (US dollars)	World Bank
UNE	Unemployment as a percentage of the workforce	World Bank
PRI	Food product price indices	FAOSTAT
BP	Total biofuel based on 1000 barrels/day	IEA and OECD
CA	Agriculture section credit as a proportion of total credits	FAOSTAT
IE	Income inequality in Gini indices	OECD

Source: Adopted from FAOSTAT and World Bank

Table 2: Variable definition and resources.

Panel data methodology was used to estimate our empirical models. The generalized method of moments (GMM) estimation was used to account for potential endogeneity (Equation 9).

$$y_{it} = \alpha y_{it-1} + \beta' X_{it} + \eta_i + \phi_t + \varepsilon_{it} \quad (9)$$

Where y is a dependent variable, x depicts an explanatory variable, η is individual effects or companies fixed, and φ is the effects of time fixed. Subscripts i and t represent the corporation and the time period, respectively.

The first-order difference is an effective method for removing fixed effects, outlined the Equation 10.

$$\Delta y_{it} = \alpha \Delta y_{it-1} + \beta' \Delta X_{it} + \Delta \phi_t + \Delta \varepsilon_{it} \quad (10)$$

Where Δy_{it-1} represents the difference for a dependent variable that correlates with $\Delta \varepsilon_{it}$.

There are inherent issues with the model that must be considered. Consequently, it is necessary to include tool variables in the model, as shown in Equations 11-14.

$$E(y_{it-s} \Delta \varepsilon_{it}) = 0 \quad s \geq 2; t = 3,4,\ldots,T \quad (11)$$

$$E(X_{it-s} \Delta \varepsilon_{it}) = 0 \quad s \geq 2; t = 3,4,\ldots,T \quad (12)$$

$$z_i = diag(y_{i1}, y_{i2}, \ldots, y_{it-2}, X_{i1}, X_{i2}, \ldots, X_{it-2}) \quad (13)$$

$$\delta\hat{} = (\beta' z A_N z' B)^{-1} \beta' z A_N z' Y \quad (14)$$

It is necessary to identify model tool variables to estimate the model. A reliable estimator is dependent on non-correlation errors and modifiable tools. To this end, the Sargan test is employed to investigate confirmation tests. In addition, the M_2 statistic examines the second-order serial correlation between sentences. The Sargan test is described in Equation 15.

$$S = \hat{\varepsilon}' z \left(\sum_{i=1}^{N} z_i' H_i z_i\right)^{-1} z' \hat{\varepsilon} \quad (15)$$

In this test, $\varepsilon\hat{} = Y - X\delta\hat{}$, $\delta\hat{}$ is a k × 1 matrix of estimated coefficients, z denotes a matrix of tool variables, and H is a square matrix.

The data were collected from Australia, Austria, Canada, The Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, South Korea, Luxemburg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Chile, Turkey, the UK, United States, Estonia, Israel, Russia, Lithuania, China, Costa Rica, India, Belgium, Romania, Bahrain, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, The United Arab Emirates, and Yemen. Bahrain, Egypt, Turkey, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, The United Arab Emirates, and Yemen were developing and other countries were developed. The data utilized were panel data collected annually from a select population. The data were collected from FAO and World Bank during 2000-2019 and analyzed by Eviews software.

Results and discussion

Descriptive data

The results for the studied variables in the selected countries are provided in Table 3. The average value of the food security index, which is calculated based on the average of four indicators of food availability, food accessibility, food stability and food utilization, is equal to 51.90%. In other words, the food security level of the studied countries is about 52%. The mean of the variable is also equal to 53.198. The highest level of the food security index is 63.778% and the lowest level is 30.301%. The standard deviation for this variable is 8.072%, in fact, the standard deviation shows the amount of dispersion compared to the average. This number indicates that there is 8.072% dispersion compared to the average, which is an average dispersion. By examining the dimensions of food security, it can be seen that the average index of food availability is 42.96%. Similarly, food

Variables	Symbol	Mean	Median	Min	Max	SD
Food security	FS	51.901	53.198	30.301	63.778	8.072
Availability	FSAVA	42.968	44.870	26.555	56.081	8.575
Accessibility	FSACC	65.816	68.744	31.497	85.329	14.042
Stability	FSSTA	25.136	22.495	6.246	53.477	14.215
Utilization	FSUTI	73.068	75.796	38.487	91.854	14.675
Population growth (%)	POP	1.760	1.246	0.164	5.944	1.572
Land area (log)	AL	5.212	5.384	3.386	6.953	0.881
Biofuel production*	BP	2.106	0.000	0.000	16.000	4.206
Credit for agriculture	CA	3.227	1.858	0.059	13.222	3.679
CO2 emission damage	ED	6.395	6.327	4.832	7.464	0.683
Income inequality	IE	32.421	31.800	26.800	41.900	4.447
Gross production	GDP	4.388	4.617	3.095	4.940	0.506
Food price	PRI	92.869	95.635	63.845	112.260	12.269
Unemployment (%)	UNI	5.122	3.905	1.044	13.555	3.452

Note: *1000 barrels/daily
Source: Adopted from findings of the current study.

Table 3: Data for the variables studied in the selected countries.

accessibility and food utilization were 65.861% and 73.068%, respectively. It should be noted that the desired indicators were normalized based on the minimum and maximum dimensions used in the range of zero to 100 percent. By comparing the four indicators, the highest level of food security index in countries is for food utilization. In fact, the values for food utilization in the study countries are close to each other. The lowest amount was for food stability. By examining other indicators, the average percentage of population growth is 1.76%. The highest population growth is 5.944% and the lowest is almost zero. The logarithm of the arable land is also 5.212. Also, the total production of biofuels for the sample countries is 2.106 thousand barrels per day. The lowest amount of biofuel production is zero and the highest amount is 16 thousand barrels. In the same way, the average credit allocated to the agricultural sector is 3.227% in relation to the total credits. The highest credit of the agricultural sector is around 13% and the lowest amount is close to zero.

By examining the logarithm of carbon dioxide emission damage, it can be seen that its average is 6.395. By taking the anti-logarithm, the damage of carbon dioxide emissions is 2.485 billion dollars. Likewise, the average income inequality based on the Gini coefficient index is 32.421%. The highest inequality is 41.9% and the lowest is 26.8%. The average logarithm of GDP per capita for the sample countries is 4.388. The average food price index and unemployment were 92.868 and 122.5%, respectively.

Comparison of developed and developing countries

Based on the results of Table 4, it can be seen that the difference in the average of two groups of Middle Eastern and developed countries for all indicators is significant ($P<0.05$). The average food security index is lower for developing countries in the Middle East. However, the food stability in Middle East countries is higher than in developed countries, which is because of the oil-rich sources. Food availability, food accessibility, and food utilization are more in developed countries. The percentage of population growth, income inequality in the GINI index, and the percentage of unemployment in the developing countries of the Middle East are higher than in developed countries. Also, the total production of biofuel, the percentage of credit to the agricultural sector, the GDP per capita, and the food price index are lower in the developing countries of the Middle East. The land area and carbon dioxide emission damage are almost the same in both groups.

Correlation between variables

Table 5 displays the results of the correlation analysis. The results show a positive and significant correlation between the food security index and each of its dimensions. In addition, there is a significant positive (0.824) correlation between food security and GDP. Similarly, there was a negative and significant correlation between the food security index and land area, income inequality in the GINI index and unemployment percentage.

Variables	Symbol	Symbol	Developing	Developed	T
Food security	FS	FS	47.342	55.321	-14.830**
Availability	FSAVA	FSAVA	37.759	46.874	-16.359**
Accessibility	FSACC	FSACC	56.559	72.759	-18.391**
Stability	FSSTA	FSSTA	33.455	18.897	15.546**
Utilization	FSUTI	FSUTI	60.370	82.591	-29.943**
Population growth (%)	POP	POP	3.014	0.820	25.267**
Land area (log)	AL	AL	5.066	5.322	-3.853**
Biofuel production*	BP	BP	0.104	3.608	-11.963**
Credit for agriculture	CA	CA	2.318	3.908	-5.791**
CO_2 emission damage	ED	ED	6.262	6.496	-4.552**
Income inequality	IE	IE	33.988	31.246	8.471**
Gross production	GDP	GDP	3.988	4.687	-24.753**
Food price	PRI	PRI	90.166	94.896	-5.139**
Unemployment (%)	UNI	UNI	7.039	3.684	14.510**

Note:** indicates significance at the 5% level
Source: Adopted from findings of the current study.

Table 4: Data for variables studied in developed and developing countries.

Variables	FS	FSAVA	FSACC	FSSTA	FSUTI	POP	AL	BP	CA	ED	IE	GDP	PRI	UNI
FS	1.000													
FSAVA	0.708*	1.000												
FSACC	0.881*	0.585*	1.000											
FSSTA	0.217*	-0.142*	-0.079*	1.000										
FSUTI	0.779*	0.590*	0.770*	-0.321*	1.000									
POP	-0.220*	-0.458*	-0.228*	0.530*	-0.539*	1.000								
AL	-0.195*	0.177*	-0.176*	-0.324*	-0.027	-0.299*	1.000							
BP	0.135*	0.282*	0.254*	-0.373*	0.265*	-0.325*	0.382*	1.000						
CA	0.036	0.183*	-0.029	-0.036	0.042	-0.239*	0.311*	-0.015	1.000					
ED	0.238*	0.209*	0.212*	-0.113*	0.359*	-0.299*	0.559*	0.459*	0.020	1.000				
IE	-0.175*	-0.056	-0.238*	0.062	-0.223*	0.121*	0.213*	0.086*	-0.177*	0.222*	1.000			
GDP	0.824*	0.546*	0.927*	-0.152*	0.814*	-0.311*	-0.128*	0.256*	0.034	0.223*	-0.282*	1.000		
PRI	0.110*	0.092*	0.185*	-0.093*	0.114*	-0.205*	0.056	0.146*	0.012	0.247*	-0.003	0.191*	1.000	
UNI	-0.621*	-0.301*	-0.696*	0.066	-0.600*	0.089*	0.242*	-0.120*	-0.004	0.022	0.292*	-0.766*	0.093*	1.000

Source: Adopted from findings of the current study.

Table 5: Correlation between variables.

Moreover, there was a positive and significant correlation between the food security index and biofuels. In the same way, there is a positive and significant correlation between the food security index and carbon dioxide emission damage, GDP per capita, and the food price index. Furthermore, the correlation between each of the food security indicators and other variables is also noticeable in the table. The highest correlation is between GDP and unemployment, which is equal to -76.6%. In estimating the research models, attention should be paid to the correlation of these two variables. The correlation of other independent variables is less than 70% and is not very worrying.

The food security model for the selected countries

According to Table 6, Sargan's test is not statistically significant. Hence, it can be said that the variables defined in the model are valid and the model does not need to define more variables. Moreover, the results show that in the research model, there is autocorrelation of the first degree but not of the second degree. Therefore, it can be seen that the second-order serial autocorrelation problem does not exist in the research models, and the GMM estimator is consistent. Food security has a positive and significant effect on food security with a time lag. Likewise, the coefficient of biofuels is -0.031 and it is significant based on the t-statistic. Indeed,

$$FS_{it} = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

Variable	Symbol	Regression coefficient	Standard Error	T-statistic	Probability
Lag of food security	FS(-1)	0.705	0.011	66.403	0.000
Population growth (%)	POP	-0.133	0.018	-7.444	0.000
Land area (log(	AL	0.305	0.104	2.928	0.004
Biofuel production (total)	BP	-0.031	0.009	-3.592	0.000
Agricultural credit (%)	CA	0.036	0.011	3.371	0.001
CO_2 emission damages	ED	0.443	0.142	3.115	0.002
Income inequality for Gini indices	IE	0.006	0.010	0.566	0.571
Gross production of internal per capita (log)	GDP	7.783	0.487	15.986	0.000
Food products indices	PRI	-0.001	0.001	-1.226	0.221
Unemployment (%)	UNI	-0.019	0.003	-5.739	0.000
Sargan test statistic	329.489				
Sargan test probability	0.513				
First-order autocorrelation (P)	-8.60 (0.000)				
Second-order autocorrelation (P)	-1.21 (0.226)				

Source: Adopted from findings of the current study.

Table 6: Food security model based on total food security indices for selected countries.

a one-barrel increase in biofuels leads to a decrease of 0.031 percent in food security. Therefore, it can be said that increasing the use of biofuels reduces food security. Also, the increase in unemployment has a negative and significant effect on food security. In this regard, it is expected that with an increase in the unemployment rate of one percent, the amount of food security will be decreased by 0.019 percent. With an increase of one percent in arable land area, food security is to be increased by 0.305 percent. A one percent increase in credit to the agricultural sector leads to an increase of 0.036 percent in food security. In the same way, an increase of one percent in carbon dioxide emission damage, 0.443 percent, increases food security, which is a positive relationship due to more production and as a result, an increase in pollution emission. As well as a one percent increase in GDP per capita increases food security by 7.783 percent. One percent population growth reduces food security by 0.133 percent. Moreover, income inequality in the GINI index and food price index does not affect food security.

The food security model based on the dimensions of food security for all the selected countries

The food security model was represented using food security dimensions in order to investigate food security dimensions (Table 7). According to the results, the probability of Sargan was greater than 5%, and the defined variables were confirmed. It was unnecessary to supply additional variables. There was a first-order autocorrelation, but no second-order autocorrelation was observed (the probability value is greater than 5%). It can be seen that research models do not include serial autocorrelation. In other words, it is a GMM estimator that is consistent. Also, the results show that in the research model, there is autocorrelation of the first degree, but not of the second degree, because the statistical probability is higher than the 5% error level. Therefore, it can be seen that the problem of second-order serial autocorrelation does not exist in the research models, and indeed the GMM estimator is consistent. Biofuels have a negative and significant effect on the dimensions of food availability, food accessibility, and food stability, but their effects on food utilization is positive and significant ($P<0.01$). The coefficient of influence of this variable on access to food is 0.141 and is significant ($P<0.01$). In fact, income inequality leads to increased access to food. However, its effect on other indicators is negative and insignificant. By examining the GDP per capita, it can be seen that the increase in the GDP per capita has a negative and significant effect on food availability. It has a positive and significant effect on food accessibility and food stability. It did not have significant effects on food utilization. In the same way, the increase in the food price index reduces food availability but increases the sustainability of food intake. Finally, the unemployment rate has almost the same results as the price index, so it has a negative and significant effect on food accessibility and food stability. It could be attributed to the replacement of capital for more production and higher food security.

$$FSAVA_{it} \text{ or } FSACC_{it} \text{ or } FSSTA_{it} \text{ or } FSUTI_{it} = \\ = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

		FSAVA		FSACC		FSSTA		FSUTI	
Variable	Symbol	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
Lag of food security	FS(-1)	0.738***	19.014	0.416***	3.270	0.674***	22.327	0.936***	73.636
Population growth (%)	POP	0.028	0.309	-0.120	-0.585	-0.030	-0.453	0.119***	5.687
Land area (log)	AL	-0.419	-0.410	1.429	0.342	-1.382	-1.093	-0.034	-0.085
Biofuel production (total)	BP	-0.087***	-7.694	-0.206***	-2.948	-0.102***	-2.986	0.021***	3.094
Agricultural credit (%)	CA	0.068	1.616	0.331**	2.334	0.086*	1.865	0.020*	1.740
CO_2 emission damages	ED	3.089***	4.598	2.144**	2.314	-1.498***	-2.258	1.169***	6.610
Income inequality for Gini indices	IE	-0.021	-0.816	0.141***	2.919	-0.103	-1.279	-0.008	-1.347
Gross production of internal per capita(log)	GDP	-3.927***	-3.390	30.059***	7.539	7.408***	3.229	-0.072	-0.165
Food products indices	PRI	-0.007	-0.911	-0.030**	-2.510	0.027***	2.782	0.000	-0.062
Unemployment (%)	UNI	-0.043	-1.241	-0.448***	-5.014	0.057**	2.539	-0.046***	-5.999
Sargan test statistic	FS(-1)	28.156		19.027		178.444		23.809	
Sargan test probability	POP	0.351		0.796		0.178		0.530	
First-order autocorrelation (P)	AL	-2.405 (0.016)		-9.307 (0.000)		-6.406 (0.000)		-2.417 (0.016)	
Second-order autocorrelation (P)	BP	-0.023 (0.981)		-0.815 (0.415)		-1.309 (0.190)		-0.072 (0.943)	

Note: *, **, *** show significant differences at 90.00%, 95.00% and 99.00%, respectively
Source: Adopted from findings of the current study.

Table 7: Food security model based on four dimensions.

The food security model for developing countries

The results of the food security model in developing countries are displayed in Table 8. The probability of the test for Sargan confirms sufficient variables ($P<0.05$). The results exhibit autocorrelation of the first order. Since the probability is less than 1%, first-order autocorrelation is established. No second-order autocorrelation exists. In other words, it is a GMM estimator that is consistent.

Food security has a positive and significant effect on the food security index with a time lag. In the same way, the coefficient of biofuels is -0.047 based on the t-statistic ($P<0.01$). In this regard, one unit increase in biofuels leads to a decrease of 0.047% in food security. It can be said that increasing the use of biofuels reduces food security. According to the findings, biofuels had positive effects on food security indices. The population growth coefficient was -0.047 and significant ($P<0.01$). Indeed, the increase in population growth as the size of one unit decreased by 0.047% in food security. An increase of 1% in the land area could increase food security by 1.557%. Additionally, the increased 1% credit to the agriculture sector increased food security by 0.081%. Thus, agricultural credits create opportunities for increased output.

Regarding CO_2 emissions, an increase of one unit in CO_2 emission damages increases food security by 1.393%. In addition, population growth (1 unit) reduces food security by 0.047%. The increase in Gini by 1% reduces food security by 0.031%. The increase in the cost of food products had a negative impact on food security. Gross domestic product per capita and unemployment had an insignificant effect on food security in developing countries.

Food security model based on food security dimensions for developing countries

Table 9 shows the results for the food security model based on the food security dimensions. Based on the results, the Sargan probability was greater than 5%. It indicates that the defined variables are confirmed, and no other variables need to be specified. In addition, there was a first-order autocorrelation, while no second-order was observed. Furthermore, serial autocorrelation failed to occur in the research models. In other words, it is a GMM estimator that is consistent. Based on the data in Table 9, lag in food security dimensions has a positive effect on the dependent variables ($P<0.01$). The results also showed that biofuels had significant effects on food accessibility and food availability. However, biofuels

$$FS_{it} = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

Variable	Symbol	Regression coefficient	Standard Error	T-statistic	Probability
Lag of food security	FS(-1)	0.745	0.024	31.668	0.000
Population growth (%)	POP	-0.047	0.016	-2.973	0.003
Land area (log(	AL	1.557	0.464	3.352	0.001
Biofuel production (total)	BP	0.530	0.141	3.746	0.000
Agricultural credit (%)	CA	0.081	0.021	3.775	0.000
CO_2 emission damages	ED	1.393	0.089	15.682	0.000
Income inequality for Gini indices	IE	-0.031	0.009	-3.363	0.001
Gross production of internal per capita (log)	GDP	-0.265	0.560	-0.473	0.637
Food products indices	PRI	-0.007	0.002	-4.562	0.000
Unemployment (%)	UNI	-0.011	0.014	-0.795	0.427
Sargan test statistic	139.142				
Sargan test probability	0.815				
First-order autocorrelation (P)	-5.410 (0.000)				
Second-order autocorrelation (P)	-0.186 (0.853)				

Source: Adopted from findings of the current study.

Table 8: The food security model for developing countries based on total food security indices.

$$FSAVA_{it} \text{ or } FSACC_{it} \text{ or } FSSTA_{it} \text{ or } FSUTI_{it} =$$
$$= \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

		FSAVA		FSACC		FSSTA		FSUTI	
Variable	Symbol	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
Lag of food security	FS(-1)	0.891***	82.040	0.606***	22.806	0.614***	21.889	0.957***	175.767
Population growth (%)	POP	-0.085***	-15.408	-0.076***	-3.109	-0.217***	-3.296	0.037**	2.201
Land area (log)	AL	1.145***	3.567	-0.592	-0.892	1.854	1.054	-0.459	-1.131
Biofuel production (total)	BP	-0.205**	-2.371	-0.900***	-2.732	3.080***	5.325	0.037***	9.155
Agricultural credit (%)	CA	-0.052***	-9.499	0.169***	11.642	0.395***	4.318	-0.016***	-2.649
CO_2 emission damages	ED	0.386***	14.670	-3.929***	-7.612	0.487	1.082	-0.049	-0.228
Income inequality for Gini indices	IE	-0.062***	-14.739	-0.026	-0.684	0.045	1.383	0.003	0.447
Gross production of internal per capita(log)	GDP	-1.618***	-16.120	21.917***	15.090	-4.473*	-1.794	0.358	0.831
Food products indices	PRI	-0.012***	-17.987	0.020***	4.251	0.009	1.312	-0.003***	-4.168
Unemployment (%)	UNI	-0.011***	-5.834	0.049***	2.330	0.111***	3.925	0.086***	9.281
Sargan test statistic	FS(-1)	161.236		144.888		139.750		144.139	
Sargan test probability	POP	0.349		0.689		0.805		0.826	
First-order autocorrelation (P)	AL	-3.223 (0.001)		-7.048 (0.000)		-4.015 (0.000)		-1.985 (0.047)	
Second-order autocorrelation (P)	BP	0.210 (0.834)		-0.442 (0.658)		-0.147 (0.883)		-0.775 (0.438)	

Note: *, **, *** show significant differences at 90.00%, 95.00% and 99.00%, respectively
Source: Adopted from findings of the current study.

Table 9: Food security model based on four dimensions in developing countries.

demonstrated positive and significant effects on stability and utilization.

Population growth has a negative and significant effect on food availability, food accessibility, and food stability in Middle Eastern countries. Also, it has a positive and significant effect on food availability in the Middle East countries. The land area has a positive (1.145) and significant effect on the food availability in the Middle East countries (P<0.01) that could be attributed to the lack of arable land in the Middle East. However, it does not affect other dimensions of food security.

Credit to the agricultural sector has a positive and significantly affects food accessibility and stability in the Middle East countries, and it has a negative and significant effect on food availability and food utilization. It is expected that by increasing the amount of credit in the agricultural sector by 1%, access to food will be increased by 0.16%. The reason for such a difference can be justified by the low efficiency of the use of facilities. In fact, although agricultural credit increases accessibility and sustainability, due to the low efficiency of credit use, in Middle East countries, food availability and utilization decrease.

The increase in agricultural credits increases food availability and stability, while low credit efficiency reduces availability and utilization. Damage caused by CO_2 emissions has a positive impact on food availability (0.386) and a negative impact on food availability in developing countries (-3.929). In addition, it had no significant impact on the other dimensions. The results of the Gini indices indicated that the variable had a negative impact on food availability (-0.062). In fact, income inequality reduces food availability but does not significantly affect the other dimensions. In terms of gross domestic product, the increase in gross production reduces food availability and stability but does not affect food consumption in developing countries. A one-percent increase in the unemployment rate leads to a 0.011% decrease in food access.

The food security model for developed countries

Table 10 shows the results of the food security model in developed countries. Since the Sargan value was 0.457, the variables were sufficient, and no other variables needed to be specified. The results show a first-order autocorrelation. Thus, a first-order autocorrelation is observed since the probability is less than 1%. No second-order autocorrelation exists. This indicates it is a GMM estimator that is consistent.

The results showed that an increase in the production of biofuels decreases food security indices. The coefficient for biofuels was 0.064%, thus, increased biofuels reduce food security. In addition, the utilization of biofuels reduces food security. This rate was higher in developed countries than in developing countries. Increased CO_2 damage by 1% increases food security by 2.244% in developed countries. The population growth coefficient was 0.275%, which is higher than that of developing countries. An increase of one percent in carbon dioxide emission damage increases food security by 2.244 percent, which is a stronger positive relationship in developed countries than in developing countries in the Middle East. The increase in population growth had a 0.275% effect on food security, which is greater in developed countries. Unemployment reduces food security in developed countries by 0.087%. Other variables had no significant effect on food safety.

$$FS_{it} = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

Variable	Symbol	Regression coefficient	Standard Error	T-statistic	Probability
Lag of food security	FS(-1)	0.670	0.030	22.574	0.000
Population growth (%)	POP	-0.275	0.076	-3.642	0.000
Land area (log(	AL	0.240	0.151	1.585	0.114
Biofuel production (total)	BP	-0.064	0.011	-5.719	0.000
Agricultural credit (%)	CA	0.027	0.049	0.541	0.589
CO_2 emission damages	ED	2.244	0.953	2.355	0.019
Income inequality for Gini indices	IE	-0.025	0.038	-0.652	0.515
Gross production of internal per capita (log)	GDP	11.207	2.493	4.495	0.000
Food products indices	PRI	-0.004	0.004	-1.000	0.318
Unemployment (%)	UNI	-0.087	0.044	-1.990	0.047
Sargan test statistic	163.271				
Sargan test probability	0.457				
First-order autocorrelation (P)	-7.338 (0.000)				
Second-order autocorrelation (P)	-1.046 (0.296)				

Source: Adopted from findings of the current study.

Table 10: Food security model based on total food security indices for developed countries.

Food security model based on food security dimensions for developed countries

Table 11 illustrates the results of the food security model based on the dimensions of food security. The Sargan test probability is not significant, which means that the defined variables are confirmed. The first and second-order autocorrelation conditions are also satisfied. Furthermore, no serial autocorrelation was observed in the research models. In other words, it is a consistent estimator of GMM. Based on the data in Table 11, the lag in food security dimensions had positive and significant effects (P<0.01). Biofuels had a negative impact on food accessibility, stability, and availability and a positive impact on food utilization (0.016%). The effects of biofuels on food security were not similar in developing and developed countries. This effect was negative and positive for developed and developing countries, respectively. Population growth negatively affected the availability and accessibility of food in developing countries. Also, credit to the agricultural sector has a positive and significant effect on food stability in developed countries, and it has a negative and significant effect on food utilization. It does not affect food availability and accessibility. Credits had positive and negative effects on food stability and utilization, respectively. CO_2 emission damages had a positive effect on food availability, accessibility, and utilization of food and a negative effect on food stability in developed countries (-3.506) (P<0.01). The Gini index has had a negative impact on the availability and use of food in developed countries. Income inequality led to a decrease in food availability and food utilization. The increase in unemployment had negative effects on food accessibility and stability and positive effects on food utilization.

Discussion

This study examined the impact of biofuels on food security in selected developing and developed countries. Indeed, some agricultural products used by humans can be used to produce biofuels that threaten food security. The increase in biofuel production leads to an increase in the consumption of animal and vegetable oils, cereals, and other agricultural products. These countries mainly produce fossil fuels and do not use agricultural products to produce biofuels. Consequently, it had less impact in developing countries. The results indicated that biofuels had negative effects on food availability. The production of biofuels requires water, workers, and other resources, which impact food availability. The results showed that the coefficients were lower

$$\textbf{\textit{FSAVA}}_{it} \textbf{\textit{ or FSACC}}_{it} \textbf{\textit{ or FSSTA}}_{it} \textbf{\textit{ or FSUTI}}_{it} =$$
$$= \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

		FSAVA		FSACC		FSSTA		FSUTI	
Variable	Symbol	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
Lag of food security	FS(-1)	0.881***	43.130	0.768***	22.430	0.669***	28.508	0.948***	231.603
Population growth (%)	POP	-0.095***	-3.370	-1.406***	-5.671	0.310*	1.738	0.015	1.319
Land area (log)	AL	-0.355***	-3.906	0.824**	2.147	-36.725	-0.937	-0.077**	-2.256
Biofuel production (total)	BP	-0.033**	-2.219	-0.168***	-6.700	-0.061*	-1.838	0.016***	7.519
Agricultural credit (%)	CA	0.003	0.234	0.048	0.931	0.208**	2.424	-0.018***	-3.221
CO_2 emission damages	ED	0.707***	2.940	4.917***	2.999	-3.506***	-3.088	0.706***	5.667
Income inequality for Gini indices	IE	-0.061***	-3.622	0.129	1.649	-0.072	-1.106	-0.010***	-2.821
Gross production of internal per capita(log)	GDP	-0.153	-0.466	20.457***	5.916	-1.631	-1.513	0.550*	1.798
Food products indices	PRI	0.004***	2.125	-0.077***	-5.847	0.058***	5.969	-0.001**	-2.121
Unemployment (%)	UNI	0.003	0.410	-0.502***	-5.791	-0.040**	-2.150	0.098***	12.593
Sargan test statistic	FS(-1)	147.865		146.503		147.337		160.661	
Sargan test probability	POP	0.780		0.803		0.805		0.581	
First-order autocorrelation (P)	AL	-3.407 (0.001)		-9.032 (0.000)		-5.828 (0.000)		-2.217 (0.027)	
Second-order autocorrelation (P)	BP	-0.584 (0.559)		-0.844 (0.399)		-1.381 (0.167)		-1.098 (0.272)	

Note: *, **, *** show significant differences at 90.00%, 95.00% and 99.00%, respectively
Source: Adopted from findings of the current study.

Table 11: Food security model based on four dimensions in developed countries.

in developing countries, which can be attributed to lower biofuel production in developing countries. Our results demonstrated the negative effects of biofuels on food accessibility in developing and developed countries. Biofuels increase the land area for agricultural production, resulting in a lower supply of food products and a lower price. From another perspective, the competition of biofuels with food production will lead to less availability and increased food costs for the poor. In particular, net buyers of food and energy will suffer from parallel increases in food and energy prices. As net buyers of food and energy, the poorest of the poor could be particularly vulnerable. These fuels have also had a negative impact on food stability in all studied countries. Indeed, biofuels reduce land area and, therefore, food stability. The FAO (2018) report states that the production of biofuels can have negative effects on food security, which can further endanger situations of poverty and hunger. The impact of biofuels on food security has been evidenced by previous studies (Koizumi, 2015). Biofuel production negatively impacts food security and can provide opportunities for agricultural development (Koizumi, 2015). The concept of utilization refers to the human ability to obtain food and nutrients. It includes other concepts such as water supply, energy, health, and medical services. Biofuels have also been reported to have negligible effects on price due to low price effects (Westhoff, 2010). The increase in biofuel production leads to an increase in the consumption of animal and vegetable oils, cereals, and other agricultural products. The use of agricultural products to produce oils jeopardizes food security. Biofuels have an impact on food availability, it should be said that biofuel production prevents food accessibility because it is one of the factors affecting the price of food goods. There is a correlation between the development of biofuels and the increase in commodity prices, exacerbating food insecurity in developing countries. A study has suggested that palm oil prices increase when Malaysian and/or Indonesian produce biodiesels from palm oil (Ghosh et. al., 2019). In this regard, increasing biofuel production also reduces the stability of food intake. The results showed lower production of biofuels in Middle Eastern countries. These countries mainly have abundant sources of fossil fuels and do not use agricultural products to produce biofuels. It must be stated that biofuels are not important in Middle-East countries due to the abundant oil and gas resources. On the other hand, the production of biofuels in middle-east countries is very low and therefore cannot have tangible effects on food security.

The estimation results of the model show that the variable of food security lag in the long term has a positive and significant effect on the characteristics of food security in developing and developed countries. It means that changes in the level of food security do not end in just one period; rather, the increase of this index can affect the improvement of food security in the following periods. Population growth reduces food security and the need for food. A shortage of food materials causes an increase in the population of food materials. The results are similar to those reported in the literature (Masters et al. , 2013; Tian et al., 2016; Subramaniam et al., 2020). Population growth leads to an increase in the consumption of water and land. The findings are consistent with previous studies that showed the importance of the global food supply and the production of ruminant milk and meat. Molotoks et al. (2021) indicated that countries with projected declines in population growth had higher food security, while countries with projected rapid population growth had the worst impact on food security by 2050. Moreover, climate change scenarios affected future crop yields, population growth is the main driver of change in malnutrition prevalence for more than 159 countries. Hall et al. (2017) showed that rapid population growth will be the main cause of widespread food insecurity and malnutrition across Africa. So that its effect is greater than the effects of climate change on reducing food safety.

Agriculture credits had significant and positive effects on food availability, while they had negative effects on food use attributable to the low efficiency of the credits. Agriculture credits increase accessibility and stability, but poor credit efficiency reduces availability and utilization. Credits for the agricultural sector offer opportunities for more produce. In this direction, a positive and significant effect of access to credit on food security among maize farmers in Nigeria was confirmed (Ogunniyi et al., 2021). In this study, it was found that if the government allocates a suitable budget, there is a possibility of improving food safety and security at the household level.

In terms of CO_2 emissions, a one-unit increase in CO_2 emissions damage increases food safety in developing countries by 1.393%. Meanwhile, Hardy et al. (2003) showed that the doubling of carbon dioxide leads to a 10-50% loss of agricultural land and a decrease in the global yield of key food crops between 10-70%. In such a way that with the reduction of agricultural lands and with the prediction of the increase of human migration, more challenges and risks will occur in connection with the successful cultivation of crops and breeding of domestic animals. As a result, these conditions will be a threat to food security.

The negative relationship between the Gini index and food security in developing countries can also be followed. The results of some studies have also shown that income inequality exacerbates food insecurity with the continuation of poverty and the expansion of inequalities in terms of affordability to receive food (Subramaniam, et. al., 2019).

Another finding is the negative relationship between unemployment and food safety in developing countries. Etana and Tolossa (2017) concluded that the prevalence of food insecurity is higher among households headed by unemployed people and that these households are unable to cope with the increase in food prices in Ethiopia. However, the relationship between unemployment and food safety in developed countries has not been statistically significant. Certainly, this effect is negative and significant in relation to food accessibility, food utilization, and food stability indicators and consistent with the theory.

Conclusion

The effects of biofuels on food security have been considerable in developed and developing countries. The utilization of biofuels is low in developing countries compared to developed countries, which could be attributed to fossil sources in each country. Based on the results, it can be hypothesized that Middle Eastern countries can use third and fourth-generation biofuels to improve environmental issues and increase food security. In these countries, the energy requirement is low due to low oil wells. In conclusion, biofuels have a negative effect on food security, but this effect is positive and significant on food security in the Middle East countries. Consequently, the use of biofuels to reduce greenhouse gas emissions is recommended due to a lack of conflicts present in this region. Considering the fact that in developing countries, a large share of the income of the poor is allocated to food consumption. Therefore, the increase in food prices due to the expansion of biofuels will increase the vulnerability of these people. Meanwhile, with the opening of trade, it is possible to earn money from the higher prices of goods, which can lead to the possibility of direct sales to factories by small owners. In such a situation, it is expected that a favorable environment for increasing employment in farms and factories will be provided. Moreover, it is recommended to increase the existing technology of biofuel production, and weigh the benefits of producing these products against its possible bad consequences. Furthermore, increasing employment opportunities along with supporting policies for poor households can improve the economic status of households while increasing the development of human capital and ultimately lead to guaranteeing food security. However, our study is also faced with limitations. In this study, we did not consider the price of oil as a factor affecting food security, and our reason was that the Middle East countries mostly have a lot of oil and this cannot be effective for them. Using oil prices for developed countries compared to developing countries will complicate the results. We also estimated the results regardless of the fact that some countries in the Middle East use limited biofuels, and we did not distinguish between countries, which is a limitation, and our suggestion is to pay attention to this issue in future studies.

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Corresponding author:
Reza Rostamian
Department of Agriculture Economic, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Mazandaran Province, Qolzam Kola, Jadenezami Rd, CR9J+WPV, Iran
E-mail: rezarostamian74@gmail.com

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The Impact of Livelihood Diversification As a Climate Change Adaptation Strategy on the Food Security Status of Pastoral Households in Southeastern and Southern Ethiopia

Baro Beyene[1,4], Mesfin Tilahun[2,3], Mebratu Alemu[4]

[1] Department of Economics, Oromia State University, Batu, Ethiopia

[2] School of Economics and Business, Norwegian University of Life Sciences, Ås, Norway

[3] Department Economics, Mekelle University, Ethiopia

[4] Department Economics, Arba Minch University, Ethiopia

Abstract

The objective of this study was to investigate the determinants of food security and quantify the impact of livelihood diversification as an adaptation strategy on the level of food security of pastoral households in Arero district in Borena zone and Rayitu district in Bale zone in Ethiopia. A multistage sampling technique was used, selecting 396 households from Arero and Rayitu districts. The study used a multidimensional food security index to measure the food security status of pastoralist households. The descriptive result showed that 60.6 percent, 20.2 percent, and 19.2 percent of the pastoralist households had medium, high and low food security, respectively. The result of ordered logistic regression showed that the age of household head, herd size (TLU) and frequency of extension contacts significantly increased the food security status of pastoralist households. However, male household head, age of household head, household size (adult equivalent) and distance to market significantly decrease the food security status of pastoral households in Arero district. On the other hand, the result of the multinomial endogenous switching regression model showed that the uptake of non-farm activities as well as crop production and non-farm activities together have a positive and significant impact on the level of food security of the pastoralist households. Therefore, the results of the study suggest that working on participatory strategies to promote livelihood diversification among pastoralist communities is very important to improve the food security of pastoralist households.

Keywords

Food security, determinants of food security, livelihood diversification, impact, Ethiopia.

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Introduction

For several decades, climate change has become one of the greatest challenges facing our planet. Climate change, which is one of the negative consequences of global warming, has become visible in the world since the Industrial Revolution. For example, by 2017, the global average temperature had increased by 1.1 degrees Celsius compared to the pre-industrial era (WMO, 2018). According to Guilyardi et al. (2018), the increase in global temperature is likely to reach 1.5 degrees Celsius between 2030 and 2052 if greenhouse gas emissions continue at the current rate.

Impacts from climate change are indiscriminately felt over the entire world. Nonetheless, dry and semi-arid rangelands, which make about 30% of the world's geographical area, have recently been badly impacted by climate change (Galvin et al., 2001; Herrero et al., 2016; Malagnoux, 2007). One effect of climate change in these regions is making the pastoral people there more susceptible to food insecurity and chronic poverty. According to FAO (2018), recurrent and overlapping climatic shocks increase the susceptibility of pastoralist communities to food insecurity, famine, and high rates of acute malnutrition in the drylands of Africa.

Short-term effects of climate change on pastoral households include more frequent and more intense extreme weather events, while long-term effects include changes in temperature and precipitation patterns. The pastoralist community's way of life is impacted by the pressure on pastoral resources, especially grazing pastures, brought on by the rising temperature, diminishing rainfall, longer and more frequent droughts, and issues with livestock feed (Hesse and Cotula, 2006). Also, it impacts the four aspects of food security in the communities of pastoralists, including food availability, food accessibility, food usage, and food stability (FAO, 2008).

Food insecurity, both chronic and seasonal, has long existed in Ethiopia. The incidence of recurring droughts and flooding is the primary cause of the latter form of food security. Areas of the nation that get frequent and insufficient rainfall are sometimes referred to be drought-prone areas. In the country's lowland pastoral and agro-pastoral zones and moist deficient highlands, the occurrence of food insecurity is especially severe (Siraje and Bekele, 2013). As a result, the country's food insecurity situation is getting worse due to climate change, which is manifesting itself in increasingly regular droughts and flooding.

A total of 268 million pastoralists and agro-pastoralists rely on the African rangelands, which stretch from the Sahelian West to the rangelands of Eastern Africa, the Horn, and the nomadic communities of Southern Africa, to feed 55 percent of the continent's livestock (FAO, 2018; World Bank Group, 2019). The effect of climate change on cattle in Africa is a generally unstudied topic, despite being the primary source of income for these underprivileged inhabitants. The interplay of the climate, which is becoming more variable, with other factors that are changing livestock systems and broader development patterns are poorly understood (Thornton et al., 2009).

Political instability (internal and external conflicts), socioeconomic conditions, corruption, military involvement in politics, religious tensions, ethnic tensions, and subpar bureaucracy are a few of the factors that worsen food security in developing nations, including Ethiopia (Abdulah et al., 2020). Moreover, several studies have shown that the food security problem in Ethiopia is due to natural and man-made factors. These include persistent droughts and irregular rainfall patterns, degraded ecosystems and land (resulting in low food production and productivity), rapidly increasing populations, inadequate rural infrastructure, and the effects of previous policy restraints (Asenso-Okyere et al., 2013; Melak and Kopainsky, 2014). Other factors that affect food security in Ethiopia include the dependence ratio, the amount of livestock owned, off-farm income, the level of education, remittances, food aid received, and credit (Hamud, 2018; Siraje and Bekele, 2013). These factors are influencing the level of food security in rural households by making it difficult to get hold of nutritiously adequate and safe food and limiting their ability to do so in socially acceptable ways.

Hence, in order to combat the negative consequences of climate change that threaten their food security and sustainable livelihoods, pastoral communities must use a variety of adaptation techniques. One of the techniques that vulnerable individuals can adopt to safeguard their current livelihood systems, diversify their sources of income, and alter their livelihood strategies is to build their resilience. Moreover, adoption of environmental and climate technologies such as renewable energies (wind energy, solar power and hydropower), conservation and storage technologies by pastoralist households plays an important role in reducing the occurrence of extreme climate events and their impacts. In accordance with Berhanu and Beyene (2014), pastoralist adaptation response strategies typically involve modifications to pastoral practices and a shift to non-pastoral livelihoods.

Several empirical studies have been carried out to examine the determinants of food security at the rural household level in Ethiopia. For example, Getaneh et al. (2022) analyzed the determinants of food security among agro-pastoral households in the northeastern Rift Valley of Ethiopia using a caloric intake approach and a logit regression model. Also, a study utilizing an identical mythology was carried out in the Abay Chomen District of Ethiopia's Oromia Regional State (Gebissa and Geremew, 2022). Additionally, solely the food availability dimension of food security was utilized to determine drivers of food security status in selected agro-pastoral communities of the Somali and Oromia Regions, Ethiopia, in a study conducted by Asenso-Okyere et al. (2013). Nevertheless, none of the research examined the level of food security in rural households using a multidimensional food security methodology.

On the other hand, some empirical studies have been done on the impact of livelihood diversification on the level of food security in Ethiopian rural households. For instance, Titay et al. (2017) used propensity score matching to examine the impact of livelihood diversification on food security in in Fedis district in Eastern Hararge Zone, Ethiopia. According to the study's findings, rural households that participated in livelihood diversification had an increase in their calorie intake. Similar findings were reached by a study on the effect of livelihood diversification on rural household food security in Goncha-Siso Enesie district of Amhara region in Ethiopia, which used the same method of measurements (Esubalew and Daniel, 2020). Nevertheless, none of the research employed a multidimensional food security approach and a multinomial switching regression model to evaluate the effect of livelihood diversification on the food security status of rural households. Instead, they all focused on utilizing a traditional method of measuring food security, the calorie intake approach. The study's objectives were to: (1) determine the multidimensional food security status; (2) identify the factors influencing the food security status of pastoral households; and (3) quantify the impact of pastoralist livelihood diversification on the food security status of pastoralist households using the multinomial switching regression model.

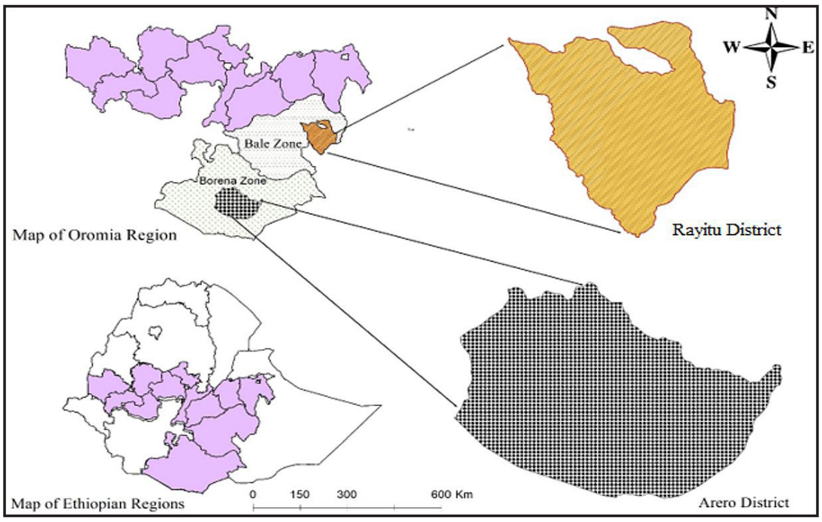
Materials and methods

Descriptions of the study areas

The study was conducted in Arero district of Borena zone in southern Ethiopia and Rayitu district of Bale zone in southeastern Ethiopia. Geographically, the Bale Zone is situated between 5.36ºN-8.12ºN and 39.21ºE-42.23ºE (Bekele et al., 2017). It is bordered by the Somali National Regional State of Ethiopia to the east, East Hararge Zone to the northeast, West Hararge and Arsi Zone to the north, West Arsi Zone to the west, and Guji Zone to the southwest (Figure 1). The eastern part of the zone is characterized by semi-desert climate and inhabited by pastoralist communities. Of the total 20 districts in the zone, seven districts, including Rayitu, Sewena, Gasara, Golgolcha, Ginnir, Goro, and Guradamole, are inhabited by pastoralist and agro-pastoralist communities.

Geographically, the Borena zone is situated in the southern region of the nation between latitudes 4º to 6º N and longitudes 36º to 42º E (Teshome et al., 2022). The Somali region borders it to the southeast, the West Guji zone to the north, the Southern Nation, Nationalities, and People (SNNP) to the west, and Kenya to the south (Figure 1). The zone is divided into 10 districts, among which Yabelo, Arero, Moyale, Dire, Telltale, Dugida Daw, and Miyu districts are all pastoral and agropastoral (Central Statistical Agency, 2013). The zone is mainly characterized by a semi-arid climate with bimodal, two rainy seasons, with average annual rainfall ranging from 350 mm to 1100 mm and an average annual temperature of 19°C (Debela et al., 2019; Desalegn et al., 2018; Worku et al., 2022).

One of the districts in the eastern part of the Bale zone is the Rayitu district. Ginnir, Somali Regional State, and Sewena all have borders with the district to the east, north, and south, respectively. Three perennial rivers, the Wabi Shebele, Weyib,



Source: Authors' drawing (2023)

Figure 1. Location of the study areas.

and Dinikte, also round the area. This district is one of the Bale zone's pastoralist community-dominated districts. With a bimodal rainfall pattern and erratic distribution, it is prone to drought. The long rainy season lasts from March to June, while the short-wet season lasts from September to October. The district is characterized by dry, hot weather, with an average annual temperature of 26 °C and lies within an altitude ranging between 500 and 1,785 meters above sea level (Getachew et al., 2014)

Arero district is one of the districts dominated by pastoralists and agricultural communities in the Borena zone. districts in the Borena zone that is dominated by pastoral and agro-pastoral communities is Arero. Arero district is situated physically at 4º45’0’N and 38º49’0’E (Giro and Jilo, 2020). It shares borders with the Somali region in the east, the Guji zone in the northeast, the Bule Hora district in the north, the Yabelo district in the west, the Dire district in the southwest, and the western districts of Moyale and Borbor (Figure 1). The only river in the area connecting Arero to Odo Shakiso and Liben, two Guji zone districts, is the Dawa River. The region is located between 750 and 1700 meters above sea level and experiences 91 millimeters of annual rainfall on average. The minimum and maximum average temperatures are 16.80 °C and 29.08 °C, respectively (Ejo et al., 2020). With Belg or Gana, the district experiences two distinct rainy seasons: a lengthy one from March to May and a brief one from September to November.

Data and methods of data analysis

A multistage sampling method was used for the study after selecting two zones, one from the southeastern and one from the southern part of Ethiopia, using a purposive sampling technique. The Bale zone was selected in the southeast and the Borena zone in the south. Each zone has seven pastoral and agropastoral districts. Rayitu, Sewena, Gasara, Golgolcha, Ginnir, Goro, and Guradamole districts are among those in the Bale zone that are predominantly pastoral and agro-pastoral. The districts of Yabelo, Arero, Moyale, Dire, Telltale, Dugida Daw, and Miyu are also pastoral agro-pastoral areas in the Borena zone. In the first phase, two districts where pastoralism dominates were deliberately selected: Rayitu in Bale Zone and Arero in Borena Zone. There are 18 and 19 kebeles in Arero and Rayitu districts, respectively. In the second phase, eight kebeles, four from each district, were selected randomly: Alona, Haro Dimitu, Fuldewa, Silala, Adela, Arda Kalo, Dedecha Farda, and Gurura. In the third phase, households were classified into different strata based on the classification of their local wealth status in the study areas. Finally, a simple random sampling method was used to select 396 pastoralist households using the Kothari (2004) formula to determine the sample size.

To achieve the objective, quantitative data were collected in addition to qualitative information. Quantitative data were collected on all livelihood capital indicators, including natural, physical, financial, human, and social capital (Table 1). Data from both primary and secondary sources were used for the study. Various data collection tools were used to collect primary data, including structured questionnaires, key informant interviews (KIIs), and observations. In addition, the Satellite Grided Meteorological Data were taken from AidData at William and Mary university website processed by (Goodman et al., 2019)

The impact of livelihood diversification on food security

Measurement of food security

Measuring food security is not a simple task, as there is no single method to measure it. Depending on the unique analysis setting, various methods have been employed to quantify food security at the household level. For example, anthropometric measurements of nutritional outcome markers of food insecurity such as underweight (low weight-for-age) and stunting (low height-for-age) reveal the effects of ongoing food poverty (WFP and CSA, 2019). This method of assessing food security has its limitations, as underweight and overweight are only proxy indicators of household food security and are not comprehensive (Haysom and Tawodzera, 2018). Additionally, a number of researchers have employed individual dietary intake and household income and spending questionnaires (Smith and Subandoro, 2007) to assess household food security

However, all of the above methods for measuring food security do not simultaneously consider the four dimensions of food security. Recently, a few (Sam et al., 2018; Wineman, 2014) have used a multidimensional food security index to assess food security status at the household level. The multidimensional food insecurity index, the other side of food security, was used by (Napoli et al., 2011) to measure and compare the severity of food insecurity in different countries around the world, particularly in developing countries. Therefore, a multidimensional food security index was used in this study to measure the level of food security of pastoralist households.

To construct a multidimensional index of food security, principal component analysis (PCA) was used to reduce the number of variables to be included in the model (Kim and Kim, 2012). In PCA, the weights for each indicator in the index are objectively derived from the data. Fourteen potential indicators are proposed to construct the index, and they are categorized under the four dimensions of food security (Table 1). Generally accepted criteria were used to select an appropriate number of these factors, based on a trade-off between having as few factors as possible (simplicity) and explaining most of the variation in the data or accounting for most of the information in the input variables (completeness). These include Kaiser's rule, which recommends that eigenvalues greater than one that cumulatively contribute to the total variance should be 70 percent (Dunn, 2008; Jolliffe and Cadima, 2016; Kaiser, 1960).

The first principal component captures the largest variation, and since data reduction is the main goal of this exercise, only the first component was used. This was converted into factor values that serve as weights for creating an index.

Following (Wineman, 2014) food security index is given by

$$FSI_j = W_i \sum\left(\frac{X_{ji}-X_i}{S_i}\right) \quad (1)$$

where FSI_j is the Food Security Index, W_i is the weight for the ith variable (the squared factor scores of i), X_{ji} is the jth household's value for the ith variable, X_i and S_i are the mean and standard deviations of the ith variable for overall households.

Then, the index will be standardized to a scale of 0-1 removing the mixture of positive and negative values (Sam et al., 2018) as follows:

$$FSIA_j = \frac{FSI_j - FSI_{min}}{FSI_{max} - FSI_{min}} \quad (2)$$

where $FSIA_j$ is adjusted FSI for jth household; FSI_j is unadjusted FSI for jth household; FSI_{min} minimum value of FSI in the sample and FSI_{max} is maximum value of FSI in the sample.

Finally, following (Sam et al., 2018) FSI was grouped into four categories, namely low food security ($0 \leq FSIA_j \leq 0.25$), medium food security ($0.25 < FSIA_j \leq 0.50$), high food security ($0.50 < FSIA_j \leq 100$).

Specification of ordered logit model

In this study, an ordered logit regression model was used to identify the determinants of food security status at the household level. Based on the FSI, the level of food security is classified into three categories, namely low food security, medium food security, and high food security. Thus, the measurement of food security based on this

Food security dimension	Indicator	Measurement
Food availability	Crop land	hectares per capita
	Food supply	All food crops in quintal per year produced and purchased
	Food aid	in quintal per year
Food access	Yearly household food expenditure	(ETB)
	Tropical Livestock Units (TLU)	Number of TLU
	Access to mkt	Distance in walking hrs. (inverse)
Food utilization	Distance to public health center	Distance in walking hrs. (inverse)
	Access to safe water	Liters of water per individual per day
	Dietary intake	(kcal/capita/day)
	Dietary diversity	HDDS (Household Dietary Diversity Score)
Food Stability	Livestock diversification	Livestock diversification index
	Livestock loss	Cost of livestock lost in the past one-year (inverse)
	Crop failure	Cost of crop failure in the past one year, (inverse)
	Stable food supplies	Number of months without any food shortage

Source: Authors' organization (2023)

Table 1: Dimensions of food security, indicators and measurement.

measurement index involves an ordered result.

Following (Greene, 2012), the model is specified as:

$$y_i^* = x'\beta + \varepsilon_i \quad (3)$$

Where y_i^* = the unobserved latent variable (FDI) measures food security status with four levels in increasing food security level, coded as 1 = low food security, 2 = medium food security and 3 = high food security and 4 = higher food security. x is the vector of independent variables and β is the vector of regression coefficients which are to be estimated.

The observed response categories are tied to the latent variable by the measurement model (Wooldridge, 2002).

$$y_i = \begin{cases} 1 \; if \; y_i^* \le \alpha_1 \\ 2 \; if \alpha_1 < y_i^* \le \alpha_2 \\ 3 \; if \; \alpha_2 < y_i^* \end{cases} \quad (4)$$

Where: μ_i's represents the thresholds or cut-points to be estimated/predicted along with the parameter vector β. For the estimated cut-off points, α follows the order $\alpha_1 < \alpha_2 < \alpha_3$

Following (Johnston and Dinardo, 1997; Wooldridge, 2002), the cumulative logistic model for ordinal response data is given by:

$$\left.\begin{aligned} Prob\{y = 1|x\} &= \Lambda(\alpha_1 \text{-} x\beta) \\ Prob\{y = 2|x\} &= \Lambda(\alpha_2 \text{-} x\beta) \text{-} \Lambda(\alpha_1 \text{-} x\beta) \\ Prob\{y = 3|x\} &= 1 - \Lambda(\alpha_2 \text{-} x\beta) \end{aligned}\right\} \quad (5)$$

Where Λ (.) is the cumulative logistic distribution function.

The parameters of the model specified in equation (4) are estimated using the maximum likelihood method. However, there is lack of clarity in interpreting the coefficients of the model. This necessitates for the partial change or marginal effect, which can reveal the effects of independent variables on the probability of four different levels of food security individually. For the four probabilities, the partial effects of changes in the regressors are:

$$\frac{\partial(y = 1|x)}{\partial x} = \Lambda(\alpha_1 \text{-} x'\beta)\beta$$

$$\frac{\partial(y = 2|x)}{\partial x} = [\Lambda(\alpha_2 \text{-} x'\beta) \text{-} (\alpha_1 \text{-} x'\beta)]\beta \quad (6)$$

$$\frac{\partial(y = 3|x)}{\partial x} = \text{-}\Lambda(\alpha_2 \text{-} x'\beta)\beta$$

Then, following (Wooldridge, 2002) the parameters α and β can be estimated by maximum likelihood as follows.

$$li(\alpha, \beta) = 1[y_i = 1]log[\Lambda(\alpha_1 \text{-} x_i\beta)] + $$
$$+ 1[y_i = 2]log[\Lambda(\alpha_2 \text{-} x_i\beta) \text{-} \Lambda(\alpha_1 \text{-} x_i\beta)] +$$
$$+ 1[y_i = 3]log[1 \text{-} \Lambda(\alpha_2 \text{-} x_i\beta)] \quad (7)$$

The brant test was used to identify whether any variable violates the parallel-lines/ the proportional odds assumption, as well as tests of the assumption for each variable separately.

Specification of multinomial endogenous switching model

The study used a multinomial switching regression model to assess the impact of livelihood diversification on food security status. The choice of livelihood diversification is assumed to be a choice by the individual pastoralist between adopting or not adopting livelihood diversification to maximize his expected utility. Livelihood diversification includes crop production and non-farm activities in addition to livestock production.

Following (Oparinde, 2021) and assuming that D_{ij}^* is the latent variable that measures the expected benefit from adoption of livelihood diversification. The latent variable model which describes the behavior of pastoral households in choosing one alternative among the different alternatives to maximize its expected benefit is given by;

$$D_{ij}^* = \beta_i C_i + E_{ij} \quad (8)$$

where D_{ij}^* is a latent variable that measures the expected benefit of the i[th] household by choosing among j[th] alternative, i =1,2,3…N, j = 0,1,2,… M, X_i is a vector of covariates, β_i is a vector of parameters to be estimated and U_{ij} is an error term. In multinomial endogenous switching model, a household has j choices and the latent outcome variable is given by;

$$F_{ij} = \begin{cases} 1 \; iff \; D_{i1}^* > \max\limits_{k \ne 1}(D_{i1}^*), & \varepsilon_{i1} < 0 \\ \vdots & \vdots \\ M \; iff \; D_{iM}^* > \max\limits_{k \ne M}(D_{i1}^*), & \varepsilon_{iM} < 0 \end{cases} \quad (9)$$

where F_{ij} is the observed value of the outcome variable for the i[th] households of choosing alternative j, U_{i1}, U_{i2} … U_{iM} are error terms of the outcome equations, i = 1,2,3…N, j = 0,1,2…M and F_{i1}^* is the latent variable.

The pastoral household without livelihood diversification adoption, $j = 0$ is the base category in this study. Hence, the food security status of the households is defined as m regime:

Regime 0: $F_{i0} = X_i \gamma_0 + V_{i0}$, if $A_j = 0$ (10)

Regime 1: $F_{i1} = X_i \gamma_1 + V_{i1}$, if $A_j = 1$ (11)

Regime 2: $F_{i2} = X_i \gamma_2 + V_{i2}$, if $A_j = 2$ (12)

where F_{ij} is the food security status, X_i is the vector other covariates, V_{ij} is the unobserved factor. Based on equations (10), (11), and (12), the following selection bias-corrected outcome equations are given.

Regime 0:

$$F_{i0} = X_i\beta_0 + \delta_0\left[\rho_0 m(P_{i0}) + \sum_j \rho_j\, m(P_{ij})\left(\frac{P_{ij}}{P_{ij}-1}\right)\right] + V_{i0,} \quad \text{if } A_j = 0 \quad (13)$$

Regime 1:

$$F_{i1} = X_i\beta_1 + \delta_1\left[\rho_1 m(P_{i1}) + \sum_j \rho_j\, m(P_{ij})\left(\frac{P_{ij}}{P_{ij}-1}\right)\right] + V_{i1,} \quad \text{if } A_j = 1 \quad (14)$$

Regime 2:

$$F_{i2} = X_i\beta_2 + \delta_2\left[\rho_2 m(P_{i2}) + \sum_j \rho_j\, m(P_{ij})\left(\frac{P_{ij}}{P_{ij}-1}\right)\right] + V_{i2,} \quad \text{if } A_j = 2 \quad (15)$$

where P_{ij} is the probability that the i[th] rural household chooses the j[th] alternative, ρ_j is the degree of correlation between the error term of adoption equation, U_{ij} and the error term of the outcome equation, V_{ij} and $m(P_{ij})$ is the inverse transformation for the normal distribution function. The multinomial endogenous switching regression model is used to create selection corrected prediction of the counterfactual data of the food security status. Assuming household without livelihood diversification adoption, $j = 0$ as the base category, the food security status for households is given by:

$$E(F_{i1}/A_i = 1) = X_i\beta_1 + \delta_1\left[\rho_1 m(P_{i1}) + \sum_{k=1}^{M} \rho_k m(P_{ik})\left(\frac{P_{ik}}{P_{ik}-1}\right)\right] \quad (16)$$

$$E(F_{i2}/A_i = 2) = X_i\beta_2 + \delta_2\left[\rho_2 m(P_{i2}) + \sum_{k=1}^{M} \rho_k m(P_{ik})\left(\frac{P_{ik}}{P_{ik}-1}\right)\right] \quad (17)$$

In addition to this, once the actual mean values of the food security status for pastoral households are determined using the above two equations, the mean food security index for households from the counterfactual data is given by:

$$(F_{i0}/A_i = 1) = X_i\beta_0 + \delta_0\left[\rho_0 m(P_{i1}) + \rho_1 m(P_{i0})\left(\frac{P_{i1}}{P_{i1}-1}\right) + \rho_1 m(P_{i1})\left(\frac{P_{i3}}{P_{i3}-1}\right)\right] \quad (18)$$

$$(F_{i0}/A_i = 2) = X_i\beta_0 + \delta_0\left[\rho_0 m(P_{i2}) + \rho_2 m(P_{i1})\left(\frac{P_{i1}}{P_{i1}-1}\right) + \rho_1 m(P_{i0})\left(\frac{P_{i3}}{P_{i3}-1}\right)\right] \quad (19)$$

Lastly, the conditional average treatment effect on treated (ATT) could be computed by subtracting equations (16) and (17) from equations (18) and (19) respectively.

Definition of variables

Definition of dependent variables

Food insecurity: Food security was measured using a multidimensional food security index. Based on the multidimensional food security index, the food security status of pastoral households was classified as low, medium, and high. The same variable, the multidimensional food security index, was used to measure the impact of livelihood diversification options on the food security status of pastoralist households using a multinomial switching regression model.

Definitions of independent variables

Gender of household head (gender): The head of household is a person, male or female, who manages the household and usually supports the household economically. The gender of the household head is a dummy variable that takes the value of 1 if the household head is male and 0 otherwise. Studies have shown that male-headed households have higher food security than female-headed households (Kebede, 2019; Enete et al., 2014). Thus, in this study, male-headed households were expected to have a positive correlation with the food security status of pastoralist households.

Age of household head: Age is a continuous explanatory variable and is measured in years. Studies show that there is a positive relationship between household age and rural household food security (Jemal and Kim, 2014; Sani and Kemaw, 2019) so in this study, household age was expected to positively influence the food security status of pastoralist households.

Household size: Household size refers to the total number of household members and is expressed in adult equivalents. Studies have shown that household size is negatively correlated with household food security status (Mbolanyi et al., 2017). In this study, family size was expected to negatively affect the level of household food security

Educational level of household head: The educational level of the household head is a continuous variable indicating the number of years of schooling of the household head. Evidence shows that educated household heads are less poor (Abdela et al., 2021). For this reason, in this study, the educational level of the household head was expected to have a positive correlation with household poverty depth.

Livestock holding/ herd size (TLU): Herd size is a continuous variable indicating the number of livestock owned by the household, measured in tropical livestock units (TLU). Each livestock species in a household was converted to the corresponding livestock unit using the suggested conversion factors (FAO, 2004). Herd size has been shown to influence household food security status (Asenso-Okyere et al., 2013). Therefore, household herd size was assumed to have a positive correlation with food security.

Access to extension services: It is a continuous variable that takes into account the average number of visits of extension agents to a household per year. (Bogale and Shimelis, 2017) showed that access to extension services and their increased frequency helped to improve food security in rural households. To this end, it was hypothesized that the frequency of extension contacts positively influences the food security of pastoral households.

Access to credit: It is a dummy variable that takes the value of 1 if the household has taken a loan and 0 otherwise. This variable can allow households to obtain alternative and additional food, thus contributing to their food security. Food security status increases with access to credit (Bogale and Shimelis, 2009; Million et al., 2019). Therefore, it was reasonable to expect a positive relationship between access to credit and food security among pastoralist households.

Distance to nearest market: It is a continuous variable measured in waking hours and refers to the distance and accessibility of markets for livestock, livestock products, and petty trade in the nearest area. Mota et al. (2019) indicated that access to the nearest market and food security status of rural households are positively correlated. Therefore, it was hypothesized that distance to the nearest market negatively affects the food security of pastoralist households.

Distance access to veterinary service: Access to veterinary service is a dummy variable that takes 1 if the households have access to veterinary service, and 0 otherwise. Studies showed a positive correlation between the availability of veterinary services and the state of food security (Aragie and Genanu, 2017; Hussein and Janekarnkij, 2013). Thus, it was hypothesized that access to veterinary service to be positively related to food security of the pastoral households.

Access to food aid: Food aid is the giving of food or money in exchange for food to needy households to address their urgent food insufficiency issue. The dummy variable "Access to Food Aid" has a value of 1 if the household is receiving food assistance and a value of 0 otherwise. According to studies, food aid and the level of food security in rural farm households are positively correlated (Agidew and Singh, 2018; Abdulah et al., 2019). Therefore, the study proposed that there was a positive correlation between food aid and the level of food security in pastoral households

Non-farm income: A continuous variable, non-farm income, tracks the cash income that pastoral household members obtain. According to studies, receiving non-farm income in addition to farm revenue raises the level of food security in rural (Mbolanyi et al., 2017; Sani and Kemaw, 2019). Therefore, it was anticipated that non-farm income would have a positive impact on the pastoral households' level of food security in this study.

The value of productive assets: The value of productive assets is a continuous variable that measures the value of productive assets the household possessed. Studies showed that productive assets possessed by rural households and food security had a positive relationship (Mofya-Mukuka et al., 2017; Mutea et al., 2019; Nepal and Neupane, 2022). Therefore, the value of productive assets was expected to influence the food security status of pastoral households positively.

Climatic shocks (Livestock Shock): In this study, the term "climatic shock" refers to cattle shocks brought on by persistent droughts in the study locations. The dummy variable has two possible values: 1 if the household is at risk from the climatic shock and 0 otherwise. The study proposed that climatic shocks and the food security status of pastoral households have a negative relationship.

Result and discussions

Socio-demographic profile of households

Age of household head, educational level of household head, household size (adult equivalent), livestock size (TLU), frequency of extension contacts, and value of productive assets make up the sociodemographic profile of the sample homes (ETB). Table 2 presents the mean comparison of the profile for male and female household heads using a t-test. The average age of women who head households is much greater than that of men. On the other hand, at a 1% significance level, the mean education level attained by the male household head was higher than that of the female household head. However, male-headed households had mean adult equivalents and mean Tropical Livestock Units (TLU) that were higher than those of female-headed households at a 1 percent significance level. The mean frequency of contact with extension agents was significantly higher for the former than for the latter.

Satellite mereological data obtained from William and Mary University's AidData website and processed by Goodman et al. (2019) show that areal temperatures and precipitation have increased in the Arero district of the Borena zone and the Rayitu district of the Bale zone. The average minimum, maximum, and mean annual temperatures in Arero district were 18.79, 23.89, and 21.66°C, respectively (Table 3). And 59.06 mm of rainfall per year on average was recorded in the district. The average minimum, maximum and mean annual temperatures of Rayitu district were 19.89°C, 26.08°C and 24.15 °C, respectively.

The trends of these climate variables were tested using the Mann-Markell test, the Sen's slope test, and the innovative Sen trend analysis (Kendall, 1970; Sen, 1968; Şen, 2012), and similar results were found. The Sen's slope test showed that the minimum, maximum, and average temperatures of Arero district increased by 0.029°C, 0.027°C, and 028°C per year at 1%, 5%, and 1% significance levels, respectively (Table 3). The Sen slope test also showed that the average annual rainfall (mm) in the same district increased by 0.666 per year at a 1% significance level. Similarly, the Sen's slope test showed that the minimum, maximum, and average temperatures of Rayitu district increased by 0.024°C and 0.024°C and 023°C per year, respectively, at a 1% significance level. Sen's slope also showed that the same district's average annual rainfall (mm) was rising by 0.331 mm annually at a 5 percent significant level. Therefore, the temperatures and rainfall of the study areas have been increasing from year to year

As far as the climate variability is concerned, the standard deviation of monthly average precipitation (mm) (2011-2020) in Rayitu (3.53) was very close to that of Arero (3.61). The climatic change and variability have resulted in the occurrence of two drought events in the last

Variables	Mean		Mean diff.& its Std. Dev		t-value
	Male (340)	Female (56)	Mean diff.	Std. Dev.	
Age	40.15	46.23	-6.08	2.1	-2.89[a]
Education	3.58	1.23	2.34	0.65	3.59[a]
Adult equivalent	5.46	4.65	0.81	0.3	2.69[a]
TLU	10.82	7.23	3.59	1.75	2.05[b]
Extension contacts	15.84	12.61	3.24	1.04	3.12[a]
Productive asset	1583.23	1089.29	493.95	325.56	1.52

Note: [a] and [b] denote significant at 1% and 5 % significance levels, respectively
Source: Authors' computation (2023)

Table 2: Socio-demographic profile of households.

Districts	Min tem. (°C)	Sen's Slope (°C/year)	Max tem. (°C)	Sen's Slope (°C/year)	Av. tem. (°C)	Sen's Slope (°C/year)	Av. annual RF (mm)	Sen's Slope (°C/year)
Arero	18.79	0.029[a]	23.89	0.027[b]	21.66	0.028[a]	60.47	0.666[a]
Rayitu	19.89	0.024[a]	26.08	0.024[a]	24.15	.023[a]	59.06	0.331[b]

Note: [a] and [b] denote significant at 1% and 5 % significance levels, respectively
Source: Authors' computation (2023)

Table 3: the result of sen's slope for minimum, maximum and average temperature, and precipitation.

ten years alone, causing the deaths and diseases of livestock and crop failures in the study areas. These necessitated the pastoral households to diversify their livelihood as means of coping strategy to these climate change and variability shocks.

Household livelihood diversification

In order to combat the negative consequences of climate change, the pastoral household adopted a variety of livelihood diversification techniques, including crop production, and non-farm occupations, along with livestock herding. As shown in Table 4, roughly 49 percent of the sample's pastoral households have opted to adopt crop production to combat the negative effects of climate change. and variability. And, 22 percent of the sample's pastoral households engaged joint adoption of crop production and non-farm activities. Additionally, just 9.85% of the pastoral households adopted non-farm activities to cope with climate shocks.

Variable	Freq.	Percent	Com.
No diversification	76	19.19	19.19
Crop production	194	48.99	68.18
Non-farm activities	39	9.85	78.03
Crop production & non-farm activities	87	21.97	100
Total	396	100	

Source: Authors' computation (2023)

Table 4: Livelihood diversification of household.

Principal Component Analysis

The study used a multidimensional food security index to assess family food security. The four dimensions of food security, provided by the definition of food security, were used to create the composite food security index (World Bank, 1986). These include availability, access, utilization, and stability over time each having its indicators. The weighted indices of each dimension were combined into a single composite index to create the index. Finally, Principal Component Analysis (PCA) was used to create the food security index for pastoral households.

The major components were selected based on the widely used Kaiser's criteria, which suggests eigenvalues surpassing unity, and cumulative contribution to total variance to be 70% (Dunn, 2008; Jolliffe and Cadima, 2016; Kaiser, 1960). Accordingly, in order to create their respective indices, the first two primary components of the food availability and access dimensions were used (Table 5). In addition, the first three primary components were used to create the food stability and utilization indices. After adding up the four indicators' individual weights, a food security index for each pastoral household was produced. As a result, the households' food security status was divided into three categories: low food security, medium food security, and high food security (Table 7). Following (Sam et al., 2018), the food security status was categorized as low food security if $0 \leq FSi \leq 0.25$, medium food security if $0.251 \leq FSi \leq 0.5$, and high food security if $0.51 \leq FSi \leq 1.00$.

FS dimension	Component	Eigenvalue	Difference	Proportion	Cumulative
Food Availability	Comp1	1.474	0.619	0.491	0,.491
	Comp2	0.854	0.182	0.285	0.776
	Comp3	0.672	0	0.224	1
Food access	Comp1	1.468	0.601	0.489	0.489
	Comp2	0.867	0.202	0.289	0.778
	Comp3	0.665	0	0.222	1
Food utilization	Comp1	1.437	0.408	0.359	0.359
	Comp2	1.03	0.177	0.257	0.617
	Comp3	0.852	0.171	0.213	0.83
	Comp4	0.681	0	0.17	1
Food stability	Comp1	1.388	0.27	0.347	0.347
	Comp2	1.119	0.26	0.28	0.627
	Comp3	0.858	0.224	0.215	0.841
	Comp4	0.635	0	0.159	1

Source: Authors' computation (2023)

Table 5: Principal components' correlation.

Mean difference for food secure and food insecure sample households

The average age of household heads who experienced food insecurity was higher than that of household heads who did not, as shown in Table 6, and the difference was statistically significant at the 1% level. This suggests that households with older household heads were more likely to experience food insecurity than younger headed households. Additionally, the food insecure households had larger average households (adult equivalent) and longer average walking distances from the veterinarian service center than the food secure ones, and the difference was statistically significant at the 1% level. This suggests that as mean adult equivalent and mean distance from veterinarian care center increase, food insecurity also increases. In contrast, the mean Tropical Livestock Unit (TLU) and the mean non-farm income of the food secure households were higher than that of the food insecure ones, and the difference is statistically different at a 5 percent significant level.

Food security status

In this study, a basic or multidimensional method to measuring food security was used to assess the food security condition of pastoral households. To compare the outcomes of the two methods, food security status as determined by the indirect method/per capita daily calorie intake was also presented. The distinction between food-secure and food-insecure households was made using the minimum daily calorie requirement of 2,200 Kcal per person. As seen in Table 7, roughly 46% of the sample households had attained lower than the minimal calories per adult equivalent. The remaining sample families, or around 54% of them, were found to have achieved enough calories to be food secure.

In terms of the multidimensional technique to gauging food security, close to 80% of the sample homes fall into the low security and medium security categories. More specifically, the food security index result revealed that approximately 60.6% of pastoral households fell into the category of medium food security (Table 7). Additionally, it was shown that 19.2% and 20.2 percent, respectively, of the pastoral households fell into the categories of low and high food security. However, in a study conducted in the Indian state of Odisha using a similar approach, only about 32 percent of households fell into the medium food security category and only about 8 percent of households fell into the low food security category (Sam et al., 2018).In addition, the study showed that more than 60 percent of the sample households in the state were in the high and highest food security categories. Another study (Wineman, 2014) used panel data and a multidimensional index to analyze household food security in rural Zambia and found that 9 percent, 50 percent and 41 percent of the households were always food insecure, some times food insecure and never food insecure, respectively. The results show that food security statuses of households in Odisha state in India and rural areas of Zambia are better compared to food security status of households in Arero and Rayitu districts in Ethiopia as measured by multidimensional approach.

Variables	Mean		Mean diff.& its Std. Dev		t-value
	Food Secure (214)	Food insecure (182)	Mean diff.	Std. Dev.	
Age	38.46	44.01	-5.55	1.46	-3.80[a]
Education	3.79	2.60	1.20	0.46	2.60[a]
Adult equivalent	4.67	6.14	-1.47	0.20	-7.37[a]
TLU	11.46	8.97	2.48	1.23	2.03[b]
Extension contacts	15.49	15.26	-0.20	0.10	0.31
Productive asset	1656.36	1345.26	311.10	227.75	1.37
Distance to market	1.63	1.83	-0.20	0.13	-1.52
Distance to veterinary	1.65	2.14	-0.49	0.15	-3.19[a]
Non-farm income	2147.26	1060.14	1087.12	518.05	2.10[b]

Note: [a] and [b] denote significant at 1% and 5 % significance levels, respectively
Source: Authors' computation (2023)

Table 6: Results of mean difference test using t-test for food secure and food insecure sample households.

As determined by both the indirect/calorie technique and the multidimensional approach, the chi-square test demonstrated a strong correlation between food security status and the particular district (Table 7). According to the daily calorie intake method of measuring food security, the Rayitu district has significantly lower food security (46.85 percent) than the Arero district (58.10 percent). One way to look at it is that the Rayitu district had a higher percentage of high food secure households than the Arero area, according to the basic food security measuring approach. On the other hand, a greater proportion of households with inadequate food security was discovered in the Arero district than the Rayitu district (Table 7).

Determinants of food security

In order to identify the determinants influencing the food security status of pastoral households in the Arero district of the Borena zone and the Rayitu district of the Bale zone, the study used ordered logit. The parallel lines/proportional odds assumption was checked using the brant test (Williams, 2006), and there was no issue with the assumption being broken. The pastoral household's level of food security, which was divided into three categories—low, medium, and high—was the dependent variable. In the model, fourteen explanatory variables were fitted. These include the, gender (the male household head), the age of the household head, the interaction between the maleness and the age of the household head, family size (adult equivalent), the household head's educational status, the stock size (TLU), frequency of extension contacts, credit, distance to market, distance to a veterinary service center, food aid, value of productive assets. livestock shock, and being in Arero district.

According to the Wald test, the MNL model with the full set of explanatory variables represents a significantly better fit (LR chi2(12) = 150.99, p = 0.000) than a null model, indicating that at least one of the explanatory variables in the model has a significant impact on the food security status of pastoral households. Out of the fourteen explanatory variables that were utilized, the model's output showed that eight of them were statistically significant in affecting the food security status of pastoral households. These include household size (adult equivalent), livestock size (TLU), frequency of extension contacts, distance to market, and being in Arero district, as well as the gender, age, and interaction of the household head's gender and age (Table 8).

It was suggested that a male household head would have a positive impact on the level of food security in pastoral households in the research locations. However, it was discovered that the male household head had a negative and significant impact on the households' level of food security. Comparing male-headed families to their female counterparts, the marginal effect showed that the likelihood of slipping into a low-food security category increases by 25% and the likelihood of being in a high food security status reduces by 24%. Synonymously, according to Mbolanyi et al. (2017), the male-headedness of households has adversely impacted the food security status of households in a rangeland area of Uganda,

The level of food security in pastoral households was also anticipated to be influenced by the age of the family head positively. In contrast, the age of the household head was found to affect the food security status of pastoral households negatively at a 5 percent significance level. The marginal effect revealed that the probability of the household falling into the low food security category increased

	Food Security Status	district		
		Arero	Rayitu	Total
Multidimensional food security	Low food security	61 (24.11)	15 (10.49)	76 (19.20)
	Medium food security	147 (58.10)	93 (65.03)	240 (60.60)
	High food security	45 (17.79)	35 (24.48)	80 (20.20)
	Total	253 (100)	143 (100)	396 (100)
	Pearson chi^2 = 11.58		Prob = 0.003	
Food security as measured by kcal per day per adult equivalent	Food insecure	106 (41.90)	76 (53.15)	182 (45.96)
	Food secure	147 (58.10)	67 (46.85)	214 (54.04)
	Total	253 (100)	143 (100)	396 (100)
	Pearson chi^2 = 4.6552		Prob = 0.031	

Source: Authors' computation (2023)

Table 7: Food security situation by district.

Variables	Coefficients and Odds ratio		Marginal effects		
	Coef.	Odds ratio	Low FS	Medium FS	High FS
Gender (male)	-2.014[b]	0.925	0.25[b]	-0.011	-0.24[b]
Age	-0.045[b]	0.018	0.006[b]	-0.0003	-0.005[b]
Sex-age interaction	0.052[a]	0.02	-0.006[a]	0.0003	0.006a
Adult equivalent	-0.142[b]	0.062	0.018[b]	-0.001	-0.017[b]
Education	0.043	0.028	-0.005	0.0002	0.005
TLU	0.063[a]	0.013	-0.008[a]	0.0004	0.007[a]
Extension contacts	0.06[a]	0.016	-0.007[a]	0.0003	0.007[a]
Access to credit	-0.108	0.313	0.013	-0.001	-0.013
Distance to market	-0.631[a]	0.098	0.078[a]	-0.004	-0.075[a]
Distance to Veterinary	0.062	0.086	-0.008	0.0003	0.007
Food Aid	0.005	0.236	-0.001	0.00003	0.001
Productive asset	0.00008	0.00005	-0.00001	0.0000005	0.00001
Livestock shock	-0.059	0.339	0.007	-0.0003	-0.007
Arero (district)	-0.797[b]	0.346	0.099[b]	-0.004	-0.094[b]
cut1	-4.216	0.985			
cut2	-0.375	0.954			
Number of obs. = 396 LR chi^2(14) 150.99 Prob > chi^2 = 0.000 Pseudo R^2 = 0.2021					
Log likelihood = -298.09478					

Note: [a] [b] and [c] denote the significance level at 1 percent, 5 percent and 10 percent
Source: Authors' computation (2023)

Table 8: Results of ordered logit model.

by 0.6 percent and the probability of falling into the high food security level decreased by 0.5 percent as the age of the household head increased by one year. However, it was discovered that the pastoral households' food security status was positively and considerably impacted by the male household head's aging. The marginal effect of the interacting variables revealed that when the male household head's age rises by one year, the likelihood that the household falls into the low food security category lowers and the likelihood that it falls into the high category rises by 0.6 percent. Similarly, a study by Sani and Kemaw (2019) found a negative correlation between Assosa rural households' food security status and household head's age.

The household size (adult equivalent) was proposed to affect the food security status of the pastoral households negatively. In line with the proposal, the household size was found to influence the food security status of the households negatively at a 10 percent significant level. According to the marginal effect of household size, as household size grows by one unit, the likelihood of having low food security levels increases by 1.8 percent and the likelihood of having high food security levels falls by 1.7 percent. Similar to this, a study conducted in Afar area of Ethiopian found a negative correlation between household size and food security for pastoral and agro-pastoral communities (Kahsay et al., 2019)

It was proposed that the livestock size (TLU) of the pastoral household would have a favorable impact on their level of food security. As predicted, the model's output showed that, at a 1% level of significance, livestock size (TLU) was found to favorably influence the food security status of pastoral households. According to the marginal effects linked to livestock size (TLU), a one-unit increase in TLU reduces the likelihood of being in a low food security level by 0.8 percent and raises the likelihood of being in a high food security level by 0.7 percent, respectively. The conclusion suggests that having more livestock helps a pastoral home maintain a high degree of food security and prevents it from slipping into a low level. The results of earlier investigations support the discovery (Abdela et al., 2021; Kahsay et al., 2019).

The frequency of extension contacts was proposed to affect the food security status of pastoral households. The model's output revealed that, at a 1% level of significance, the frequency of extension contacts was found to positively influence the households' food security status.

The marginal effects showed that by 0.7 percent, the likelihood that a household is in a high-security level of food security improves and the likelihood that it is in a low-security level of food security reduces. This suggests that the extension agent's ongoing assistance to the pastoral households helped to improve their level of food security. Participation in extension services had also been proven to favorably and significantly influence smallholder farmers' level of food security, according to a study carried out in Kenya's coastal Kilifi South Sub-County (Chege et al., 2018).

The proximity of markets to the residential areas of the pastoral household is one of the factors that influences access to food. Due to this, it was assumed that the pastoral households' level of food security would be negatively impacted by their distance from the market. At a 1% level of significance, it was discovered that the households' food security status was negatively impacted by the distance to the market center, as predicted. The model's results showed that the probability of having low food security levels increases by 7.8% and the probability of having high food security levels decreases by 7.5% the farther one walks from the nearest market center. The outcome may imply that a household's ability to access food decreases with increasing distance from the nearest market center, negatively affecting food security status. The results are consistent with those of the earlier studies (Abdela et al., 2021; Sani and Kemaw, 2019).

Being in Arero district was found to have a negative and significant impact on the food security status of pastoral households. Consistent with the descriptive statistics, the marginal effects of being the Arero district have demonstrated that, when compared to their counterparts in the Rayitu district, pastoral households in the Arero district are more likely to be in low food security levels and less likely to be in high food security levels, respectively, by 9.9 percent and 9.4 percent. The results imply that, in comparison to the Rayitu district of the Bale zone, the food security position of pastoral households has gotten worse in the Arero district of Borena. According to a study carried out in the Gamo Gofa zone of Ethiopia, rural households in the Kamba district (semi-arid) were more sensitive to food security than those in the arid Kamba district (Fassil and Adem, 2021).

The impact of livelihood diversification as climate change adaptation strategy on pastoralists' food security status.

The multinomial endogenous switching regression model was used to examine the impact of livelihood diversification on the degree of food security in the pastoral families in the study areas. The multidimensional food security index was not significantly impacted by the instrumental factors (access to climate information and distance to a road), indicating that the model was well-fitted. The model generates the mean outcomes for adopter household livelihood diversification and what would have happened if the adopters had not diversified. The mean outcome for the non-adopters (the control group) is also included, as is the mean outcome that would have occurred if the non-adopters had chosen livelihood diversification or the alternative scenario. The disparities between the first two outcomes provide average treatment on those who have been treated and adopted (ATT), while the differences between the last two outcomes offer average treatment on those who have not been treated and have not adopted (ATU). Table 9 summarizes the average impact of livelihood diversification as a method for coping with climate change on the multidimensional food security of pastoral households.

The findings showed that households that engaged in non-farm activities, joint crop production and non-farm activities, together with livestock keeping, had higher levels of food security than households that did not engage in these activities. At a 5% level of significance, the difference between the mean food security index value of crop-producing households and the counterfactual (had the producers not produced) (ATT) was 0.091. The adoption of non-farm activities by households greatly raises the food security index value by 28.38. The food security index value would have grown by 12.30 percent if non-adopters of non-farm activities had chosen to engage in non-farm activities. On the other hand, if the households that haven't adopted non-farm activities had done so, the indexed value of food security would have gone up by 16.53 percent. Similarly, a study done in Nigeria found that households who adopted strategies for coping with climate change had higher levels of food security than those who didn't (Ogunpaimo et al., 2021).

The joint adopters of crop production and non-farm activities had a mean indexed value of food

Outcome variable	Diversification	Mean outcome		Treatment Effects	
		Adopted	Not Adopted	ATT/ATU	Impact (%)
		Actual (X)	Counterfactual (Y)	*Z = (X-Z)*	$\left(\frac{Z}{Y}\right) * 100$
Multidimensional food security	Crop production	0.364	0.349	0.015 (0.011)	4.27
		0.29	0.268	0.022^{b} (0.011)	8.01
	Non-farm activities	0.411	0.32	0.091^{a} (0.023)	28.38
		0.301	0.268	0.033^{b} 0.016)	12.3
	Crop & Non-farm	0.506	0.426	0.080^{a} (0.029)	18.83
		0.384	0.268	0.115^{a} (0.016)	42.97
HT Effects		BH_1	BH_0	TH	
Multidimensional food security	Crop production	0.0744^{a} (0.01)	0.0811^{a} (0.015)	-0.0065 (.012)	
	Non-farm activities	0.1094^{a} (0.023)	0.0516^{a} (0.015)	0.0578^{b} (0.023)	
	Crop & Non-farm	0.1224^{a} (0.021)	0.1576^{a} (0.028)	-0.0352 (0.027)	

Note: ^{a,} and ^{b} denote the significance level at 1 percent and 5 percent; values in the parenthesis are standard errors
Source: Authors' computation (2023)

Table 9: ATT and ATU of Livelihood diversification: MESR Estimates.

security of 0.506. At a 1% level of significance, the difference between the joint adopter's mean food security index value and the counterfactual value (ATT) was 0.08, making it significant. In comparison to the counterfactual, pastoral households' joint adoption of crop production and non-farm activities significantly raises the food security index by 18.83 percent. The conclusion suggests that combining crop production and non-farm activities leads to a greater improvement in the degree of food security for the adopting pastoral families. A similar increase (42.97 percent) in the food security index would have occurred if non-adopters of the joint activities had chosen to do so. Similarly, a study carried out in southwest Nigeria revealed that adopting measures for adapting to climate change had raised the food security index of adopter fish farmers (Oparinde, 2021).

The base heterogeneity values for adopters (BH_1), non-adopters (BH_0), and transitional heterogeneity (TH) was presented in Table 9. There were positive and significant values of base heterogeneity (BH_1) in the adopters of crop production, indicating that there are no sources of heterogeneity among adopters and non-adopters of crop production and that adopters had more food security than non-adopters. Similar to adopters, non-adopters' positive base heterogeneity values (BH0) show that if they had adopted the same activities, crop production, non-farm activities, and joint of both activities, they would have been more food secure. The positive and significant values of transitional heterogeneity (TH) for the adopter of non-farm option imply that the impact of adopting the non-far activities on food security level would be significantly higher for pastoral households who adopted compared with those who did not adopt (if they would decide to adopt).

Conclusion

The study's objectives were to investigate the factors that affect the food security of pastoral households and the impact of adopting livelihood diversification on the level of food security for households in the districts of Arero in the Borena zone and Rayitu in the Bale zone. The study measured the level of food security in pastoral households using multidimensional approach and classified it as low, medium, and high. According to the approach's descriptive results, the percentages of pastoral households with medium, high and low levels of food security were 60.6 percent, 20.2 percent, and 19.2 percent, respectively. More particular, the majority of pastoral households - nearly 80% - were in low and medium food security categories. Additionally, Rayitu district had 24.48 percent households with high food security than Arero district did (17.79 percent). In contrast to Rayitu district (10.49 percent)., Arero district had a considerably greater percentage of households with low food security, about 24%.

Ordered logit regression and multinomial endogenous switching regression models were the two econometric models used in the study. To determine the variables influencing the households' level of food security, the ordered logit was utilized. The impact of implementing livelihood diversification on the degree of food security in pastoral households was evaluated using the multinomial endogenous switching regression model. According to the results of ordered logistic regression, the interaction between the household head's age and gender, the size of the livestock (TLU), and the frequency of extension contacts considerably improves the food security situation of pastoral families. The food security status of the pastoral households is, however, significantly reduced by the maleness of the household head, age of the household head,

The results of the multinomial endogenous switching regression model, on the other hand, demonstrated that the adoption of non-farm activities and the combination of both activities had a favorable and significant impact on the degree of food security of pastoral households. The model's output showed that the pastoral household's degree of food security increased as a result of engaging in livelihood diversification as an adaptation strategy. More specifically, adopter households' adoption of non-farm activities and joint adoption of crop production and non-farm activities boosted the food security index by 28.38% and 18.83%, respectively. In addition, the positive and significant value of base heterogeneity (BH1) revealed that the adopters are more food secure than non-adopters.

The study offers some guidance for governmental bodies working at various levels and non-governmental organizations to work on the situation of food security of the pastoral community in semi-arid areas. The local government should concentrate on enlarging local markets to ensure food accessibility and make it easier for people to sell their livestock to buy food items because the households' level of food security was influenced by the distance to the market center. Working on community-participatory policies that encourage the diversification of livelihoods in pastoral communities is extremely important, as the study's findings showed that the adoption of non-farm activities and crop production and non-farm activities jointly improved the food security level of the pastoral household. More realistically speaking, it appears crucial to promote livelihood diversification by developing the appropriate infrastructure, addressing the financial issues facing pastoral households, and launching the formation and growth of micro and small businesses in semi-arid regions.

The study contributes to the food security literature by flashing lights on pastoral households' food security status using cross-sectional data and a multidimensional food security index method of measuring food security in semi-arid areas. Additionally, it adds to the body of literature a more accurate way to assess the impact of livelihood diversification as an adaptation strategy on the degree of food security in pastoral households through the use of multinomial endogenous switching model. However, as the study focused only on the selected districts, a wider scope, further study on food security and vulnerability to food insecurity of pastoral households in semi-arid appears to be crucial,

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Corresponding author:
Baro Beyene
Department of Economics, Oromia State University, P. O. Box 209, Batu, Ethiopia
and School of Economics and Business, Norwegian University of Life Sciences, 1432 Ås, Norway
E-mail: bar.beyen@gmail.com

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Appendix

Used abbreviations

ATT	Average treatment effect on the treated
ATU	Average treatment effect on the untreated
CSA	Central Statistical Agency
FAO	Food and Agriculture Organization of the United Nations
FSI	Food Security Index
PC	Principal component analysis
SNNP	Southern Nation, Nationalities, and People
TLU	Tropical Livestock Units
WFP	World Food Program
WMO	World Meteorological Organization

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Analyzing Meat and Seafood Import Demand in Trinidad and Tobago Using the Linear Approximate Almost Ideal Demand System Model

David Forgenie[1], Sharon D. Hutchinson[1], Nikmatul Khoiriyah[2], Meera Mahase-Forgenie[3]

[1] Department of Agricultural Economics and Extension, Faculty of Food and Agriculture, The University of the West Indies, St. Augustine Campus, Trinidad snd Tobago

[2] Department of Agribusiness, Faculty of Agriculture, University of Islam Malang, Java, Indonesia

[3] Department of Geography, Faculty of Food and Agriculture, The University of the West Indies, St. Augustine Campus, Trinidad and Tobago

Abstract

A linear approximated almost ideal demand system model is specified to estimate imported meat and seafood demand in Trinidad and Tobago for the period 1976 to 2019 using annual data. Model parameters were estimated using seemingly unrelated regression with theoretical restrictions imposed. The results found that own-price of imported poultry and seafood negatively affected import expenditure share while own-price positively affected import expenditure share for imported beef, pork, and mutton. In addition, income negatively affected the import expenditure share of imported beef but positively affected the import expenditure share of imported pork, poultry, seafood, and mutton over the study period. Expenditure elasticity for imported meats and seafood reveals that they are all normal goods. Imported beef, pork, poultry, seafood, and mutton had expenditure elasticities of 0.57, 1.13, 1.94, 1.12, and 1.05, respectively. Imported pork, poultry, seafood, and mutton were found to be luxuries with income-elastic import demand. Own-price elasticities reveal that imported poultry was the most import elastic with an own-price elasticity of 1.40, followed by imported seafood (1.22), beef (0.65), mutton (0.54), and pork (0.48). Cross-price elasticities revealed that various complementary and substitution relationships existed among imported meats and seafood over the study period. Hicksian cross-price elasticities showed that mostly substitution relationships existed between various pairs of imported meats and seafood. The study also highlighted some policy recommendations that can be derived from the results.

Keywords

Meat and seafood imports, LA-AIDS, elasticities, food policy, Trinidad and Tobago.

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Introduction

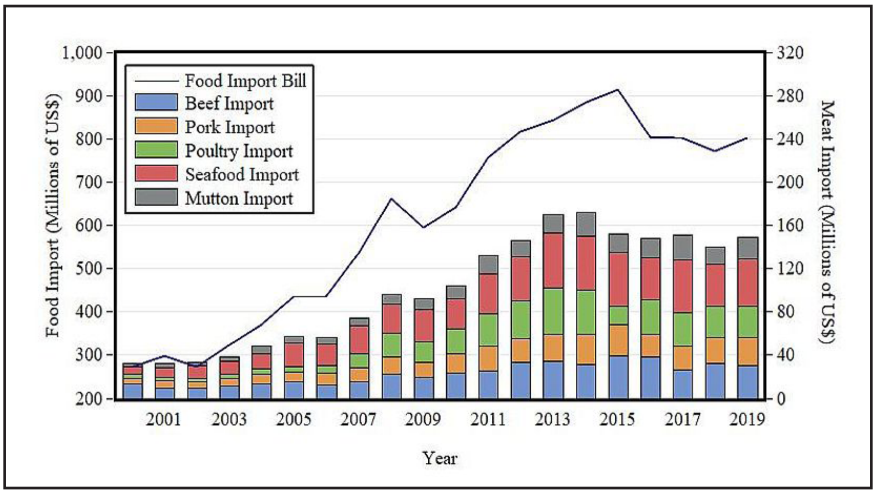
In 2010 the global consumption of animal protein was estimated to be 209.20 million tonnes but in 2019 was estimated to be 248.73 million tonnes (FAO 2022b). Between 2009 and 2019, global consumption of animal protein has seen an 18.9% increase. Global per capita consumption of animal protein between 2010 and 2019 increased by 3.9% on average (FAO 2022a). Projected increase in income and population growth is expected to positively correlate with increased animal protein consumption and production in the future (OECD/FAO, 2022). Whitton et al. (2021) also notes that there is a direct relationship between development and increased meat consumption. According to OECD/FAO (2022), the availability of protein from beef, pork, poultry and sheep meat is projected to increase by 5.9%, 13.1%, 17.8%, and 15.7% by 2030, respectively. Current consumption patterns suggest that consumers are shifting meat consumption toward poultry, especially in developing nations with low income levels (OECD/FAO, 2022). Furthermore, it is projected that by 2030 poultry meat will account for around 41% of all protein derived from animal sources globally (OECD/FAO, 2022).

Trinidad and Tobago is a small island developing state (SIDS) with an ever-growing food import bill (FIB). In 2015, the national FIB was reported to be US$915.13 million but decreased to US$801.47 million, or 12.4% in 2019 (Figure 1). Meat imports accounted for 16.6% of the 2015 FIB, however, in 2019 it accounted for 18.6%. In 2019, seafood accounted for 29.3% of meat imports while mutton accounted for only 13.2% (FAO 2022c).

Per capita animal protein consumption in Trinidad and Tobago is increasing annually. In 2010, per capita animal protein consumption was reported to be 75.69 kg, which increased to 77.71kg in 2019 (FAO, 2022a). In the future, animal protein consumption is expected to increase further as income increases.

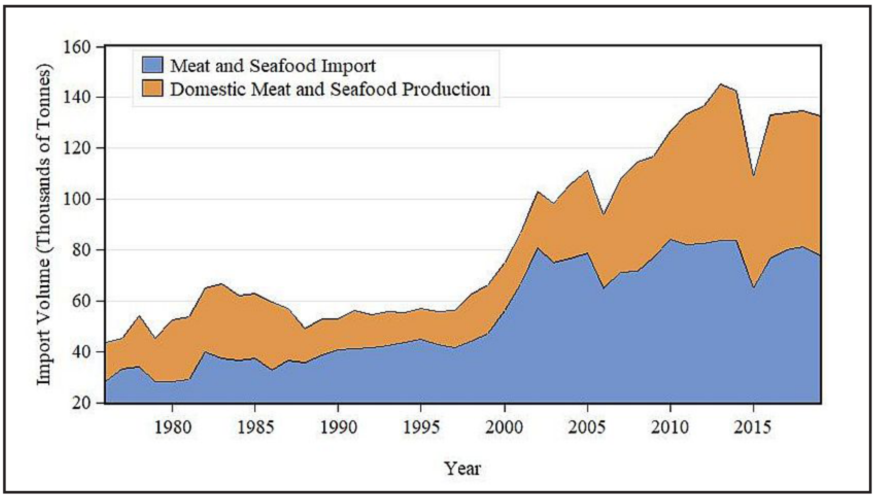
Domestic meat and seafood production for Trinidad and Tobago reached 84.06 thousand tonnes in 2010, but decreased to 77.82 thousand tonnes in 2019 (Figure 2). Meat and seafood import volume in 2010 was estimated to be 42.56 thousand tonnes, and grew to 54.93 thousand tonnes in 2019 (Figure 2). Meat and seafood production between 2010 and 2019 decreased by 7.4% on average while imports experienced increases of 29.1% to account for decreasing production volumes and increasing consumption patterns.

Studies on meat and seafood demand estimation has been carried out in various countries such as Karagiannis et al. (2000) and Nikolaou and Velentzas (2000) for Greece, Motallebi and Pendell (2013), and Pourmokhtar et al. (2018)



Source: FAO (2022c)

Figure 1: Trinidad and Tobago food import bill and meat imports.



Source: FAO (2022c)

Figure 2: Trinidad and Tobago Imports versus Domestic Production.

for Iran, Forgenie et al. (2023), Khoiriyah et al. (2020), and Anindita et al. (2020) for Indonesia, Basarir (2013) for the UAE, Jabarin (2005) for Jordan, Selvanathan et al. (2020) and Wadud (2006) for Bangladesh, Taljaard et al. (2004), and Taljaard et al. (2006) for Africa, Shibia et al. (2017) for Kenya, Singh et al. (2011) and Zhou (2015) for the United States, Verbeke and Ward (2001) for Belgium, Golan et al. (2001) and Ramírez Tinoco et al. (2011) for Mexico, Memon et al. (2015) for Pakistan, Ezedinma et al. (2006) in Nigeria, Ramírez (2013) for Colombia, Zhang et al. (2018) and Hejazi et al. (2019) for China, and Henneberry and Hwang (2007) for South Korea, using the Almost Ideal Demand System (AIDS) approach. Most of these studies examined demand at the household level were imported huge quantities of animal protein to meet domestic demands. It is widely suggested that income support policies such as government food assistance and household subsidies would be most effective in promoting household consumption of animal-sourced protein. It must be noted that most studies conducted in developing countries report that domestic consumption of animal-sourced protein is low which has serious negative implications for health and nutrition.

Import elasticities are valuable tools in policy formulation. They can help to gain a better understanding of the degree of responsiveness of quantity demanded and demand, as a result of changes in one of the determinants of import demand such as price or income. Reliable and efficient import elasticities can aid in the development of policy that can help to foster improvements in consumer welfare since consumption patterns can be better understood. Singh et al. (2011) and Lokuge and Edirisinghe (2015) notes that reliable price and income elasticities can be used to develop effective campaigns and marketing strategies. Additionally, studies that focus on import demand estimation can be extremely valuable not only for the importing country but also for their trading partners as a comprehensive understanding of how factors such as prices and income affect demand can be better understood.

Despite being net-importers of meat and seafood, Trinidad and Tobago lacks comprehensive studies on the importation of these food products. Such studies are of utmost importance as enablers of effective planning and management of domestic production, distribution, and trade. Understanding the dynamics of import demand can help to ensure that the dietary needs of the population are met, while also addressing the concerns regarding food and nutrition security. Additionally, elasticity estimates play a vital role in formulating policies that promote sustainability, reduce dependency on imports, and provide support to local producers. By considering the broader context of factors such as food and nutrition security, trade balances, and health implications, this study seeks to shed light on the significance of studying the dynamics of imported meat and seafood demand in Trinidad and Tobago.

Therefore, this article seeks to study meat and seafood import demand in Trinidad and Tobago using the linear approximate almost ideal demand system (LA-AIDS) model for the period 1976 to 2019 using annual data. We will examine the effect of price and income on the import demand for various imported meat categories and calculate price and income elasticities for these commodities. To the best of our knowledge, no study has been done for Trinidad and Tobago using the LA-AIDS model to study meat and seafood import demand. Therefore, this study will fill this gap in the literature. This article will also provide policy-relevant import price and income elasticities for Trinidad and Tobago.

Materials and methods

Model specification: the linear approximate almost ideal demand system

The almost ideal demand system (AIDS) model proposed by Deaton and Muellbauer (1980) is widely used in the empirical literature. Despite there being numerous other demand systems, the AIDS model remains one of the most preferred specification in empirical work. This is because the AIDS model possesses many desirable properties, such as it aggregates perfectly over consumers, has a functional form which is consistent with known data, satisfies the axiom of choice, is rather straight-forward to estimate, and allows for the theoretical restrictions of adding-up, homogeneity, and symmetry to be imposed on the model parameters and tested (Barnett and Seck 2008, Deaton and Muellbauer 1980, Byrne et al. 1996). These properties make the AIDS model extremely popular among scholars (Alston and Chalfant, 1993, Eales and Unnevehr, 1994). Following Deaton and Muellbauer (1980), the AIDS demand equation is specified as follows:

$$s_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} lnp_j + \beta_i ln\left(\frac{m}{P^*}\right) + \varepsilon_i \qquad (1)$$

Where:

s_i: Budget Share for the i[th] imported commodity group calculated as $s_i = \frac{p_i q_i}{m_i}$

q_i: Import quantity of the i[th] imported commodity group.

ln: Natural logarithm

p_i: Prices of beef, pork, poultry, seafood, and mutton

m: Total expenditure on imported meat

ε_i: White noise error term

α_i: Intercept parameter

β_i : Expenditure parameters

γ_{ij}: Price parameters

The price index used to deflate total expenditure is represented by P^* and is a translog price index given as follow:

$$lnP^* = a_0 + \sum_{i=1} a_i lnp_i + \frac{1}{2}\sum_{i=1}\sum_{j=1}\gamma_{ij} ln\, p_i\, lnp_j \qquad (2)$$

Substitution of equation (2) into equation (1) produces the non-linear or traditional AIDS model. However, according to Taljaard et al. (2004), using the translog price index makes the demand system non-linear which complicates the estimation process. However , to overcome the problem of non-linearity, Deaton and Muellbauer (1980) suggested using the stone price index to linearize the model. The stone price index is given as follow:

$$ln\, P^{**} = \sum_{i=1} s_i\, lnp_i \qquad (3)$$

Substituting equation (3) into equation (1) produces the linear approximate almost ideal demand system (LA-AIDS) which is used to study import demand for various meats in Trinidad and Tobago. In order to ensure that the demand system is consistent with demand theory, the theoretical restrictions of adding-up, homogeneity and symmetry are imposed. Adding-up ensures that the budget shares all sum to one, homogeneity ensure that there is no "money illusion", and symmetry ensures that cross-price elasticities are symmetric. In order estimate α_i, γ_{ij}, and β_i in equation (1), adding-up, homogeneity, and symmetry restrictions are imposed as follows:

Adding-Up: $\sum a_i = 1\,;\ \sum \beta_i = 0\,;\ \sum_{i=1}^{n} \gamma_{ij} = 0$ (4)

Homogeneity: $\sum_{i=1}^{n} \gamma_{ij} = 0$ (5)

Symmetry: $\gamma_{ij} = \gamma_{ji}$ (6)

Equation (1) with the price index highlighted in equation (3) along with the theoretical restrictions in equations (4)-(6) imposed is estimated using the seemingly unrelated regression (SURE) technique by Zellner (1962) in Stata 17 software. In order to avoid singularity of the variance co-variance matrix, one of the share equation was dropped during empirical estimation and then recovered via the adding-up restriction.

Deriving price and expenditure elasticities

Now that a theoretically sound demand system is specified, price and expenditure elasticities can be derived for each imported meat group. The estimated parameters are used to derive Marshallian and Hicksian own- and cross-price elasticities along with expenditure elasticities for the various imported meats. Marshallian or uncompensated price elasticities measure the degree of responsiveness of the quantity demanded as a result of changes in prices. The Marshallian own-price elasticity measures changes in the quantity demanded of a good in question due to changes in its prices. The law of demand notes that price and quantity demanded share an inversed relationship, hence, the own-price elasticity most of the time is expected to be negative. Cross-price elasticity on the other hand measures the relationship that exist between two goods, substitution or complementary. Two goods would be considered substitutes if their cross-price elasticity is positive, however, they would be complements if cross-price elasticity is negative. Hicksian price elasticities are similar to Marshallian price elasticities, however, unlike Marshallian price elasticities that reflect changes in both price and income, Hicksian elasticities only measures the effect of a price change. Hence, Hicksian elasticities tend to be smaller in magnitude than Marshallian elasticities. Expenditure elasticities in the context of the LA-AIDS model measures the changes in demand brough about by changes in expenditure or income. Economic theory notes that for a normal good, expenditure elasticities should be positive and negative for an inferior good. Expenditure, and Marshallian, and Hicksian elasticities are calculated as follow:

Expenditure elasticity: $\eta_{ij} = 1 + \frac{\beta_i}{\bar{s}_i}$ (7)

Marshallian price elasticity: $\epsilon_{ij}^{M} = \frac{\gamma_{ij} - \beta_i \bar{s}_j}{\bar{s}_i} - \delta_{ij}$

$\delta_{ij} = 1$ for $i = j$,0 otherwise (8)

Hicksian price elasticity: $\epsilon_{ij}^{H} = \epsilon_{ij}^{M} + \eta_{ij}\bar{s}_j$ (9)

Data and source

This article utilized annual import quantity and expenditure of beef (bovine meat), pork (pig meat), poultry (chicken and turkey), seafood (fish, shrimp, squid, and crustaceans), and mutton (sheep and goat) for the period 1976 to 2019 imported into Trinidad and Tobago. All quantities are given in metric tonnes and expenditure in US dollars. Data for beef, pork, poultry, and mutton was collected from the Food and Agriculture Organization online database (FAOSTAT). Seafood data was collected from FishStatJ. Since import prices for each imported meat group was not available, unit import value of import was used as a proxy for price obtained by dividing expenditure by quantity. Total expenditure on meat for each period was obtained by summing expenditures of the five imported meat groups. All empirical estimation was done in Stata 17.

Results and discussion

LA-AIDS parameters

The results of the LA-AIDS demand system for the five imported meat categories with theoretical restrictions of homogeneity and symmetry imposed are presented in Table 1. From Table 1 it is observed that the effect of the own-price parameter for each of the import share equations is statistically significant except for imported beef. For imported pork and mutton, it was found that own-price had a positive impact on import share. Ceteris paribus, it is suggested that a 1% increase in the import price of imported pork and mutton is expected to bring about a 0.074% and 0.048% increase in import expenditure share, respectively. These findings are consistent with those of Kharisma et al. (2020) who highlighted that there is usually a positive relationship between own-price and the budget share. In contrast, the own-price of poultry and seafood was found to have a negative impact on import shares. This is consistent with Nendissa et al. (2021) who found that the own-price of fish and seafood had a negative impact on the budget share equation. Ceteris paribus, it is suggested that a 1% increase in the import price of poultry and seafood is expected to bring about a 0.032% and 0.052% decrease in import share expenditure, respectively. The imported meat share equation that was found to be the most responsive to changes in import price was pork while poultry was found to be the least responsive.

The expenditure parameter is also presented in Table 1 for each import meat group. All of the estimated parameters for expenditure were found to be statistically significant. It was discovered that an increase in expenditure or income is expected to bring about an increase in the import expenditure share of pork, poultry, seafood, and mutton. In contrast, it was found that an increase in import expenditure or income will bring about a decrease in the import expenditure

Parameter	Meat import share equation				
	Beef	Pork	Poultry	Seafood	Mutton
Intercept	2.034*** (0.227)	-0.036 (0.118)	-0.979*** (0.149)	-0.077 (0.158)	0.068*** (0.014)
Beef price	0.071 (0.057)	-0.036*** (0.005)	0.055** (0.005)	0.024 (0.039)	-0.114*** (0.032)
Pork price	-0.036 (0.029)	0.074** (0.032)	-0.024 (0.016)	-0.039*** (0.006)	0.025 (0.020)
Poultry price	0.055** (0.026)	-0.024 (0.016)	-0.032* (0.019)	0.014 (0.021)	-0.013 (0.018)
Seafood price	0.024 (0.039)	-0.039** (0.017)	0.014** (0.006)	-0.052*** (0.007)	0.053* (0.029)
Mutton price	-0.114*** (0.032)	0.025 (0.020)	-0.013 (0.018)	0.053* (0.029)	0.048** (0.018)
Expenditure	-0.161*** (0.023)	0.018** (0.008)	0.105*** (0.015)	0.333** (0.016)	0.005* (0.003)

Note: *** p <0.01, ** p <0.05, * p <0.1. Standard errors in parentheses
Source: Own calculation based on data from FAOSTAT

Table 1: Estimated parameters of the LA-AIDS model for imported meats.

share of beef. In addition, the results for beef confirms Bennet's Law in Trinidad and Tobago which states that higher income levels causes a shift in consumption towards better quality food items (Kharisma et al. 2020). According to Rathnayaka et al. (2019), a negative sign attached to the expenditure parameter can also be interpreted as the good in question can be considered to be a necessity whist a positive sign would mean that the good is a luxury. Hence, the results suggest that imported beef is a necessity whilst all other imported meat categories can be considered to be luxuries.

Expenditure elasticities

Income is one of the critical determinants of demand, and by extension, import demand. Income elasticity generally measures changes in demand that is brought about by changes in income. Economic theory dictates that for a normal good, when income increases the demand for the that good will also increase, hence, income elasticity for a normal good is supposed to yield a positive sign. In contrast, an inferior good would have an inverse relationship with income. For an inferior good, when income increases, the demand for that good would decrease, hence, income elasticity would generally have a negative sign. Additionally, goods can be regarded as luxuries if the income elasticity is greater than unity. However, when income elasticity is less than unity, the good is regarded as a normal good.

Table 2 presents income or expenditure elasticities for the five imported meats categories for Trinidad and Tobago calculated using equation (7). It was found that all expenditure elasticities were statistically significant at the 1% level. This signifies that income fosters an increase in demand for all imported meat categories for the study period. All calculated expenditure elasticities were found to be positive, which suggest that all imported meats for the study period are normal goods. Expenditure elasticity for all imported meats, except beef, was found to be greater than unity which suggest that they are luxuries. With respects to imported pork, poultry, seafood, and mutton, a 1% increase in income is expected to bring about on average a 1.31%, 1.94%, 1.12%, and 1.05% increase in import consumption annually, respectively. Imported poultry meat was found to be the most luxurious imported meat item followed by seafood. In contrast, imported beef was found to have an expenditure elasticity of 0.569, which suggest that it is a necessity. A 1% increase in income is expected to bring about a 0.57% increase in demand for imported beef on average annually. Imported beef was found to be the lest responsive to changes in income compared to other imported meat categories.

Imported meat group	Expenditure elasticity
Beef	0.569 (0.062)
Pork	1.131 (0.087)
Poultry	1.938 (0.137)
Seafood	1.123 (0.059)
Mutton	1.047 (0.069)

Note: Standard errors in parentheses.
Source: Own calculation based on data from FAOSTAT.

Table 2: Expenditure elasticity for imported meats.

Marshallian price elasticities

Marshallian price elasticities have both a price and income effect. In addition, Marshallian own -price elasticities measure the responsiveness of quantity demanded as a result of changes in price. Economic theory notes that there is an inversed relationship between quantity demanded and price, hence, own-price elasticity should be negative. Additionally, although own-price elasticity is expected to yield a negative sign, economists usually interpret in absolute terms, as the negative sign is ignored, and with the ceteris paribus assumption imposed. Own-price elasticity values that are greater than unity is regarded as elastic while those that are less than unity are inelastic. Elastic goods tend to be very sensitive to changes in price, therefore, small changes in prices generally lead to more than proportionate changes in quantity demanded. Inelastic goods on the other hand are usually less responsive to price changes, hence, large changes in price results in less than proportionate changes in quantity demanded.

Table 3 presents Marshallian own- and cross-price elasticities for the various imported meats calculated using equation (8). For Trinidad and Tobago, it was found that all own-price elasticities for imported meats were statistically significant and carried a negative sign. It was found that for imported beef, pork and mutton, a 1% increase in price is expected to bring about on average 0.65%, 0.48%, and 0.54% decrease in import volumes,

Import Meat Group	Beef	Pork	Poultry	Seafood	Mutton
Beef	**-0.650 (0.157)**	-0.036 (0.078)	0.195 (0.066)	0.182 (0.105)	-0.260 (0.088)
Pork	-0.308 (0.215)	**-0.480 (0.233)**	-0.189 (0.116)	-0.324 (0.193)	0.171 (0.152)
Poultry	0.140 (0.242)	-0.345 (0.146)	**-1.395 (0.169)**	-0.129 (0.188)	-0.210 (0.169)
Seafood	0.044 (0.148)	-0.165 (0.099)	0.018 (0.074)	**-1.224 (0.177)**	0.183 (0.112)
Mutton	-1.114 (0.456)	0.238 (0.201)	-0.125 (0.109)	0.497 (0.468)	**-0.543 (0.105)**

Note: Standard errors in parentheses.
Source: Own calculation based on data from FAOSTAT

Table 3: Marshallian price elasticities for imported meats and seafoods.

respectively. Furthermore, own-price elasticities in absolute form for imported beef, pork, and own price mutton suggest that these meat categories have inelastic import demand. This means that they are not very responsive to changes in prices. Imported pork was found to be the least responsive to import price changes compared to other imported meat categories. In contrast, imported poultry and seafood was found to have elastic import demand. Both imported meat groups had own-price elasticities that were greater than unity. For imported poultry and seafood, a 1% increase in prices is expected to bring about on average a 1.39% and 1.22% decrease in import volumes, respectively. Imported poultry was found to be the most responsive to changes in import price among all other imported meats.

Table 3 also presents cross-price elasticities for imported meats. Cross-price elasticity is generally used to assess the relationship between two goods, substitution or complementary. It generally looks at how changes in the price of one good affects the demand for another good. Generally, if the cross-price elasticity between two goods is positive, then they are substitutes. This means that as the price of one of the goods in question increases the demand for the other related good would also increase as consumers would shift consumption away from the relatively more expensive good towards the one that is less expensive. However, if the cross-prices elasticity is negative, then they are complements. Two goods are complements if they are usually consumed together, therefore, an increase in the price of one will lead to a decrease in the quantity demanded for the other related good.

For Trinidad and Tobago meat imports, there were various substitution and complementary relationships that existed among pairs of imported meats. For instance, imported beef had complementary relationships with imported pork and mutton, but substitued with imported poultry and seafood. Imported poultry on the other hand had complementary relationships with all other imported meats except imported beef. In general, if imported beef prices increased by 1% on average, import demand for imported pork and mutton will fall by 0.04% and 0.26%, respectively, but will rise for imported poultry and seafood by 0.20% and 0.18%, respectively. It was also discovered that changes in the price of imported seafood leads to substitution for imported beef, poultry, and mutton. A 1% increase in the price of imported seafood is expected to result in a 0.04%, 0.02%, and 0.18% increase in import consumption of imported beef, poultry and mutton, respectively. Imported seafood was mostly substituted with imported mutton when prices change. However, imported seafood and imported pork were found to be complements. A 1% increase in the price of imported seafood is expected to bring about a 0.17% decrease in the demand for imported pork.

Hicksian elasticities

Hicksian price elasticity measures the responsiveness of quantity demanded due to changes in prices only, hence, it is usually referred to as elasticity of substitution. Additionally, Hicksian elasticities tend to be smaller in magnitude than Marshallian elasticities since Hicksian elasticities have a price effect while Marshallian elasticities have both price and income effects. Table 4 presents Hicksian price elasticities for the various import meat categories for Trinidad and Tobago derived using equation (9). It was

Import Meat Group	Beef	Pork	Poultry	Seafood	Mutton
Beef	**-0.437** **(0.153)**	0.043 (0.078)	0.259 (0.068)	0.336 (0.105)	-0.200 (0.086)
Pork	0.115 (0.211)	**-0.324** **(0.234)**	-0.062 (0.119)	-0.018 (0.195)	0.289 (0.148)
Poultry	0.856 (0.228)	-0.077 (0.146)	**-1.178** **(0.175)**	0.396 (0.186)	-0.007 (0.163)
Seafood	0.464 (0.145)	-0.009 (0.099)	0.164 (0.077)	**-0.920** **(0.179)**	0.301 (0.109)
Mutton	-0.718 (0.293)	0.382 (0.205)	-0.010 (0.111)	0.780 (0.254)	**-0.434** **(0.103)**

Note: Standard errors in parentheses.
Source: Own calculation based on data from FAOSTAT

Table 4: Hicksian price elasticities for imported meats and seafoods.

found that all calculated own-price Hicksian elasticities were statistically significant, except for imported pork. In addition, all Hicksian elasticities carried the appropriate negative sign. For Trinidad and Tobago, it was found that a 1% increase in the price of imported beef, pork, poultry, seafood, and mutton is expected to bring about on average a 0.44%, 0.32%, 1.18%, 0.92%, and 0.43% decrease in import volumes, respectively. Imported beef, pork, seafood, and mutton was found to have inelastic import demand. Imported poultry on the other hand was found to be import elastic. Imported beef and mutton was found to be the least responsive to changes in their import prices while poultry was found to be the most responsive.

Table 4 also presents Hicksian cross-price elasticities for the five imported meat categories. The study found that mostly substitution relationships existed among the various imported meat categories for the study period. This is since most cross-price elasticities were found to be positive, which signifies that an increase in the price of one particular imported meat group would most likely result in reduced consumption of their group and consumers would substitute that particular meat group with another relatively cheaper one.

Imported beef was found to have substitution relationships with imported pork, poultry, and seafood but a complementary relationship with imported mutton. A 1% increase in the price of imported beef is expected to bring about a 0.04%, 0.26%, and 0.34% increase in demand for imported pork, poultry, and seafood, respectively. In contrast, a 1% increase in the price of imported beef is expected to bring about on average a 0.20% decrease in demand for imported mutton. Imported seafood was found to be the most responsive to changes in the price of imported beef. Imported pork was found to be substituted for imported beef and mutton when price changes. A 1% increase in the price of imported pork is expected to bring about a 0.12% and 0.29% increase in demand for imported beef and mutton, respectively. However, imported pork was found to have complementary relationships with imported poultry and seafood as a 1% increase in the price of imported pork is expected to bring about a 0.06% and 0.02% decrease in demand for imported poultry and seafood, respectively. Imported seafood was found to be substituted with imported beef, poultry and mutton when prices change, but complementary with imported pork.

Policy recommendations

Based on the findings of the study, several policy implications and recommendations can be made to address the import demand for meat and seafood in Trinidad and Tobago, with the aim of promoting food security and sustainability. Firstly, given that imported beef was found to be income inelastic, policymakers could focus on enhancing domestic production and reducing reliance on imported beef. This could be achieved through initiatives such as providing support to local farmers, improving breeding and rearing practices, and implementing quality assurance measures to ensure competitiveness in the domestic beef market. Additionally, since imported poultry, pork, seafood, and mutton were identified as luxury goods with income elasticities all exceeding unity, there is an opportunity for policymakers to explore strategies that balance import demands while encouraging local production. One potential approach could be to promote sustainable aquaculture practices and invest in the development of local poultry and pork industries. This could involve offering incentives to farmers, providing technical assistance, and facilitating access to financing options to stimulate growth in these sectors. Furthermore, policymakers could consider implementing trade policies that incentivize the consumption of locally produced meat and seafood. This could include imposing tariffs or import quotas on luxury imports while simultaneously providing support and incentives for local producers. Such measures would not only enhance food security but also contribute to the overall sustainability of the agricultural sector in Trinidad and Tobago.

The own-price elasticities of imported meat and seafood provides valuable insights for policy recommendations. Beef, pork, and mutton were found to be inelastic, indicating that trade policies should be managed to ensure a stable supply of these meats at reasonable prices. Negotiating favorable trade agreements with exporting countries can help maintain a steady and affordable supply. However, the own-price elasticities of imported poultry and seafood indicate that policies should focus on encouraging local production. This can be achieved through supporting domestic farmers, investing in research and development, and implementing quality standards to ensure the safety and competitiveness of domestic poultry and seafood products. Moreover, consumer awareness and education campaigns can play a vital role in stimulating demand for locally produced meats and seafood. Promoting the benefits of consuming locally sourced products can foster a sense of food security and sustainability among the population. By implementing a combination of these policy measures, Trinidad and Tobago can strike a balance between managing trade policies, promoting local production, and ensuring a resilient and self-sufficient food system that meets the dietary needs of the population while reducing dependency on imports.

Conclusion

This article analyzed the import demand for beef, pork, poultry, seafood, and mutton in Trinidad and Tobago for the period 1976 to 2019 using a linearized almost ideal demand system model. The goal was to analyze the impact price and income on meat and seafood import demand. It was found that own-price for imported poultry and seafood negatively affected import expenditure share. In contrast, own-price positively affected the import expenditure shares of imported pork and mutton. With respects to income or expenditure, increase in income negatively affected import expenditure share of imported beef while it positively affected the import expenditure share of all other imported meats and seafood.

The study also calculated import expenditure and price elasticities for imported meat and seafood. Based on import expenditure elasticities, imported meat and seafood were found to be normal goods. Imported pork, poultry, seafood, and mutton were all found to be luxuries while imported beef was found to be import inelastic. Imported poultry was found to be the most income elastic among all imported animal proteins with an import expenditure elasticity of 1.938. Imported beef had an import expenditure elasticity of 0.569 which signified that this imported meat category was least responsive to changes in income.

The article also presents Marshallian and Hicksian own- and cross-price elasticities. Based on Marshallian own-price elasticities, imported beef, pork, and mutton were found to be price inelastic while imported poultry and seafood were found to be price elastic. Imported poultry was found to be the most price elastic with an elasticity of 1.395 followed by seafood which was 1.224. Imported pork was found to be the least responsive to price changes with an own-price elasticity of 0.480. Marshallian cross-price elasticities revealed that various complementary and substitution relationships existed among various imported meats and seafood. Hicksian cross-price elasticities revealed that mostly substitution relationships existed among imported meats and seafood during the study period. The study also suggested some policy recommendations as it relates to the results.

It is important to acknowledge the limitations of this study. One limitation is the reliance on historical data, which may not fully capture current market dynamics and consumer preferences. The study utilized annual data which makes it difficult to assess seasonal variations in import meat and seafood import demand. Additionally, the use of the LA-AIDS model has inherent limitations in capturing complex relationships between import demand, prices, and income, potentially resulting in oversimplified representations of demand behavior. Furthermore, the possibility of omitted variable bias should be acknowledged, as there may be other factors influencing import demand for meat and seafood that were not accounted for in this analysis. Despite these limitations, the study provides valuable insights into import demand elasticities and offers a foundation for further research and policy discussions on promoting food security and sustainable meat and seafood production in Trinidad and Tobago.

Corresponding author:
Dr. Ir. Nikmatul Khoiriyah, MP.
Department of Agribusiness, Faculty of Agriculture, University of Islam Malang,
Jalan Mayjen Haryono No.193, Dinoyo, Kec. Lowokwaru, Kota Malang, Jawa Timur 65144, Indonésia
E-mail: nikmatul@unisma.ac.id

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Mapping the ICT in Agricultural Research: A Bibliometric Analysis

Adriana Novotná

Faculty of Economics, Technical University of Košice, Slovak Republic

Abstract

In recent years, the information and communication technologies (ICT) with the agricultural sector has garnered significant attention due to its potential to transform and optimize agricultural practices. This study provides a comprehensive picture of the previous and current state of ICT in agricultural research, thereby shedding light on the existing knowledge landscape and key research themes. The study presents a mapping research approach that explores the conceptual structure of ICT in agriculture research using co-occurrence analysis drawing upon the Web of Science database with the results of 8,654 documents that have been published from 1989 to 2023. From a total of 2,930 keywords and the five most frequent keywords have been identified as: "performance", "growth", "expression", "impact", and "identification". The findings from this study contribute to the broader understanding of the ICT-agriculture research landscape and provide valuable insights for researchers, practitioners, and policymakers in this evolving field.

Keywords

Agricultural research, ICT, co-occurrence analysis, scientific map, VOSviewer.

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Introduction

In the 1970s, researchers started showing interest in the potential of computer technology in agriculture. These early stages were associated with the development of software applications for managing agricultural data (Brockington, 1979), such as yield management (Joyce and Griffin, 1978), crop planning (Bauer and Cipra, 1973), and farm management improvement (Connor and Vincent, 1970). Since that time, there has been a significant transformation in the utilization of technologies, marked by notable advancements and changes. Information and Communication Technologies (ICT) have become a vibrant topic in various sectors, revolutionizing the way how to collect, analyse, and disseminate information. One such sector where the application of ICT holds significant potential is agriculture. The intersection of ICT and agricultural research opens new avenues for improving productivity sustainability, and decision-making in the agricultural industry.

In 2011, World bank (2011) published a document about ICT in agriculture that presents various case studies from where ICT has been utilized to support the agricultural sector primarily focused on developing countries. The publication examining the utilization of ICT in agriculture and its potential benefits for smallholder farmers and highlights the challenges and limitations in implementing ICT in agriculture. The significance of ICT has been also examined and affirmed through various publications, such as Lin, et al. (2017) arguing that an ICT e-agriculture with a blockchain infrastructure is the next step in the evolution of ICT e-agriculture. Gangopadhyay et al. (2019) conduct their study in India, where agriculture is the main source of livelihood for most of the population and the sector is acutely susceptible to the impacts of climate change. They claim that ICT-based climate information and agro-advisory services can help to manage agricultural inputs (water, seed, fertilizer, and energy) to get maximum benefit of good climatic conditions. Chowhan and Ghosh (2020) analyse features of ICT in agriculture in Bangladesh and claiming that future of farming will be more information based, computerized, software oriented and wireless. A study by Li et al. (2023) carries out a review of smart agriculture and production practices in Japanese large-scale rice farming contributing that smart technology enables data collection and mining for efficient agricultural production. In these publications, authors endeavoured to evaluate the practical utilization of ICT in selected domains, but to explore the application of ICT in agriculture, researchers can focus also on examining practical applications and utilization of ICT technologies through bibliometric analyses of publications. For example, Ayim et al. (2020) explore ICT innovations in the agriculture sector of Africa and their results show that the primary adopted ICT technologies are text and voice-based services targeting mobile phones aimed at improving access to accurate and timely agriculture information. Onyancha and Onyango (2020) analyse dominant occurrence of keywords related to agricultural domains, which represent the primary livelihoods of numerous impoverished families in sub-Saharan Africa, implies deliberate efforts to strategically employ ICTs in these areas to optimize agricultural production and foster regional development. Stefanis et al. (2022) provide the visualization mapping of the research agenda through a bibliometric analysis of 453 articles in the field of ICT and climate change that affects the productivity of agriculture in the period from 1999 to 2021. The authors claim that acquiring knowledge about the specific associations between ICTs and agricultural practices or specific tasks would significantly enhance the effectiveness and efficiency of ICT application. Recently, there is also an increasing number of examples of studying bibliometric publications in the given field, e.g., Bertoglio et al. (2021), Ribeiro et al. (2021), Punjani et al. (2023).

This study reveals a growing interest in analysing the role of ICT in agriculture, as evidenced by the increasing number of relevant documents published over the years. Based on the above-mentioned bibliometric studies we provide co-occurrence analysis method to map the field of the ICT in agriculture research between 1989 and 2023, which aims to assess significant keywords within the topic. Despite the extensive body of academic literature about ICT in agriculture in recent decades, the research landscape remains fragmented and lacks consensus. There is a need to illuminate the key factors of this significant research area over broader period. Motivated by these gaps, the present study undertakes an examination of the conceptual structure of ICT in agriculture research as an interdisciplinary field that draws upon diverse theories and knowledge from various disciplines. With the aim of expanding the existing knowledge base, this study seeks to provide insights into the current paradigms of ICT and agriculture and identify future research directions. To achieve these objectives, the following three research questions (RQ1-RQ3) will be addressed in this paper:

- RQ1: What are the most important topics in ICT and agriculture research?
- RQ2: How have the publication dynamics in the topic of ICT in agriculture research changed between 1989 and 2023?
- RQ3: What are the future directions of ICT in agriculture research?

First question seeks to identify the most significant topics in ICT and agriculture research, providing insights into the key areas of focus within this domain. Second question explores the publication dynamics over the period from 1989 to 2023, providing insights into the trends and developments within the ICT in agriculture research landscape. Lastly, the study aims to outline the future directions of ICT in agriculture research, offering valuable insights into the potential areas of growth and exploration in this field. By addressing these research questions, this study contributes to a comprehensive understanding of the previous, current state and future potential of ICT in agriculture research. To accomplish these research objectives, an extensive dataset comprising 8,654 documents sourced from the Web of Science (WOS) database is employed. The utilization of this comprehensive dataset allows for a comprehensive analysis of keywords within the field of ICT in agriculture.

Materials and methods

This study undertook a systematic review of academic research on the ICT and the agricultural sector spanning the period from 1989 to 2023. Despite prior academic attention to the topic, the study sought to assess of past and the current state of knowledge in the field and capture its developments. By examining studies published up until July of 2023, it aimed to provide insights into the most recent advancements and ensure our evaluation reflects the current understanding in the field. The study utilized the Clarivate Analytics WOS database to obtain data. The search scope focused on papers consisting of the keywords "ICT agriculture", which, after trying various versions such as "ICT agricultural" or "ICT in agriculture," yielded the highest number of results. This research string served as a focused query to retrieve relevant documents specifically related to the examined topic. A comprehensive search compiled on July 12, 2023, yielded a total of 8,654 documents relevant to the research topic. Of these, 6,905 were articles and 109 early access articles, 1,159 were proceeding papers, 560 were review articles, 102 were book chapters and the rest consists of meeting abstracts (36), editorial materials (30), data papers (12), letters (12), corrections (6), and one biographical-item and retracted publication. To map the conceptual structure of the topic, this study employed co-occurrence networks analysis using the VOSviewer software, building upon prior research by Luckyardi et al. (2022) who provide bibliometric analysis of climate smart agriculture research or Kushartadi et al. (2023) with their analysis of two decades of smart farming. This established method was selected to gain insights into the interrelationships and patterns within the ICT and agriculture research domain in general. As authors typically tend to focus solely on specific areas within agriculture, the utilization of VOSviewer in such a comprehensive manner, as presented in this study, has not been previously demonstrated.

The inception of VOSviewer can be traced back to its initial publication by Van Eck and Waltman (2010) but since that time subsequent advancements and expansions have rendered the content of the paper partially outdated, so we decided to follow the current manual by Van Eck and Waltman (2023). By visualizing and analysing the co-occurrence networks between items, researchers can identify patterns, relationships, and dependencies that might not be apparent through other methods. According to Van Eck and Waltman (2023), in co-occurrence network analysis of keywords, the co-occurrence relationships can be used to identify important keywords or topics that co-occur frequently in a corpus, enabling the discovery of thematic patterns or topic clusters. This analysis can aid in identifying hidden associations, exploring collaborative opportunities, improving recommendation systems, and gaining deeper insights into the structure and dynamics of the analysed data. The insights gained from co-occurrence network analysis can provide valuable knowledge for decision-making, knowledge discovery, and understanding complex systems. Due to the complexity of this issue and analysed keywords, special techniques such as thesaurus methodology or other advanced keyword analysis methods, we opted for a more generalized analysis approach that allowed us to explore broad trends efficiently. While this approach provided valuable insights, it should be noted that specific keyword analysis techniques were not employed, does represent a limitation in terms of potential depth and specificity in our analysis.

VOSviewer software offers three distinct visualizations for data analysis. There is network visualization, the overlay visualization, and the density visualization. In the network visualization, items are visually represented by their labels and are typically depicted as circles. The size of both the label and the circle associated with an item corresponds to its weight. A higher weight results in a larger label and circle for the item. The colour assigned to an item corresponds to the cluster it belongs to. The second one, the overlay visualization shares similarities with the network visualization, with the primary difference lying in the colour scheme assigned to the items. If items are associated with scores, their colour is determined by the score value assigned to each item. By default, the colour scale ranges from purple (indicating the lowest score) to yellow (representing the highest score). In the density visualization, items are represented by their labels, like the network visualization and overlay visualization. Each point in the item density visualization is assigned a colour that indicates the density of items in particular area. The colour of a point reflects the density of neighbouring items. Points with a higher number of items in their vicinity and higher weights of the neighbouring items tend to have colours closer to yellow (Van Eck and Waltman, 2023).

Vosviewer utilizes a similarity measure called association strength, which has been referenced as the proximity index (for example, Peters and Van Raan, 1993 or Rip and Courtial, 1984) or the probabilistic affinity index (for example, Zitt et al. 2000). The association strength, employed to determine the similarity between two items *i* and *j*, is computed as per the following formula:

$$s_{ij} = \frac{c_{ij}}{w_i w_j} \quad (1)$$

Where c_{ij} represents the count of co-occurrences of items *i* and *j*, while w_i and w_j represent either the total occurrences of items *i* and *j* or the total co-occurrences of these items.

The VOS mapping technique aims to minimize a weighted sum of squared Euclidean distances between pairs of items. The weighting factor increases as the similarity between two items increases, indicating a greater influence on the overall distance. To prevent trivial mappings where all items are in the same position, a constraint is enforced to maintain an average distance of 1 between pairs of items. Mathematically, the objective function to be minimized can be expressed as follows:

$$V(x_1, \dots, x_n) = \sum_{i<j} s_{ij} ||x_i - x_j||^2 \quad (2)$$

The vector $V(x_1,\dots, x_n)$ represents the coordinates of item i in a two-dimensional map, and ||•|| denotes the Euclidean norm. The objective function is minimized under the following constraint:

$$\frac{2}{n(n-1)} \sum_{i<j} \left|\left|x_i - x_j\right|\right| = 1 \quad (3)$$

The numerical solution to the constrained optimization problem, minimizing (2) subject to (3), is achieved through a two-step process. Initially, the constrained optimization problem is transformed into an unconstrained optimization problem. Subsequently, a majorization algorithm, a variant of the SMACOF algorithm used in multidimensional scaling literature (for example, Borg and Groenen, 2005), is employed to solve the unconstrained problem. To enhance the likelihood of obtaining a globally optimal solution, the majorization algorithm is executed multiple times, each time with a distinct randomly generated initial solution.

In the last step, VOSviewer applies three key transformations to the solution: translation, rotation, and reflection. Firstly, the solution is centred at the origin through translation. Secondly, a rotation is performed to maximize the variance on the horizontal dimension using principal component analysis. Lastly, the solution may be reflected in the vertical or horizontal axis based on the median values. According to Van Eck and Waltman (2010), these transformations collectively guarantee the production of consistent and reliable results in VOSviewer analyses.

Results and discussion

Firstly, with the aim to bring a valuable starting point to understand the academic landscape and the dissemination of research in the analysed area, Table 1 provides an overview of top 10 journals by the number of documents in the analysis. The list is organized based on the frequency of publications in each journal, offering valuable insights into the leading scholarly outlets that are significant contributors to the discourse in the field of ICT and agriculture. By presenting this comprehensive overview, it aims to highlight the prominent journals that have been published a substantial number of documents relevant during the period between 1989 and July 2023 with information of the H-index and Impact factor up to the latest available data.

The "Scientific Reports" was the top journal in terms of the number of articles with 137 documents. The number of documents 112 represented "International Journal of Molecular Science". For the others, the number of documents was below 100, for example "PLoS ONE" with the number of 95 and last mentioned, "Applied Sciences Basel", with the number of documents 57. The place of publication of these journals is in Switzerland and Germany and the United

Journal	Country	Publisher	H-index (2022)	Impact Factor (2022)
Scientific Reports	United Kingdom	Nature Publishing Group	282	4.44
International Journal of Molecular Science	Switzerland	Multidisciplinary Digital Publishing Institute	230	5.57
PLoS ONE	United States	Public Library of Science	404	3.7
Sustainability	Switzerland	Multidisciplinary Digital Publishing Institute	136	3.9
Computers and Electronics in Agriculture	Netherlands	Elsevier	149	6.757
Journal of High Energy Physics	Germany	Springer Verlag	247	5.4
Advances in Intelligent Systems and Computing	Germany	Springer Science and Business Media Deutschland	58	0.63
Food Chemistry	United Kingdom	Elsevier	302	8.8
Frontiers in Plant Science	Switzerland	Frontiers Media	187	6.627
Applied Sciences Basel	Switzerland	Multidisciplinary Digital Publishing Institute	101	2.838

Source: Prepared by author

Table 1: Overview of the top ten journals that represent ICT and agriculture research (1989 – July 2023).

Kingdom also have two representatives.

Table 2 provides an overview based on affiliations to specific organizations that can help readers to identify organizations active in ICT and agriculture research for potential collaborations and knowledge exchange.

Name	Country	Number of documents
Seoul National University	South Korea	1,231
Chonnam National University	South Korea	535
Chinese Academy of Science	China	503
Kyungpool National Universi-ty	South Korea	476
Korea University	South Korea	467
National Taiwan University	Taiwan	402
Sungkyunkwan University	South Korea	369
Kangwon National Universtiy	South Korea	305
Jeonbuk National University	South Korea	299
University of California	United States	287

Source: Prepared by author

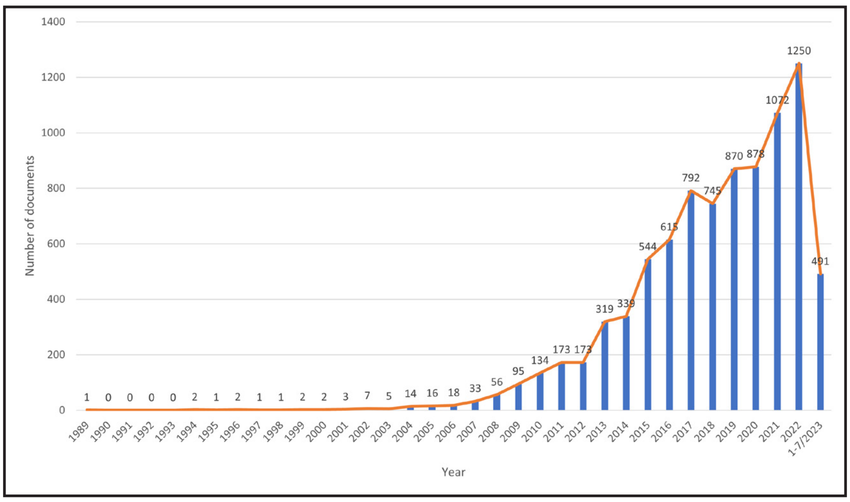
Table 2: Overview of the top ten affiliations that represent ICT and agriculture research (1989 – July 2023).

The results indicate that most organizations involved in ICT and agriculture research are universities in South Korea. This could suggest that South Korean universities are actively engaged in this research area and may be leading contributors to the advancement of innovations in the field. Their dominant presence may also indicate a strong emphasis on research and development initiatives related to ICT applications in agriculture, potentially driven by the country's agricultural landscape and the recognition of the significance of ICT in enhancing agricultural practices and productivity.

The final step preceding the actual analysis using VOSviewer was the examination of the trend in publication growth over the observed period. This trend is illustrated in Figure 1 and conducted a systematic analysis of the growth pattern of publications related to ICT and agriculture research throughout the specified time period.

The overall trend of published documents started in 1989 with one article, and over time, this number gradually increased. The count of publications in the double digits began in 2004, while three-digit figures emerged from 2010 onwards. The most significant period occurred, particularly after 2021, when more than a thousand publications were published. The highest number of studies was reported in 2022, with 1,250 documents. As of July 12, 2023, there have been 491 publications. However, given the upward trend in the number of publications, it is expected that this count will surpass the previous years, as indicated by the increasing trend presented in Figure 1.

In the following section, the study focuses on the analysis of keywords within the analysed dataset. We decided to remove the keywords "ICT" and "agriculture" from the analysis as they were primarily used to create an overview of the dataset. Including these terms in the subsequent analysis could potentially bias the results and misrepresent the actual focus of research in the field. By dividing the study into distinct timeframes, it is possible to examine how the prevalence and significance of keywords evolved during different phases of research. To capture the changes that occurred during the analysed period, we set a threshold for keyword frequency into four periods (from 1989 to 2009, from 2010 to 2020, from 2021 to 2023



Source: Prepared by author

Figure 1: Publication trend.

and all periods). Except for the first period, where only 14 keywords met the specified thresholds, Table 3 shows the top 25 frequent keywords in these time periods.

First analysed period in Table 3, from 1989 to 2009, represent the early years of research in the field, where ICT and agriculture was a relatively new topic, and the number of publications was low. Keywords with highest frequency number include "Information", "Management", "Impact", and "Internet", which reflect the growing importance recognition of the potential benefits of integrating ICT into agriculture. "Information" appears predominantly due to its representation as an abbreviation for ICT. Upon closer examination, we examined that the term "Management" can be associated with concepts such as "quality of management" (e.g., Schiefer, 1999) or "knowledge management" (e.g., Bianca, 2005 or Zschocke et al., 2007). Other keywords such as "Plants", "Gene", and "Cloning" suggest a focus on agricultural biotechnology and genetic research indicates interest in improving crop yields, enhancing plant traits, or developing genetically modified organisms to address challenges in agriculture and were predominantly observed from 2000 onwards (e.g., Macek et al., 2002; Entry et al., 2008; or Khan et al., 2009). Period from 2010 to 2020 could indicate a time when ICT and agriculture gained more attention, resulting in a significant increase in the number of publications. Analysing this period can provide insights into emerging technologies and keywords that emerged during this transformative decade. For instance, keywords like "Expression", "Identification", and "Growth" have substantially higher frequencies, indicating a surge in research focusing on emphasis on molecular and genetic research in agriculture. The combination of these keywords, for example, is found in study by Liu et al. (2013), Ryu et al. (2014), Zhou et al. (2016), etc. "Model" and "System" suggest

Keywords (1989-2009)	Fr.	Keywords (2010-2020)	Fr.	Keywords (2021-2023)	Fr.	Keywords (All Periods)	Fr.
Information	11	Expression	332	Expression	149	Expression	489
Management	11	Identification	225	Growth	133	Growth	333
Impact	9	Growth	196	Performance	112	Identification	316
Internet	8	Model	170	Impact	97	Model	258
Diversity	6	Gene	161	Quality	86	Protein	229
Plants	6	Protein	159	Identification	86	Gene	228
Accumulation	5	Management	122	Model	83	Performance	226
Expression	5	Information	118	Protein	70	Management	193
Gene	3	Performance	114	Temperature	69	Impact	186
Cloning	2	Activation	112	Oxidative stress	66	Information	184
Linked-immunosobent--assay	2	Oxidative stress	105	Gene	62	Oxidative stress	172
Model	2	Arabidopsis	102	Machine Learning	62	Quality	172
Simulation	2	Gene-expression	100	Management	61	System	165
System	1	Rice	99	System	61	Activation	162
		In-vitro	99	Information	59	In-vitro	157
		System	99	Deep Learning	58	Temperature	148
		Cells	94	In-vitro	56	Arabidopsis	141
		Biosynthesis	90	Behaviour	52	Water	140
		Evolution	90	Mechanisms	51	Rice	139
		Plants	88	Resistance	51	Resistance	139
		Water Resistance	87	Activation	50	Gene-expression	136
		Acid	86	Water	50	Apoptosis	130
		Metabolism	85	Optimization	49	Acid	129
		Systems	85	Design	48	Biosynthesis	126
		Apoptosis	84	Nanoparticles	46	Cells	125

Source: Prepared by author

Table 3: Top keywords in the ICT and agriculture research.

the use of computational and modelling approaches to understand agricultural systems and processes. "Activation", "Oxidative stress", "Cells", "Water Resistance", "Acid", "Metabolism", "Biosynthesis", "Evolution", "Plants", "Apoptosis", and "In-vitro" imply a focus on various biological processes and pathways relevant to agricultural organisms. Overall, the keywords suggest that during this period, there was a significant interest in molecular and genetic aspects of agriculture, along with continued attention to agricultural management and information technologies. The current period (from 2020 to July 2023), which represents period with increase in the number of documents beyond thousand, might represent as a phase of rapid expansion and innovation in the field. Comparing to previous periods, some keywords that were prominent in the earlier periods, such as "Internet", "Diversity", and "Plants", have been replaced by new keywords like "Machine Learning", "Deep Learning", and "Nanoparticles". This suggests an increasing emphasis on technological advancements and interdisciplinary approaches in ICT and agriculture research. Additionally, the higher frequency of keywords like "Expression," "Growth," and "Performance" in the current period indicates ongoing interest in genetic and biotechnological studies related to agricultural development and productivity. In this period, some of the most highly cited documents with the particular keywords are by Sultana et al (2020), Lin et al. (2020) or Li et al. (2020). Among the most frequently occurring keywords during all analysed periods, there are "Expression" "Growth" "Identification" and "Model" which indicate significant research focus in the field of ICT and agriculture aiming to investigate the roles and mechanisms of gene expression in agricultural systems, exploring the factors that influence agricultural growth, developing identification methods for specific agricultural components, and employing various models to simulate and analyse agricultural processes. Additionally, keywords like "Protein", "Gene", "Performance", and "Management" have consistently featured, demonstrating their sustained relevance and importance in the scholarly discourse over time.

In the following part, we conducted co-occurrence network analysis using VOSviewer. Due to the limited number of keywords, we decided to explore the network across all the periods. This approach allows us to gain a comprehensive understanding of the interconnections and relationships between various key terms in the field of ICT and agriculture. Figure 2 represents co-occurrence network analysis.

The most frequent keywords were divided into seven clusters with seven different colours. Keywords that were similar in content were grouped in a cluster. For example, the keywords "Information" and "Management" were in the blue cluster and the keywords "Model" and "Hadron-hadron scattering" were in the orange cluster. The size of the circles indicated keyword frequency, and the thickness of the lines indicated the strength

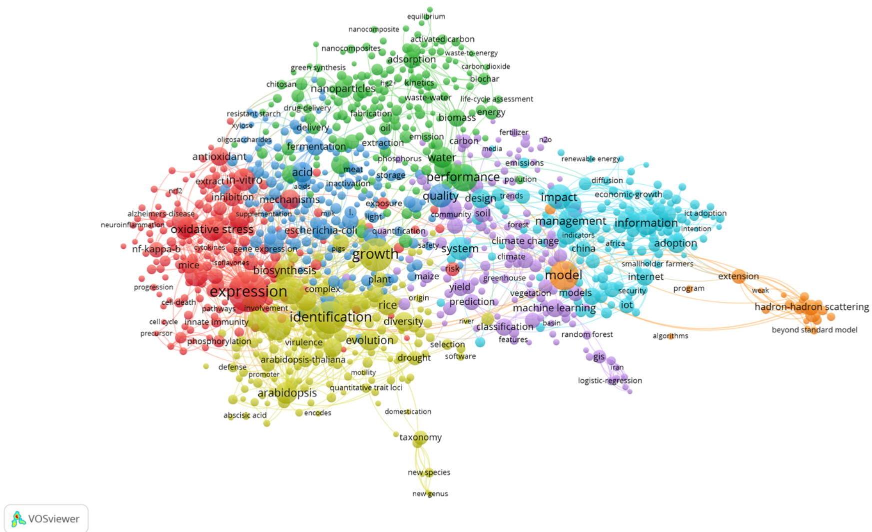


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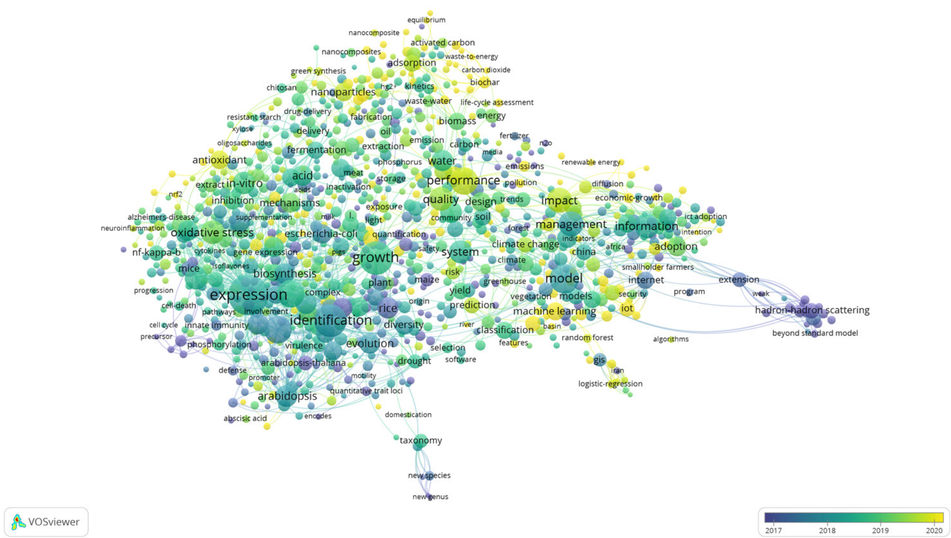
Figure 2: Co-occurrence network analysis (1989 – July 2023).

of co-occurrence within and between clusters. As the Figure 2 shows, all the clusters were interconnected, and there were strong relationships between all seven clusters. This indicated the high interdependence of different area of ICT and agriculture research. Overall, there were 998 keywords, 7 clusters, and 39,813 links in this network, with a total link strength of 68,046. Cluster 1 (represented in red colour) emerged as the largest cluster with 183 keywords, prominently featuring the term "Expression." Within this cluster, keywords related to human entities and various diseases (e.g., oxidative stress, in-vitro) were also observed. This alignment can be attributed to the focus on investigating the expression of genes in diverse biological contexts. Cluster 2, represented in green and comprising 175 keywords, revolves around the concept of "Performance". The keywords in this cluster pertain to different forms of performance in the agricultural sector, including biomass, nanoparticles, and water, indicating a strong emphasis on assessing and enhancing agricultural productivity. Cluster 3, characterized by its dark blue colour and comprising 17 keywords, encompasses terms such as "Acid", "Fermentation", "Escherichia-coli", and "Metabolism". These keywords share a common theme of being related to biochemical processes and metabolic pathways. Cluster 4, depicted in yellow and comprising 166 keywords, prominently features terms like "Growth" "Identification" "Gene" "Diversity" "Arabidopsis" "Cloning" and "Evolution". These keywords indicate a significant research focus on the genetic aspects of plant growth and evolution. Cluster 5, represented in purple colour and encompassing 145 keywords, centres around terms such as "Machine learning", "Yield", "Dynamics", and "Climate changes". This cluster suggests a shared interest in studying the application of machine learning techniques to enhance agricultural productivity and address the challenges posed by climate changes. Cluster 6, in light blue colour and consisting of 134 keywords, is characterized by keywords like "Management", "Information", "Impact", "Adopting", and "System". This cluster highlights a strong emphasis on the management and adoption of ICT and related systems in agriculture. Cluster 7, the smallest cluster represented in orange colour with 22 keywords, includes terms like "Model", "Algorithms", "Beyond standard models" "Hadron-hadron scattering". These keywords indicate a focus on modelling and advanced algorithms, particularly in the context of complex systems and physical phenomena.

Figure 3 shows results of overlay visualization, the yellow colour denotes terms that have appeared in recent research, while purple indicate that research on a term is carried out closer to the year 2017 (Luckyardi et al., 2020 and Van Eck and Waltman, 2023). Among the darker shades, we find keywords such as "Hadron-hadron scattering", "Rice", or "Mice" that might represent more established or traditional topics in the field of ICT and agriculture. In contrast, the lightest and most recent shades, including terms like



Source: Prepared by author

Figure 3: Co-occurrence overlay visualization analysis (1989 – July 2023).

"Machine learning", "IoT", "Nanoparticles", and "Antioxidant", suggest that these topics are currently gaining significant attention and are likely to be the focus of recent or ongoing research in the field of ICT and agriculture.

As illustrated in Figure 4, increased density is observed within the range of Cluster 1 to Cluster 4 and their corresponding keywords. The concentration of yellow areas around Clusters 1 to 4 signifies that these clusters and their associated keywords are more prevalent and frequently occurring in the research literature. On the other hand, keywords from other clusters, such as "Management", "Innovation", "Impact", and "Model", can be also considered as frequently occurring terms.

For a more in-depth analysis, we decided to create a trend analysis of publications based on the most frequently cited keywords within each cluster. We chose to perform a trend curve analysis for the past ten years in research, using publications presented through WOS database. For this analysis, the term "ICT agriculture" is used along with the word that appeared most frequently in each cluster. As the year 2023 was still ongoing at the time of this study, we chose not to disrupt the trend analysis. Consequently, we decided to focus this examination on the previous 10-year period, encompassing the years from 2013 to 2022.The result of this investigation is shown in Figure 5.

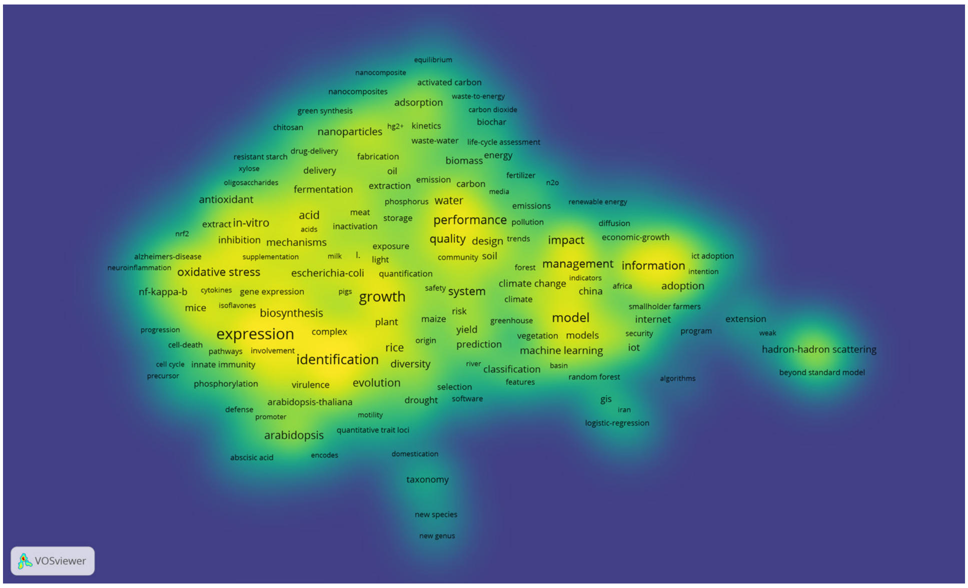


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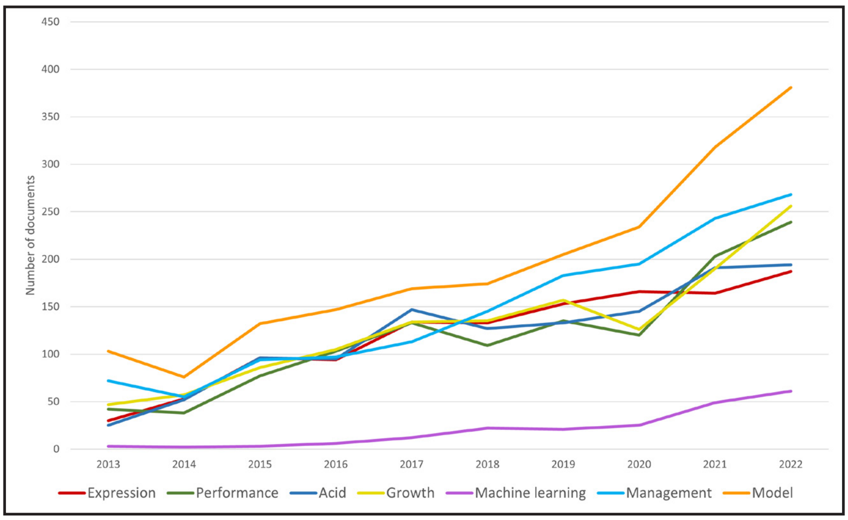
Figure 4: Co-occurrence density analysis (1989 – July 2023).



Source: prepared by author

Figure 5: Publication trend of keyword frequencies over 10 years.

According to results, the frequency of the keyword "Expression" steadily increased from 30 in 2013 to 187 in 2022, indicating a growing interest in this area of research. Similarly, "Performance" also exhibited an upward trend, reaching its peak at 239 in 2022. In contrast, keywords like "Acid" (Cluster 3) and "Management" (Cluster 6) showed relatively stable patterns over the years, suggesting a consistent focus on this topic. "Machine learning" keyword experienced a significant increase in frequency, from 3 documents in 2013 to 61 documents in 2022, reflecting the increasing importance of this technology in the domain. The keyword "Model" displayed an interesting trend over the ten-year period from 2013 to 2022. In 2013, it had a frequency of 103, indicating a significant presence in the research landscape. Over the following years, its frequency fluctuated but generally showed an upward trajectory, reaching 381 in 2022. This substantial increase suggests that the concept of "Model" gained prominence in the field of ICT and agriculture research. Such an upward trend may be indicative of a growing reliance on modelling techniques and computational approaches within this domain, reflecting a broader trend toward data-driven and simulation-based research methodologies.

Conclusion

As global challenges such as population growth, climate change, and resource constraints continue to exert pressure on the agriculture sector, harnessing the power of ICT becomes increasingly crucial. By leveraging advanced technologies, data analytics, and smart solutions, ICT can enhance agricultural productivity, optimize resource utilization, and improve supply chain efficiency. This study delved into the realm of ICT and its profound impact on agriculture with comprehensive search that has yielded a total of 8,654 documents relevant to the research topic of ICT and agriculture during the period from 1989 to July 2023, providing a substantial dataset for analysis and insights into the advancements and trends in the field over time.

The overview of top journals showcases the leading scholarly outlets that have contributed significantly to the discourse, offering a comprehensive snapshot of the most prominent publications relevant to the field over the analysed period. Notably, "Scientific Reports" emerged as the top journal with 137 articles, followed by "International Journal of Molecular Science" with 112 documents. These findings shed light on the key academic platforms that have played a pivotal role in disseminating knowledge and fostering research in this critical area. Of particular significance, South Korean universities emerged as the predominant contributors in this domain. This underscores the importance of collaboration and knowledge exchange with South Korean institutions for the advancement of research and innovation in the field. While we acknowledge that approximately half of the examined papers originate from South Korea, this regional specificity was not explicitly explored in our analysis, which can be considered a limitation of this study. Future research could delve deeper into regional nuances and their impact on research trends within the field of ICT in agriculture to provide a more comprehensive perspective.

Through the exploration of three pivotal research questions, we gained valuable insights from VOSviewer and provide comprehensive analysis of research literature spanning from 1989 to 2023 allowed us to decipher the evolving landscape of ICT in agriculture. Regarding the first research question, we identified the most important topics in ICT and agriculture research. The analysis revealed that topics such as "Expression", "Growth", "Identification", and "Model" were among the most frequently occurring keywords across all the analysed periods. Additionally, keywords like "Management", "Innovation", "Impact", and "Model" also emerged as prominent and frequently researched terms in the domain of ICT and agriculture. To understand the publication dynamics in the field, we conducted a systematic examination of research outputs between 1989 and 2023. The results showed a significant increase in the number of publications over the years, with a notable surge in research output starting mainly from 2010. This trend indicates a growing interest and focus on the integration of ICT in agriculture, reflecting the increasing importance of this field in addressing contemporary agricultural challenges. As we explore the future directions of ICT in agriculture research, our findings suggest a growing interest in emerging areas of inquiry. The analysis indicates a notable shift towards investigating cutting-edge technologies and their applicability to agricultural practices. This trend reflects the evolving nature of ICT and its increasing relevance in the agricultural sector. Given the continued importance of agriculture for livelihoods and the evolving landscape of ICT, it is reasonable to anticipate a growing body of research in this field in the coming years.

Corresponding author:
Adriana Novotná, PhD.
Department of Banking and Investments, Faculty of Economics, Technical University of Košice
Němcovej 32, 040 01 Košice, Slovak Republic
E-mail: adriana.novotna@tuke.sk

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Efficiency of Use Fixed Assets in the Context of Profitability – Empirical Evidence of Food Industry Enterprises in Visegrad Group

Martina Novotná, Tomáš Volek

Faculty of Economics, University of South Bohemia in České Budějovice, Czech Republic

Abstract

Efficient use of production resources in enterprises is necessary for increasing their competitiveness and the potential for their future development. In today's global world, companies are forced to invest in new technologies that are both more energy-efficient and more environmentally friendly, including in the food industry. The paper focusses on the efficiency of production factors in relation to their economic success. The aim is to find possible variants of the development of the links between capital labour ratio and labour productivity in relation to the development of profitability of returns. Empirical analysis coved 2,526 enterprises in food industry in four examined European countries (Visegrad group -V4) - Czech Republic, Hungary, Poland, Slovak Republic. The contribution of the paper is the generalization of the links between the indicators of the efficiency of production factors in the form of recommended inequalities that can be used by enterprises for economically successful development..

Keywords

Food industry, profitability, labour productivity, capital labour ratio.

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Introduction

The covid crisis, followed by the energy and security crises, caused shortages in the production factors of labour and capital, which leads to a reduction in the potential and production capacity of some firms in the food industry and may, in many cases, lead to postponement of investments. At the same time, changes in climate policy are triggering a reorientation of firms towards a low-emission economy, i.e., firms adapting to various regulatory constraints, investing in "green technologies", developing digital infrastructure, and managing resources more efficiently. The desire and need to pursue intensive growth over extensive growth is coming. Thus, assess the relationship between capital intensity and labour productivity of enterprises. The food industry today is also significantly influenced by the situation in agriculture and its shift towards organic farming and the increasing demand for organic products (Redlichová et. al, 2021). In assessing its competitiveness in the future, it is also necessary to assess the efficiency of the factors of production in relation to their economic success. The main aim of this paper is to find possible variants of the development of the links between capital labour ratio and labour productivity in relation to the development of the profitability of returns.

In the food industry, investments and innovations basis for competitiveness companies (Firlej et al., 2017). However, new technologies, which affect all areas of activity, are only a means of achieving sustainable business growth. On the one hand, companies, in any sector, are forced to invest in new technologies that are both more energy-efficient and more environmentally friendly, but on the other hand, depending on the size of the company, it is questionable whether they are making sufficient use of these investments.

The paper is structured as follows: The theory of firm productivity, profitability, and investment company policy are briefly analysed in the first part. The second part presents the data and the research methodology. The third part shows and discusses the main results of companies' profitability and fixed assets productivity analysis. The last part summarises the results.

Theoretical background

The efficient use of factors of production such as capital in account fixed assets is a prerequisite for the economic success of firms. The basic indicator that measures this efficiency of factors of production are productivity indicators. Productivity shows how efficiently the factors of production (capital, labour) are used in production. Productivity is the ratio of outputs to inputs (Coelli et al., 2005). Productivity = output/input. Productivity is an important driver for economic growth and prosperity (Fried et al., 2008) for companies. The most frequently used indicators for measuring productivity are labour productivity and capital productivity. At the enterprise level, productivity is one of the factors of growth in the competitiveness of enterprises, which means increasing the efficiency (effectiveness) with which production factors are used in production. Not only is the general capital intensity monitored, but also the capital intensity of corporate investment (Gilje and Taillard, 2016). The dynamics and level of capital intensity depend on the type of sector (Berends, 2021; Romme, 2001). The level of labour productivity and capital productivity can also be positively affected by the integration of innovation (Mura and Hajduchova, 2020) and improved management. There are two sources of productivity growth: technical progress and growth in the capital-labour (C-L) ratio (Guest, 2011), i.e., investment growth.

The size of capital investment can also be influenced by external factors (Brennan, 2021; Apostolov et al., 2006; Doytch and Narayan, 2016). An enterprise study by Bialowolski and Weziak-Bialowolska (2014) pointed out that macroeconomic factories are the driving force determining investment decisions. Among these, we can include the business cycle and the economic situation in the world or investment support policy of EU in sector (Naglova and Šimpachová Pechrová, 2019). The results of the study Bialowolski and Weziak-Bialowolska (2014) also indicate that the results are strongly tied to the organizational form, size and industry in which the firm operates, thus preventing more universal conclusions.

The main direction of current investment is investment to the R&D and technology area of Industry 4.0. The Rodrigues (2020) enterprises study reveals the strong influence of institutional context and argues that without strong government support, corporate investment in R&D would be at a low level. The study by Li et al. (2020) points out that another direction is the area of corporate environmental responsibility (CER). In view of the current trend in reducing energy intensity, we can also expect a strong focus on a green investment policy for companies with strong investment support from governments or the EU. According Náglová a Pechrová (2019) investments in fixed assets by subsidies causes a slight increase in production efficiency in food industry enterprises. On the other hand, also the technical efficiency of non-subsidised enterprises is higher than that of subsidised enterprises and differs statistically significantly over time, so that the effect of subsidies is negative without affecting the higher technical efficiency of enterprises. The production factor plays an important role here, whether the investment is oriented towards increasing production or improving the quality of production.

The implementation of technology investments also affects capital intensity. Deepening the level of capital (fixed assets) increases output when labour productivity increases - i.e., capital is complementary to labour. Brennan (2021) argues that a higher capital-to-labour ratio tends to imply more output per worker or hour worked. In most cases, capital deepening and productivity growth are related, but people are the carriers of investment ideas, and subsequently the investment may not prove to be sufficiently effective. Businesses, however, always consider the impact of investments on the profitability of the business when evaluating investments.

The profitability of companies shows the efficiency of the company's management. It evaluates the profitability of the enterprise, i.e., the ability of the enterprise to produce maximum output (e.g., profit) ideally with minimum inputs. A study by Khazaei (2021) found a positive relationship between indicators of competitiveness, entrepreneurship and business environment and financial performance and profitability for multinational companies. In contrast, a study of European companies by Nylund et al. (2020) indicated that innovation has a positive impact on profitability but its impact varies across sectors, with debt financing being a limiting factor. It is evident that the sector can play a significant role in assessing the profitability of firms.

The profitability of businesses in the food industry can be affected by many external factories as subsidy policy (Svobodová, et al., 2022) or new technology as Industry 4.0 (Vrchota et al., 2020). Among one of the significant factors, a study of Bieniasz and Gołaś (2011) identified the negative impact of prolonging the cycle time of inventories, receivables and current liabilities on the profitability of firms in the food industry in Poland. However, the study by Hirsch et al. (2014) shows a large effect of firm size and industry concentration on profitability growth, while firm risk and age, as well as industry growth have a negative effect. The study by Vavrina and Lacina (2018) indicates that financial factors had a predominant positive effect on the profitability of food industry enterprises compared to nonfinancial factors during the global financial crisis between 2008 and 2012. In another relevant study, Šeligová and Koštuříková (2004) measure and evaluate the relationship between working capital and profitability of companies operating in the food industry in the Czech Republic from 2009 to 2019. The study found statistically significant relationships between, for example, return on sales and variables such as cash conversion cycle, current assets ratio, current liabilities ratio and working capital ratio. This study is added by research by Blažková and Dvouletý (2017) who tackled the problem in market concentration. The results of their study showed a positive effect of higher market concentration on the profitability of firms in the food industry. In contrast to previous studies focusing on companies' investment in the food industry, this one highlights the problem of new investment. New investments in technology are usually associated with increased capital needs, which can translate into higher debt, higher debt risk and lower profitability.

It can be assumed that efficiency in the use of capital with technological progress will become a fundamental means of increasing the competitiveness of enterprises and their profitability in the future.

Materials and methods

The paper is focused on the efficiency of using fixed assets in the context of profitability. Efficiency of use fixed assets is measured through the index Turnover fixed assets (FAT = Operating revenues/(Tangible and intangible assets) and takes into account possible variations in the development of links between indicators capital labour ratio (c.l.ratio = (tangible and intangible assets)/costs of employees) and labour productivity (LP = Operating revenues/Costs of employees).

Furthermore, the objective is to assess the relationship with the development of the profitability of revenues (ROS = Operating profit/Operating revenues). Empirical analysis covered 2,526 companies in food industry in four examined European countries (Visegrad countries) – Czech Republic, Hungary, Poland, Slovak Republic. Data were taken from the European company database for the years 2020 and 2019. The analysis considers other aspects such as the effect of the factor of the country of establishment of enterprises, the effect of the factor of the size of enterprises, through ANOVA analysis.

The analytical part is based on the linkages between the indicators:

$$FAT = \frac{Operating\ revenues}{(Tangible + Intangible\ assets)} = \frac{Operating\ revenues}{Costs\ of\ employees} \Big/ \frac{(Tangible + Intangible\ assetss)}{Costs\ of\ employees} \quad (1)$$

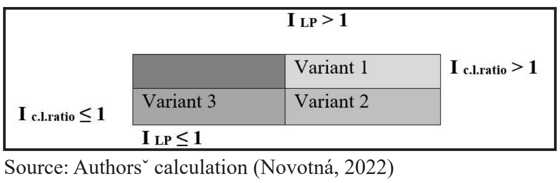
$$FAT = LP / c.l.ratio$$

The same relationships hold for the indices of these indicators:

$$i_{FAT} = i_{LP} / i_{c.l.ratio} \quad (2)$$

Enterprises are divided according to I FAT into two groups. The first group includes enterprises preferring investment activities in which tangible and Intangible assets grow faster than their revenues (I FAT < 1). The second group includes enterprises more economical in terms of investment activities. These enterprises are more oriented towards higher utilisation of Tangible and Intangible assets and thus their revenues grow faster than Tangible and Intangible assets (I FAT > 1).

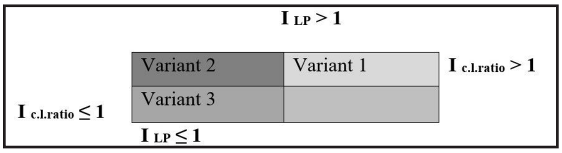
The level and dynamics of all indicators for both groups of enterprises. Based on the relationships between the indicators, three variants of development were defined for each group (Novotná, 2022). For enterprises having I FAT < 1, Variant 1 can occur, which means simultaneous growth of both indicators (the LP and c.l.ratio indices are higher than 1 year on year), respectively Variant 2, in which capital intensity grows and labour productivity decreases at the same time, respectively Variant 3, in which both indicators under study decrease (Figure 1).



Source: Authorsˇ calculation (Novotná, 2022)

Figure 1: Efficiency of use fixed assets (I FAT < 1).

Companies which having I FAT > 1, there can be Variant 1, which means simultaneous growth of both indicators (LP and c.l.ratio indices), respectively Variant 2, in which labour productivity grows while capital intensity decreases or does not change, respectively Variant 3, in which both observed indicators decrease (Figure 2).



Source: Authors' calculation (Novotná, 2022)

Figure 2: Efficiency of use fixed assets (I FAT>1).

Subsequently, the relationship between the development of indicators of efficiency of production factors and the development of profitability of revenues after the division of enterprises into groups was analysed.

Results and discussion

The analysis covered 2,526 enterprises from the V4 countries whose main activity is classified in Section 10 of the standardised NACE classification, which is the food industry, in 2020 and 2019. The indices of the observed efficiency of production factors, indices of selected absolute indicators including the Return on Sale index (Figure 3).

Based on the dynamics of the indicators for the monitored companies in the food industry, it can be concluded that in 2020 compared to 2019, there is a growth in the cost of employees and fixed assets. Although revenues increased at the same time, their growth was lower compared to the previous items, which meant an overall decrease in labour productivity and capital intensity. The operating result in food processing enterprises also declined, which affected the decline in the profitability of revenues.

$$1 > I_{c.l.ratio} > I_{LP} > I_{ROS}$$

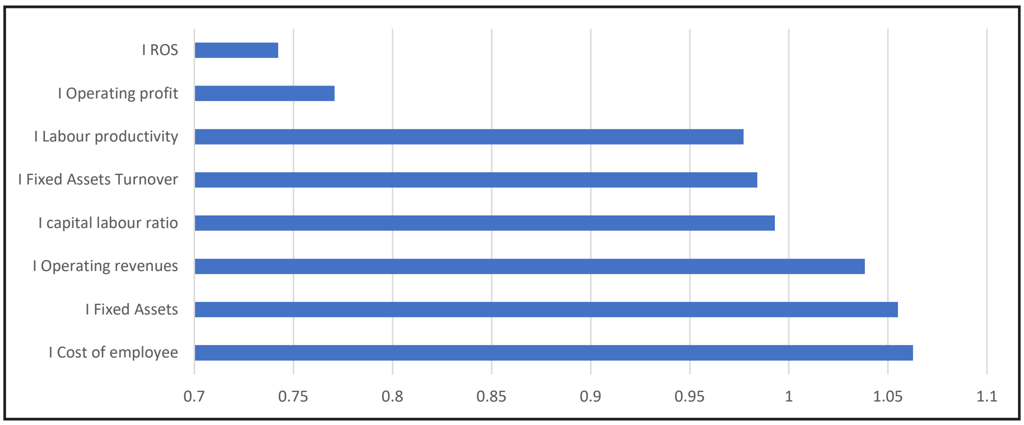
$$I_{costs\ of\ employees} > I_{Fixed\ Assets} > I_{Operating\ revenues} > 1 > I_{Operating\ profit}$$

The development of the dynamics of the indicators shows an unfavourable development, as the growth of costs per employee and the growth of fixed assets exceeds the growth of operating income, leading to a decline in the economic result and to a decreasing profitability of the food industry companies.

The ANOVA analysis (Figure 4) showed that the Turnover Fixed Assets index for food industry enterprises is not affected by either the factor of enterprise size or the location of the enterprise in a V4 country. The effect of both factors is statistically insignificant ($p > 0.05$).

In the more detailed analysis of the efficiency of the use of fixed assets, attention was focused in more detail on individual enterprises, which were subsequently classified into groups (see methodology). Figure 5 illustrates the division of enterprises into two groups and then variants (see methodology), further broken down by enterprise size (LE - large enterprises, SMEs - small and medium enterprises, see EU methodology).

It is clear from Figure 5 that enterprises with an increasing asset turnover rate are slightly predominant (absolute frequency is 1500 enterprises, i.e., 59.4% of all surveyed enterprises). The largest part of these enterprises is classified to variant 3, followed by variant 2. Variant 3 prevails for SMEs, variant 2 for large enterprises (LE).



Source: Own calculations

Figure 3: Development of selected economic indicators in food industry enterprises (index 2020/2019).

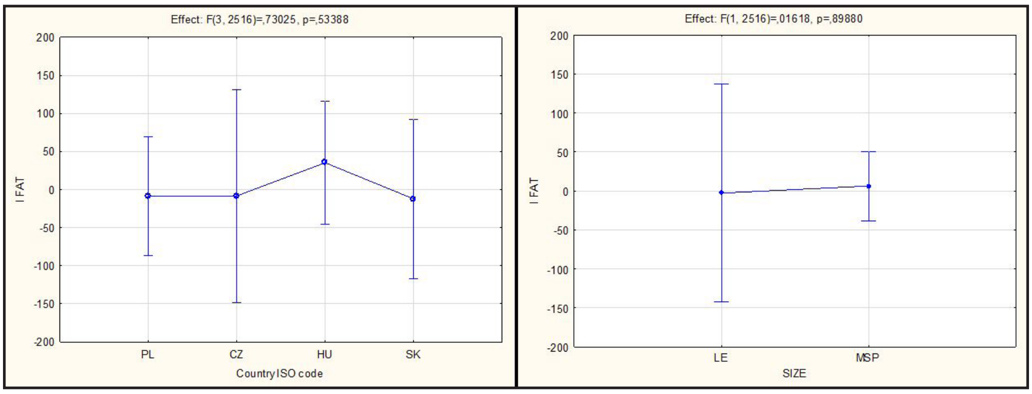


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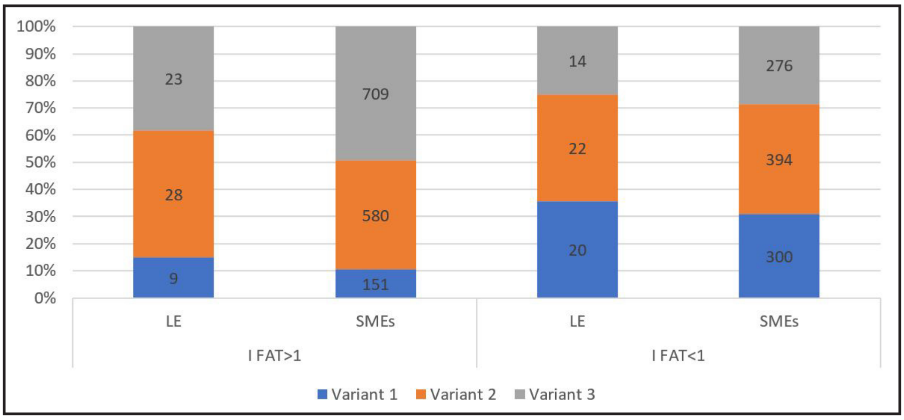
Figure 4: The ANOVA result for Turnover Fixed Assets index – size and location factor.



Source: Own calculations

Figure 5: Numbers of enterprises by intensity of investment assets, by size in %.

For enterprises using more fixed assets (I FAT < 1), variant 2 prevails for both SMEs and LE, followed by variant 1 again for both SMEs and LE. In a more detailed analysis of the economic success of both groups of enterprises in all variants of development, the level and dynamics of indicators assessing the efficiency of production factors and the level and dynamics of the profitability of sales indicator were monitored (Table 1 and 2).

For those firms with higher year-on-year fixed asset utilisation (I FAT<1), Variant 1 (Table 1) is the most successful, especially in terms of return on sales. The ROS level is clearly the highest despite a slight year-on-year decline. The level and dynamics of labour productivity in this variant are also developing positively. The c.l.ratio also increases in this variant, i.e. costs of employees grow more slowly than fixed assets. The most frequent variant (Variant 2) reaches about half the level of ROS, while at the same time its year-on-year decline is observed. Labour productivity also declines. Variant 3 is the least economically successful, with a year-on-year decline in all the indicators monitored.

Table 2 illustrates the economic performance of a group of companies characterised by higher revenue growth compared to fixed asset growth. The most represented is Variant 3, where the return on revenues has fallen sharply year-on-year, by more than 50%. The second most frequent variant in this group is Variant 2, in which ROS increases, although it does not reach the same level as for firms in the first group in Variant 1 (Table 1). The highest level and dynamics of labour productivity, the c.l. ratio, can be observed in the least numerous Variant 1. In this variant, although enterprises reach a lower level of ROS, but with a positive dynamic (annual growth of about 30%).

I FAT < 1	Indicator (EUR)	Average value in		Index
		2020	2019	
Variant 1 (320 companies)	Return on Sales -ROS	0.0625	0.0673	0.9294
	Labour productivity - LP	12.2811	11.8175	1.0392
	The capital labour ratio - c.l. ratio	3.3024	2.4853	1.3288
	Fixed assets Turnover - FAT	3.7188	4.7550	0.7821
Variant 2 (416 companies)	Return on Sales - ROS	0.0317	0.0451	0.7012
	Labour productivity - LP	11.6059	12.5182	0.9271
	The capital labour ratio - c.l. ratio	3.0773	2.6880	1.1448
	Fixed assets Turnover - FAT	3.7715	4.6570	0.8098
Variant 3 (290 companies)	Return on Sales - ROS	0.0174	0.0398	0.4363
	Labour productivity - LP	10.2326	12.4325	0.8231
	The capital labour ratio - c.l. ratio	3.0859	3.4272	0.9004
	Fixed assets Turnover - FAT	3.3159	3.6276	0.9141

Source: 'authors' calculation

Table 2: Indicators by individual variants (I FAT>1).

I FAT > 1	Indicator (EUR)	Average value in		Index
		2020	2019	
Variant 1 (160 companies)	Return on Sales -ROS	0.0262	0.0201	1.3045
	Labour productivity - LP	14.5458	12.3099	1.1816
	The capital labour ratio - c.l. ratio	3.529	3.2466	1.087
	Fixed assets Turnover - FAT	4.1218	3.7916	1.0871
Variant 2 (608 companies)	Return on Sales - ROS	0.0372	0.0305	1.2182
	Labour productivity - LP	11.809	10.9057	1.0828
	The capital labour ratio - c.l. ratio	2.7226	2.9960	0.9087
	Fixed assets Turnover - FAT	4.3374	3.64	1.1916
Variant 3 (732 companies)	Return on Sales - ROS	0.0386	0.0788	0.49
	Labour productivity - LP	8.8342	9.6386	0.9165
	The capital labour ratio - c.l. ratio	2.3673	2.8721	0.8242
	Fixed assets Turnover - FAT	3.7318	3.356	1.112

Source: 'authors' calculation

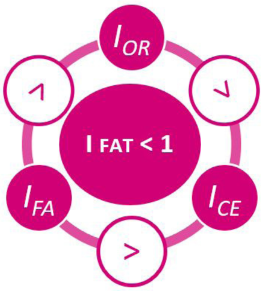
Table 2: Indicators by individual variants (I FAT>1).

Conclusion

The enterprises in the food industry in the V4 countries play an important role not only in the aspect of production, i.e., GDP creation but also in terms of employment or foreign trade (Kowalska et al., 2021). Enterprises in the V4 countries are examined together as one large group. This is due to many common features, such as geographical location, their history (transition from a centralised economy to a market-oriented economy at the same time), which indicate the same starting point for the business cycle in all V4 countries. Another reason for examining the firms as a whole is the ANOVA test analyses performed, which confirm non-significant changes in the analysed firm characteristics depending on the V4 country.

Enterprises have to follow their profitability on the one hand and on the other hand invest in the future to increase their international competitiveness. The present study in food enterprises in the V4 countries puts these two aspects in combination. On average, enterprises in the food industry in the V4 countries experienced unfavourable developments in 2020 compared to 2019. There has been a decline in both the profitability of revenues and the efficiency of using fixed assets. However, when analysing groups of enterprises in more detail, it is possible to draw conclusions regarding the dynamics of the monitored indicators. Based on a deeper analysis of capital intensity, labour productivity and related indicators, including the profitability of revenues, it can be concluded that for enterprises engaged in the food industry, the economically advantageous variant (with respect to the profitability of revenues) always appears to be variant 1. From the empirical evidence of enterprises in the food industry, it can be stated and confirmed that enterprises, regardless of size and country, achieve the best economic results if they observe the relationships between the dynamics of the indicators of operating revenues (OR), costs of employees (CE) and fixed assets (FA).

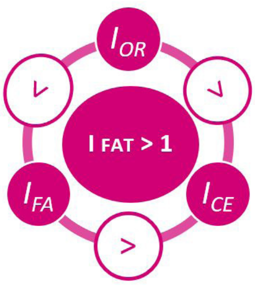
The economically successful variant for food processing enterprises that invest more (investment growth rate exceeds operating revenues) is based on compliance with these relationships (Figure 6), corresponding to variant 1.



Source: Authors´ calculation

Figure 7: Relationships between selected indicators (I FAT>1).

In this situation, the growth rate of capital intensity is higher than the growth rate of labour productivity I_(c.l.ratio)>I_LP>1, but the level of profitability of revenues is well above the average ROS of food firms. The economically successful variant for food enterprises that make more use of existing fixed assets (i.e., the growth rate of revenues exceeds the growth rate of fixed assets) is again based on these relationships (Figure 7).



Source: Authorsˇ calculation

Figure 7: Relationships between selected indicators (I FAT>1).

In this presented situation, labour productivity growth companies exceed capital intensity growth $I_{LP} > I_{c.l.ratio} > 1$. Both successful variants 1 imply increasing dynamics of these indicators (c.l.ratio, LP). The findings of empirical research (Vukšiće 2016) conducted in Croatian industry also show that higher capital intensity growth contributes significantly to stronger labour productivity growth. Smejkal et al. (2022) highlight high the importance of the corporate investment strategy. The effects of increasing fixed assets (increasing capital intensity) according to the study of Grozdic et al. (2020) may be negatively affected in the profitability of firms in the year of realized investment. The positive effect on the profitability of enterprises will only be seen in the year following the investment. The structure of fixed asset investment plays a crucial role in respect of the contribution of investment to increased profitability. The type of fixed asset (investment) is an important factor in assessing the impact of an investment on the performance of a company. Greater benefit for company can be expected for investment in machinery, while for investment in buildings or large technological investments the effects will be more delayed. According to a study by Campbell (2012), the biggest profit benefits from investment in technology are 3 years after the investment is made. The authors also recommend taking into account the structure and type of investment to assess the impact of investments on profitability. The paper no considers the time lag of the investment, but focused on the relationships between the trend of indicators in relation to profitability. The results of the paper can be a useful tool not only for businesses themselves, but also for policy makers within subsidy policy and other institutions.

Among the limitations of the above analysis, the focus on a single industry and the short period analysed can be considered. The further research will focus on the differences in the relationships between economic efficiency (productivity) indicators and economic success indicators of enterprises in different sectors. The contribution of the paper is the generalization of the links between the indicators of factor efficiency in the form of recommended inequalities that can be used by companies for economically successful development.

Corresponding author:
doc. Ing. Martina Novotná, Ph. D.
Faculty of Economics, University of South Bohemia
Studentská 13, 370 05 České Budějovice, Czech Republic
E-mail: novotna@ef.jcu.cz

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Appendix

Variable (EUR)	Year	Average	Median	Minimum	Maximum	Standard deviation
Operating revenue	2020	10 846 176	909 149	9596	1 220 804 031	51 818 916
	2019	10 446 538	869 382	3	1 764 247 902	56 226 935
Costs of employees	2020	987 654	151 770	91	74 451 763	3 719 660
	2019	929 489	140 190	68	122 084 842	4 023 052
Fixed assets	2020	3 396 089	180 980	39	677 001 320	22 437 440
	2019	3 239 698	173 517	90	679 726 601	21 925 271
ROS	2020	-0.008	0.025	-12.25	0.877	0.436
	2019	-0.04	0.028	-20.279	0.904	0.865
Resource productivity	2020	3.85	1.626	0.514	189.408	13.041
	2019	4.401	1.575	0.128	446	21.517
Capital labor ratio	2020	9.292	1.099	0	6976	157.564
	2019	7.296	1.177	-0.096	7101	143.194
FAT	2020	43.952	5.609	0.004	7727.25	260.135
	2019	42.678	5.547	0	6143.571	255.694
Labour productivity	2020	15.014	5.25	0.156	8119.433	165.281
	2019	23.46	5.392	0.003	15851.235	364.821

Source: Authors´calculation

Table 3: Descriptive statistics of the data set.

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ICTs Use, Agroforestry Technologies' Adoption and Crop Farmers' Welfare: An Empirical Evidence from Southwest, Nigeria

Lawrence Olusola Oparinde

Department of Agricultural and Resource Economics, The Federal University of Technology, Akure, Nigeria

Abstract

There is a glaring shortage of studies on the impact of ICTs use on the adoption of agroforestry technologies and combined effects of ICTs use and agroforestry technologies' adoption on farmers' welfare. To fill the information gap, this study examined the impact of ICTs use on agroforestry technologies' adoption and their heterogenous impacts on crop farmers' welfare in Southwest, Nigeria. Endogenous-treatment poisson regression (ETPR) model and unconditional quantile regression (UQR) model were used to analyse the data collected from 488 respondents. The results indicated that the use of ICTs improved the adoption of agroforestry technologies which facilitate friendly environment. Also, ICTs use and agroforestry technologies' adoption statistically and heterogeneously influenced farm revenue and household food insecurity access scale (HFIAS). Precisely, ICTs use had the highest influence on farm revenue at the lowest quantile, while agroforestry technologies' adoption had the highest effect on household food insecurity access scale (HFIAS) at the lowest quantile. Therefore, policies that promote crop farmers' access to ICTs should be the priority of policy makers who are interested in the welfare of crop farmers and increased farmers' level of agroforestry technologies' adoption.

Keywords

ICTs, agroforestry, HFIAS, revenue, RIF, UQR, ETPR, IRR.

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Introduction

It is a known fact that Nigeria's climate has been changing as shown by temperature increase; inconsistent rainfall pattern; increase in flooding and sea-level; desertification and drought; land degradation and so on, which have been leading to loss of biodiversity and affecting fresh water resources (Elisha et al., 2017). The contributing factors to the land degradation include population explosion, unsustainable agricultural practices, mining, infrastructural development and energy. Land degradation has resulted to unemployment, flood, erosion, food insecurity, desertification and conflict over resources. Therefore, adoption of sustainable agricultural technologies that improve and sustain agricultural production must be promoted. Agroforestry is one of such agricultural technologies, which is a land-use measure that addresses the issue of climate change and provides other ecological, pecuniary and social gains (Waldron et al., 2017).

According to Minang et al. (2014), one of the means of evading deforestation, reducing CO_2 emissions and lessening climate change is agroforestry. In developing countries like Nigeria, deforestation is a critical issue primarily due to subsistence and commercial agriculture being practiced (Weatherly-Singh and Gupta, 2015). Campaign in favour of agroforestry is important because of its potential for carbon sinking, control of soil erosion, improved nutrients and water cycling, socio-economic gains and higher agricultural yield (Fagerholm et al., 2016; Wilson et al., 2016). Agricultural production, productivity and farm income can be increased using agricultural technologies (Tambo and Mockshell 2018; Rola-Rubzen et al., 2019). According to Mekonnen (2017), boosting agricultural yield enhances the welfare of farmers by raising food availability and decreasing agricultural outputs' prices.

According to Jack and Tobias (2017), over the years, information and communications technologies (ICTs) have been seen as important part of farmers' lives in Africa. Information and communication technologies (ICTs) (for instance, mobile phones) have gained the attention of donor agencies as they are being used as tools in supporting transfer of knowledge and encouraging acceptance and spread of innovations (Aker et al., 2016; Westermann et al., 2018). Information and communications technologies (ICTs) have the capacity to assist in improving agricultural technologies adoption. Sharing information through ICTs can enlighten crop growers about new technologies and state of market, such as prices, which helps to resolve on where and when to trade their agricultural commodities (Aker, 2010). Therefore, ICTs present a means through which maintainable economic and social development are supported in rural African countries. ICTs allow farmers to have access to a more comprehensive set of information and technologies capable of increasing productivity, improving market access, and contributing to household revenues and food security (Voss et al., 2021).

The Impact of ICTs use on welfare of farmers (Zhu et al. 2020), agricultural technologies' adoption on welfare of farmers (Mendola, 2007; Mekonnen, 2017), internet use on adoption of agricultural technologies (Zheng et al. 2022; Zheng et al. 2023) have been well documented in the literature. This is not so in the case of impact of agroforestry technologies' adoption on farmers' welfare which is very scarce in the literature. Also, there is a glaring shortage of studies on the impact of ICTs use on the adoption of agroforestry technologies in the literature. As far as I know, this is the first study that estimates the joint effects of ICTs use and agroforestry technologies' adoption on farmers' welfare. It is therefore, imperative to carry out this study that answers the following research questions; what is the impact of ICTs use on agroforestry technologies' adoption among crop farmers? and what is the heterogenous impact of ICTs use and agroforestry technologies' adoption on the respondents' welfare? The welfare indicator used in this study are farm revenue and household food insecurity access scale (HFIAS).

This research contributes to the existing body of knowledge in the literature in four ways. To start with, many studies are around the impact of farming technologies on wellbeing without specifically considering the impact of agroforestry technologies adoption on crop farmers' welfare. Therefore, this study fills the gap in the literature by examining the impact of agroforestry technologies' adoption on the welfare of crop farmers. Furthermore, there is little or no information on studies that investigated the impact of ICTs use on agroforestry technologies' adoption in the literature, which this study examined. Moreover, endogenous-treatment poisson regression (ETPR) model is used for the purpose of correcting selection bias related to voluntary ICTs use through the consideration of both observed and unobserved heterogeneities. This is lacking in the literature because the only study that considered this issue was on internet use and sustainable agricultural practices in China. More so, the heterogeneous effects of ICTs use and agroforestry technologies' adoption on farmers' welfare is examined by modelling the two together using unconditional quantile regression (UQR) model. Studies in the literature either investigated the effect of ICT use on welfare (Ma et al., 2018; Zhu et al., 2022) or impact of agricultural technologies adoption on farmers' welfare (Adams and Jumpah, 2021; Kopalo et al., 2021) without modelling the two together. The effects of ICT use and agroforestry technologies' adoption on welfare should be jointly modelled because of likely interdependence between them. Evidence from this study will assist policymakers as well as other stakeholders to formulate policies that engender sustainable agricultural development in Nigeria. It equally gives empirical evidence that can be used to encourage farmers to embrace agroforestry technologies for the purpose of having increase in productivity and skill intensive activities on the farm, which lead to improved welfare.

Materials and methods

Data used in this study were gotten from the survey of crop farming families which took place in January 2022. The respondents used for the study were selected using a multistage sampling procedure. To start with, random sampling technique was used to pick two States out of six States in Southwest, Nigeria. Furthermore, random sampling technique was used to pick five Local Government Areas (LGAs) from the respective States chosen. Moreover, five communities were chosen from each of the chosen LGAs. More so, ten arable crop farmers were randomly picked from each of the chosen communities. The selection was made possible through information gotten from Agricultural Development Project (ADP) Offices in the two States. Eventually, the process resulted in the collection of data from 282 ICTs users and 218 non-users totaling 500 respondents. As it is typical of data collection in Nigeria, few of the respondents were not cooperative which made them to supply data that are not usable. As a result of this, data from 488 respondents were used for the analysis, while data from the remaining 12 respondents were removed from the analysis. A well-organized questionnaire which was used to collect the data covered socio-economic characteristics, agroforestry technologies adopted, farm revenue, use of information and communication technologies (ICTs), credit constraints, land ownership, food security related questions and so on. Descriptive statistics, endogenous-treatment poisson regression (ETPR) model and unconditional quantile regression (UQR) model were used to analyse the data. Household food insecurity access scale (HFIAS) was used to measure food security status of the respondents.

Coates et al. (2007); Maxwell et al. (2014) stated that HFIAS is a measure of the psychological and behavioural dimensions of food insecurity with respect to food access. The measurement is from zero to twenty-seven, with zero suggesting a family with no record of food insecurity. The highest value of twenty-seven signifies the maximum level of food insecurity, with high occurrence of eating less food and skipping meals because of inadequate food access (Coates et al., 2007). Agroforestry technologies' adoption was measured as a count variable in this study. Considering the prevalent agroforestry technologies in the study area, farmers were asked to identify the technologies they adopted in the last cropping season. The final list of agroforestry technologies used are home gardens, alley cropping, windbreaks, improved fallow, fuel wood production, silvopastoral system and apiculture with trees. Once a farmer indicated that he or she adopted any of the strategy, one (1) is assigned and zero otherwise.

Estimation strategies

Selection of model and issue of selection bias

The decision to use ICTs is not random but voluntary by farming households (Leng et al., 2020). There may be steadily diverse characteristics between arable crop farmers who used ICTs (that is, treated group) and those who did not use ICTs (that is, control group). Estimation of impact of ICTs use on agroforestry technologies' adoption (a count variable that measures the number of technologies adopted) through Poisson regression approach would give estimates that are biased when there is an existence of self-selection issue. Studies in the literature have estimated the effects of technology acceptance or intervention programme using propensity score matching (PSM) method (e.g Hou et al., 2019: Ma and Wang, 2020) and inverse-probability weighted regression adjusted (IPWRA) estimator (e.g Adolwa et al., 2019: Ma and Wang, 2020). The two approaches (that is, PSM and IPWRA) alleviate the issue of selection bias based on observed heterogeneities without addressing unobserved factors (such as farmers' innate abilities and motivations) that affect farmers' decision to use ICTs and agroforestry technologies concurrently. Normative assumptions underlie this study since there are some unobservable factors that can influence outcome variables of the two groups (users and non-users). Therefore, estimates from IPWRA and PSM would be unfair. It is against this background that this study employed an endogenous-treatment Poisson regression (ETPR) model to estimate the impact of ICTs use on agroforestry technologies' adoption (a poisson distributed count) as used by Ma and Wang (2020). The issue of selection bias emanating from both noticeable and unnoticeable factors is addressed by ETPR model, which can also estimate the treatment effects of ICTs use on agroforestry technologies' adoption.

Selection of ETPR model

The estimation using this model has a two-stage approach with farming household's decision to use ICTs being modelled in stage one. The decision of crop farming households to use of ICTs is modelled in a framework that uses random utility as done by Ma et al. (2020). Let D_i^* represent the difference in utility between the use of ICTs (I_{iU}) and utility from non-use of ICTs (I_{iN}) to the extent that a crop farming household will decide to use ICTs when $D_i^* = I_{iU} - I_{iN} > 0$. It is worthy of note that the utilities for the two groups cannot be observed. Using alternative way, the two utilities can be mathematically stated as a function of components that are observable in a latent variable model as:

$$D_i^* = \alpha_i K_i + \mu_i \; with \; D_i = \begin{cases} 1 & if \;\; D_i^* > 0 \\ 0 & otherwise \end{cases} \qquad (1)$$

where D_i^* stands for a latent variable which is for the ICTs use probability. The latent variable is gotten by the observed variable D_i which shows the actual ICTs use status of the respondents (that is, $D_i = 1$ if crop farming household i uses ICTs, while $D_i = 0$ otherwise); K_i represents crop farming family and farm-related characteristics (for example, age, farm size and education); α_i stands for the parameters to be estimated; and μ_i represents a random error term.

According to Westermann et al. (2018), information and communication technologies (ICTs) are being used as apparatuses in supporting transfer of knowledge, adoption and spread of innovations. It is on this premise that the impact of ICTs use on agroforestry technologies' adoption is identified in the stage two of the ETPR model estimation. Let us assume that agroforestry technologies' adoption is a linear function of ICTs use being a dichotomous variable and other independent factors, M_i, the agroforestry technologies' adoption function is then mathematically shown as:

$$A_i = \delta_i D_i + \tau_i M_\mathrm{i} + \epsilon_i \qquad (2)$$

where A_i denotes variable for the adoption of agroforestry technologies (number of agroforestry technologies adopted); D_i is the ICTs use; δ_i and τ_i are parameters to be estimated; ϵ_i denotes an error term. The parameter δ_i is used to quantify the impact of ICTs use on the level of agro-forestry technologies' adoption. As a minimum, one variable known as an instrument should be included in K_i in Equation 1 but not in M_i in Equation 2. This is done for model identification purpose. The instrumental variable is only effective if it influences crop farmers' decision to use ICTs but does not directly affect farmers' decision to adopt agroforestry technologies. In this study, the instrument used is a variable that describes whether crop farming household's neighbour uses ICTs to buy goods online or not. Peer influence can make a crop farming household to decide to use ICTs because his or her neighbor uses ICTs but does not influence the farming household's agroforestry technologies' adoption decision directly. Appendix 1 shows the Pearson correlation test results for the soundness of the instrument used.

It is to be noted that only partial information about relationship between ICTs use and agroforestry technologies' adoption is provided by the coefficients of the variables in the ETPR model. It is against this background that average treatment effects (ATE) and average treatment effects on the treated (ATT) were calculated for the purpose of having more understanding about the impact of ICTs use on agroforestry technologies' adoption as follows:

$$ATE = E(V_{1i} - V_{0i}) = E\{E(V_{1i} - V_{0i} \,|\, K_i)\} \qquad (3)$$

$$ATT = E(V_{1i} - V_{0i} \,|D_i = 1) = \\ = E\{E(V_{1i} - V_{0i} \,|K_i, D_i = 1) \,|\, D_i = 1\} \qquad (4)$$

Both ICTs users and non-users were included in the sample used to estimate ATE, while data from ICTs users (treated group) only were used to estimate ATT in a counterfactual context.

Selection of UQR model

Previous studies in the literature separately analysed the impact of ICTs use on welfare (Ma et al., 2018; Zhu et al., 2022) or impact of agricultural technologies' adoption on farmers' welfare (Adams and Jumpah, 2021; Kopalo et al., 2021) without modelling the two together. The effects of ICT use and agroforestry technologies' adoption on welfare should be jointly modelled because of likely interdependence between them. Therefore, this study did not only capture the interaction between ICTs use and agroforestry technologies' adoption on crop farmers' welfare but also checked how ICTs use and agroforestry technologies' adoption affect distributions of farmers' welfare. This is the reason for considering quantile regression model analysis. According to Mishra et al. (2015) and Ma et al. (2020), conditional quantile regression model estimation largely depends on the covariates that are employed and freely altering the control variables is not possible without redefining the quantiles. Hence, an unconditional quantile regression (UQR) model is estimated to capture the heterogenous effects of ICTs use and agroforestry technologies adoption on farmers' welfare (farm revenue and HFIAS).

A UQR model can be estimated like a simple OLS regression on a regressand that is transformed using the recentered influence function (RIF) (Firpo et al., 2009). The equation to be estimated is given as follows:

$$IF(V_i; Q_\sigma, L_V) = \beta_i D_i' + \rho_i A^{i'} + \omega_i M_i + \varphi_i \qquad (5)$$

where V_i denotes an outcome variable (that is, farm revenue or HFIAS); Q_σ refers to the σ-th quantile of the cumulative distribution (L_V) of the outcome; D_i' is the predicted ICTs use and A_i' is the predicted agroforestry technologies' adoption variable. The reason for the use of predicted variables instead of the original variables is to adequately address the endogeneity issue of ICTs use and agroforestry technologies' adoption variables (Chang and Mishra, 2012). The explanatory variables are represented by M_i; β_i, ρ_i and ω_i are the parameters to be estimated; and φ_i represents error term which captures unobserved heterogeneities. Specifically, the RIF in Equation 5 is expressed as follows:

$$R\hat{I}F(V_i; Q_\sigma, L_V) = Q_\sigma + \frac{\sigma - I(V_i \leq Q_\sigma)}{l_V(Q_\sigma)} \quad (6)$$

where l_V is the probability distribution function of variable V_i, while $I(V_i \leq Q_\sigma)$ shows whether the outcome variable (farm revenue or HFIAS) is below Q_σ and it is captured as a dummy variable.

Results and discussion

Description of variables used in the model

Table 1 shows the description and descriptive statistics of the variable used in the study where about 55.0% of the sampled crop farmers used ICTs. This indicates that fairly more than half of the sample used ICTs. The average number of agroforestry technologies adopted by the respondents is 0.79, indicating low adoption rate of these technologies. Adesina and Chianu (2002) reported that some farmers have not been adopting agroforestry technologies in spite of the farmers' awareness and associated gains. The little rate of adoption of agroforestry technologies have been linked to some factors in the literature (Owombo and Idumah, 2017). On the average, the log of farm revenue and household food insecurity access scale of the sampled crop farming households are 12.77 and 15.66, respectively. The mean age of a household heads is 47 years and 75% of the respondents are males. Also, the average number of years spent in school by the respondents is 10 years. On the average, the household size and farm size of the respondents are 7 and 2.27 hectares, respectively.

Differences in the variables between users and non-users of ICTs

The differences in the mean values of the selected variables between ICTs users and non-users are presented in Table 2. It is indicated that there are momentous differences between ICTs users and non-users in some of the variables. For instance, ICTs users adopted more agroforestry technologies and recorded higher revenue than non-users of ICTs with the difference of 0.23 and 2.34 respectively. The household food insecurity access scale for ICTs users is less than the one recorded by the non-users, indicating that ICTs users were more food secure than non-users. According to Aker (2010), ICTs have the capacity to assist in improving agricultural technologies adoption. Also, these results just confirmed the assertion of Voss et al. (2021) which states that ICTs allow farmers to have access to a more comprehensive set of information and technologies capable of increasing household incomes and food security. It is indicated in Table 2 that ICTs users are likely

Variables	Description	Mean	Standard Deviation
ICTs use	1 if household adopted ICT, 0 otherwise	0.55	0.50
Agroforestry technologies' adoption	The number of agroforestry technologies adopted by a household	0.79	0.63
Log of revenue	Log of farm revenue	12.77	1.14
HFIAS	Household food insecurity access scale	15.66	5.32
Sex	1 if male, 0 otherwise	0.75	0.44
Age	Age of the respondents in years	47.23	8.71
Years of education	Number of years spent in school	10.14	4.88
Household size	Number of people living in a household	7.39	2.29
Farm size	Area of land cultivated in hectares	2.27	1.63
Farming experience	Number of years spent in farming	11.66	9.03
Hours spent on farm	Number of hours spent on farm per day	5.81	2.59
Extension visits	Number of extension visits per month	0.85	1.34
Cooperative membership	1 if a member of cooperative society, 0 otherwise	0.47	0.50
Credit constraints	1 if non-credit constrained, 0 otherwise	0.50	0.40
Non-farm income	1 if farmer has non-farm income, 0 otherwise	0.52	0.50
Land right	1 if farmer has use and transfer right, 0 use only right	0.44	0.50
Neighbours using ICT	1 if neighbour uses ICT, 0 otherwise	0.40	0.49

Source: Author's estimations based on data from survey 2022

Table 1: Description and descriptive statistics of the variables used in the study.

Variables	ICTs Users	ICTs Non-users	Mean Difference
Agroforestry technologies' adoption	0.80	0.57	0.23*
Log of revenue	12.68	12.42	0.26*
HFIAS	14.66	17.00	-5.34***
Sex	0.71	0.79	-0.08
Age	45.32	48.65	-3.33***
Years of education	10.32	9.89	0.43
Household size	7.29	7.52	-0.23
Farm size	2.51	1.96	0.55***
Farming experience	14.58	7.75	6.83***
Hours spent on farm	5.61	6.09	-0.48*
Extension visits	0.76	0.97	-0.21
Cooperative membership	0.50	0.43	0.08
Credit constraints	0.38	0.67	-0.29***
Non-farm income	0.62	0.38	0.24***
Land right	0.46	0.41	0.05
Neighbours using ICT	0.47	0.31	0.16***
Observations	270	218	

Note: ***P < 0.01, **P < 0.05, *P < 0.1

Source: Author's estimations based on data from survey 2022

Table 2: The differences in the mean values of the selected variables between ICTs users and non-users

to be non-credit constrained, younger, have larger farm size and more experienced than their non-users' counterparts in the study area. Higher revenue and farming experience are recorded by the ICTs users than non-users. Having these fantastic results in favour of ICTs users cannot be said to be satisfactory since some confounding factors such as age, farm size, household size and farmers' innate abilities have not been accounted for. These confounding factors also influence crop farmers' resolve to use ICTs. Hence, the reason for more rigorous analysis of the impact of ICTs use on agroforestry technologies adoption, farm revenue and food security using robust econometric methods.

Factors influencing ICTs use

The impact of ICTs use on adoption of agroforestry technologies is presented in Table 3. The significant value of the correlation between the treatment-assignment error and the outcome error is -0.552. This signposts the existence of negative selection bias which means that there are some unobservable factors that have direct influence on the probability of using ICTs but inversely related to the number of agroforestry technologies adopted by the crop farmers. Therefore, it is sufficed to state that ETPR model is more suitable because PSM method and Poisson regression model would have underestimated the impact of ICTs use on the adoption of agroforestry technologies.

Table 3 shows that years of education, farm size, cooperative membership, credit constraints, non-farm income and neighbours using ICTs were the significant determinants of ICTs use among the sampled crop farmers in the study area. The coefficient of years of education is positive and statistically significant, indicating that higher number of years of education increased the likelihood of using ICTs. This is in congruence with Aldosari, et al. (2019); Salam and Khan (2020) who reported a direct association between education and the decision to use ICTs. The coefficient of farm size has a direct and significant association with decision to use ICTs, while non-farm income has an inverse relationship with decision to use ICTs. This indicates that rise in farm size increased the probability of using ICTs, while increase in income from non-farm source(s) would reduce the probability of using ICTs. The inverse relationship between non-farm income and probability of using ICTs is not expected because income generation from other sources of income outside farming activities should help in the procurement of ICT tools. This relationship between farm size and likelihood of using ICTs confirmed the findings of Chhachhar and Memon (2019); Leng et al. (2020) who reported that rise

Variables	ICTs use	Agroforestry technologies adoption	Agroforestry technologies adoption
ICT use		0.556**(2.18)	1.744**
Sex	0.168 (1.64)	0.078 (0.54)	1.081
Age	-0.012 (0.45)	-0.004 (0.54)	0.996
Years of education	0.012*** (5.12)	0.020* (1.86)	1.020*
Household size	0.036 (1.45)	0.063*** (2.91)	1.065***
Farm size	0.082*** (4.21)	-0.003 (0.06)	0.997
Farming experience	-0.097 (1.21)	0.016* (1.85)	1.016*
Hours spent on farm	-0.079 (1.72)	0.023 (1.02)	1.023
Extension visits	0.060 (0.23)	-0.014 (0.46)	0.986
Cooperative membership	0.118*** (6.31)	0.215* (1.88)	1.240*
Credit constraints	0.684*** (3.47)	0.143** (2.00)	1.154**
Non-farm income	-0.577** (1.97)	0.191 (1.44)	1.210
Land right	0.163 (0.89)	0.311*** (2.41)	1.365***
Neighbours using ICTs	0.585*** (3.91)		
Constant	0.834 (0.71)	0.556 (2.18)	1.744
$\rho_{\mu\varepsilon}$	-0.552 (7.23)		
Wald Test (rho = 0)	Chi^2 (1) = 41.41, Prob > Chi^2 = 0.0000		
Observation	488		

Note: Figures in bracket represent t-value. Standard errors in parentheses; ***P < 0.01, **P < 0.05, *P < 0.1.
Source: Author's estimations based on data from survey 2022

Table 3: Impact of ICT use on adoption of agroforestry technologies.

in farm size would raise the likelihood of using ICTs. The results further reveal that being a member of cooperative society and non-credit constrained increased the likelihood of using ICTs. This finding is like the report of Wawire et al. (2017) where membership of farmers' organization was reported to have increased the farmers' chance of using ICTs. However, this result contradicts the findings of Mdoda and Mdiya (2022) where it was stated that having access to credit reduced the probability of using ICTs. Lastly, the coefficient of neighbours using ICTs has a direct and significant nexus with the likelihood of using ICTs as expected because the variable is used as an instrumental variable which should be significant. This implies that the use of ICTs by crop farming household's neighbour made the farming household to decide to use ICTs.

Factors determining adoption of agroforestry technologies

The factors that influenced the number of agroforestry technologies adopted are presented in column three of Table 3. For better understanding and ease of interpretation, the incidence rate ratios (IRRs) is calculated and presented in column four of Table 3. This is necessary since the interpretation of the coefficients of the variables from count model regression is not always straightforward. Zhang et al. (2019) explained that IRRs are gotten by taking the exponential of the coefficients of the count regression model (IRR = exp (regression coefficient)).

The variable ICTs use has an IRR that is positive and statistically significant, signifying that, on the average, ICTs users adopted agroforestry technologies more than non-users in 1.744 times. It is therefore, clear that use of ICTs improves the adoption of agroforestry technologies that facilitate friendly environment. This is done in a way that the use of ICTs supports better access to information on agroforestry technologies' adoption and their benefits, which subsequently lead to rise in the rate of the technologies' adoption. This is the validation of the statement of Aker et al. (2016); Westermann et al. (2018) that ICTs have gained the attention of donor agencies as they are being used as tools in supporting transfer of knowledge and encouraging adoption and spread of innovations. On the average, the coefficients of years of education and household size are positive and statistically significant. The respective IRR estimates indicate that crop farmers who have higher number of years spent in school and higher household size adopted 1.020

and 1.065 times more agroforestry technologies, respectively. One of the possible reasons could be that well-educated crop farmers could easily search for information and decide based on their preferences using the collected information (Mahouna et al., 2018). Also, having large household members increased technology acceptance because agricultural technologies require more labour to practice (Adofu et al., 2013). Shita et al. (2020); Oparinde et al. (2023) reported that education had direct influence on the likelihood of adopting agroforestry technology.

The positive and significant IRR for the connection between farming experience and adoption of agroforestry technologies indicates that crop farmers with more experience tend to adopt agroforestry technologies more in 1.016 times on the average. This is in line with Ainembabazi and Mugisha (2014) who stated that farming experience plays significant roles in the adoption of agricultural technology. This could be ascribed to the on-the-job skills development over time that makes farmers to fit well into the new technology being taken to them for adoption. The direct and significant IRR of cooperative membership and credit constraints suggests that crop farmers who are members of cooperative society and non-credit constrained are more likely to adopt agroforestry technologies more in 1.240 and 1.154 times, respectively. The possible reason for the relationship between cooperative membership and number of agroforestry technologies adopted is that cooperative society plays financial and advisory roles that enhance adoption of agricultural technologies. Finding from this study confirmed the report of Wossen et al. (2017) where it was reported that cooperative society had an increasing effect on technology adoption through the provision of market information. The relationship that exists between credit constraints and agroforestry technologies' adoption could be because of the liquidity effects which lowers the issue of capital shortage that hinders investment in improved technologies. Abate et al. (2016) had also reported that farming households' access to credit raises the rate of agricultural technology adoption.

There is a direct and significant connection between land rights variable and agroforestry technologies' adoption. The positive and significant IRR of land rights indicate that having "use and transfer rights" would make crop farmers to adopt 1.365 times more agroforestry technologies than their colleagues who had "use only rights". This is expected because crop farmers who have "use and transfer rights" will be willing to invest in agroforestry technologies since they are aware of the long-term gains connected to the adoption of the technologies. This is in agreement with Owombo and Idumah (2017) where it was reported that landownership positively increased the probability of adopting agroforestry technology.

Treatment effects of ICTs use on agroforestry technologies' adoption

The treatment effects of ICTs use on agroforestry technologies adoption from ETPR model are presented in Table 4. ATE and ATT cannot be interpreted directly because they are not the same as IRR. The IRR of ICTs use on the number of agroforestry technologies adopted in Table 3 is presented from the perspective of marginal analysis. The significant estimated ATE of ICTs use on the number of agroforestry technologies adopted is 0.432, which implies that an average crop farming household will adopt 0.432 more agroforestry technologies when ICTs are used by such household. Also, the significant estimated ATT of ICTs use on the number of agroforestry technologies adopted is 0.477. This indicates that the average crop farming household in the ICTs user's category (that is, treated category) will adopt 0.477 more of agroforestry technologies than such household would if it did not use ICTs. It can be generally stated that ICTs use promotes adoption of agroforestry technologies in Southwest, Nigeria.

ATE	Z-value	ATT	Z-value
0.432	2.03	0.477	2.06

Source: Author's estimations based on data from survey 2022

Table 4: Treatment effects of ICTs use on agroforestry technologies' adoption from ETPR model.

Estimates from UQR for the joint effects of ICTs use and agroforestry technologies' adoption on revenue and HFIAS

Impact of ICTs use and agroforestry technologies' adoption on revenue and HFIAS from Unconditional Quantile Regression model estimates is presented in Table 5. For better understanding, Equations 1 and 2 were estimated simultaneously using seemingly unrelated regression equation (SURE) model in order to predict ICTs use and agroforestry technologies' adoption variables. In the estimation process, ICTs use was not included in Equation 2 for the purpose of avoiding issue of autocorrelation of the predicted ICTs use and agroforestry technologies' adoption. In line with Mishra et al.

(2015) and Ma and Wang (2020), $v_i = [\exp(\beta_i) - 1]$ is used to measure the proportional impact of dummy variables (Sex, Cooperative membership, Credit constraints and non-farm income) on farm revenue and HFIAS, where v_i and β_i represent proportional impact and coefficient of the variable, respectively. From this perspective, it is believed that the estimates give a descriptive comparison of the farm revenue and HFIAS for the households. The claim is not that the estimates possess a causal interpretation.

The estimates in Table 5 indicates that ICTs use and agroforestry technologies' adoption statistically and heterogeneously influenced farm revenue and HFIAS. Precisely, ICTs use had positive and significant association with farm revenue at the 25th and 75th quantiles with the uppermost influence of ICTs use on farm revenue occurring at the lowest quantile. This result confirmed the finding of Zhu et al. (2020) where it was stated that ICTs adoption brought about increase in farm income. There is an inverse relationship between ICTs use and HFIAS at the 50th quantiles, suggesting that use of ICTs by the crop farmers would improve their food security status since reduced HFIAS implies better food security status. These results validated the statement of Voss et al. (2021) that ICTs allow farmers to have access to a more comprehensive set of information and technologies capable of increasing productivity, improving market access, and contributing to household revenue and food security. Adoption of agroforestry

Variables	Farm revenue			HFIAS		
	25th	50th	75th	25th	50th	75th
Predicted ICTs Use	0.171*** (5.33)	-0.263 (1.05)	0.143*** (2.95)	0.047 (0.06)	-0.868** (1.97)	-0.417 (0.60)
Predicted Agroforestry Technologies Adoption	0.006*** (3.21)	-0.561 (1.32)	0.010 (0.02)	-0.969* (1.93)	-0.515 (0.68)	-0.958*** (2.74)
Sex	0.086 (0.71)	0.028 (0.21)	0.107*** (2.52)	-0.429 (0.99)	-0.189* (1.80)	0.260 (0.70)
Age	0.023 (0.08)	-0.001 (0.07)	0.010 (0.84)	-0.064*** (2.49)	0.003 (0.24)	0.050** (2.28)
Years of education	0.008 (0.73)	0.016*** (3.29)	-0.006 (0.34)	-0.028 (0.69)	-0.047** (2.17)	-0.038 (1.13)
Household size	0.023 (0.74)	0.057 (0.76)	0.060 (1.12)	0.383*** (3.35)	0.200*** (3.26)	-0.113 (1.15)
Farm size	-0.019 (0.51)	0.032 (0.76)	0.126** (1.97)	-0.183 (1.35)	-0.003 (0.04)	-0.236** (2.03)
Farming experience	-0.004 (0.19)	0.012 (0.49)	0.090*** (2.42)	-0.150* (1.91)	0.022 (0.53)	-0.001 (0.01)
Hours spent on farm	0.024 (0.98)	-0.034 (1.26)	-0.066 (1.58)	-0.068 (0.76)	-0.122*** (2.55)	-0.020 (0.27)
Extension visits	0.014 (0.37)	0.023*** (4.53)	0.060 (0.88)	-0.033 (0.23)	0.147* (1.93)	0.371*** (3.06)
Cooperative membership	0.113** (1.98)	0.225* (1.77)	0.090 (0.46)	-0.809* (1.94)	0.278 (1.24)	-0.071 (0.20)
Credit constraints	-0.118 (0.59)	-0.094 (0.43)	0.501*** (2.47)	-0593 (0.82)	-0.257** (5.66)	0.249 (0.40)
Non-farm income	0.179 (1.01)	0.343* (1.79)	0.966*** (3.16)	0.804 (1.62)	-0.378*** (2.81)	-0.598 (1.08)
Constant	12.314 (27.24)	12.662 (25.36)	11.875 (15.31)	20.938 (12.77	17.222 (19.48)	16.017 (11.41)
Observation	488			488		

Note: Standard errors in parentheses; ***P < 0.01, **P < 0.05, *P < 0.1. The mathematical expression $v_i = [\exp(\beta_i) - 1]$ cannot be used directly to calculate the proportional impact of the predicted ICTs use variable and agroforestry technologies' adoption variable on farm revenue and HFIAS since the two variables are used in the UQR model estimations.
Source: Author's estimations based on data from survey 2022

Table 5: Impact of ICT Use and agroforestry technologies' adoption on revenue and HFIAS from Unconditional Quantile Regression model estimates.

technologies positively and significantly influenced farm revenue at the 25th quantile, indicating that agroforestry technologies positively contribute to farm revenue. The results of Rola-Rubzen et al. (2019) has just been confirmed in this study, that adoption of agricultural technologies increases farm income. Household food insecurity access scale (HFIAS) is negatively influenced by adoption of agroforestry technologies at the 25th and 75th quantiles with the uppermost effect of agroforestry technologies' adoption on HFIAS at the 25th quantile. This indicates that the more the number of agroforestry technologies adopted the better the food security status of the respondents. It was earlier reported by Ogundari and Bolarinwa (2019) that agricultural technologies have increasing effects on household welfare measured in terms of nutrition.

Sex has a direct and significant nexus with farm revenue at the 75th quantile, while it has an indirect and significant association with HFIAS at the 50th quantile. This suggests that being male crop farmers brings about increase in farm revenue by about 11.29% (v_i = [exp(0.107)-1]) at the 75th quantile but decrease in HFIAS (that is, reduced household food insecurity) by around 20.80% (v_i = [exp(0.189) - 1]) at the 50th quantile. The positive relationship between sex and farm revenue could be linked to better access to productive resources by male farmers than their female colleagues. Zhu et al. (2020) reported similar results in the study carried out among rural farmers of China. Also, the negative relationship between sex and HFIAS supports the finding of Oparinde (2021) where it was reported that male aquaculture farmers were more food secure than their female colleagues. Age of respondents contributed negatively and significantly to HFIAS at the 25th quantile but had a positive and significant relationship with HFIAS at the 75th quantile. This indicates that increase in age of respondents reduced the level of food insecurity by 6.4% at the 25th quantile but increased the level of food insecurity by 5.0% at the 75th quantile. The increasing effect could be attributed to old age when farmers would not be agile enough to get involved in farming activities being energy sapping in nature. This is in line with Ajayi and Olutumise (2018) who reported that older farmers had higher probability of being food insecure. Years of education variable had positive and negative significant correlation with farm revenue and HFIAS at the 50th quantile, respectively, indicating that increase in number of years spent in school will improve farm revenue by 1.6% and reduce level of food insecurity of the crop farming household by 4.7%. Similar result was reported by Oparinde (2019) who stated that increase in years of education raised the likelihood of farmers being food secure, while Zhu et al. (2020); Zhang (2020) reported that education increased farm income.

The coefficient of household size was positive and significant at 25th and 50th quantiles, suggesting that household size increased HFIAS by 38.3% and 20.0% at 25th and 50th quantiles, respectively. The implication of this is that increase in family size would increase the level of food insecurity among the respondents. The results further confirmed the finding of Oparinde (2019) that household size increased food insecurity. Farm size increased farm revenue by 12.6% and reduced HFIAS by 23.6% at the 75th quantile, which implies that crop farmers with higher farm size would have more farm revenue and improved food security status. Shahzad and Abdulai (2020) also reported that level of food insecurity declined as a result of increased farm size in Pakistan, while Liu et al. (2019) stated that larger farm size contributes significantly to farm income. Farming experience positively contributed to farm revenue and negatively contributed to HFIAS at the 75th and 25th quantile, respectively. This suggests that more farming experience increased farm revenue but reduced level of food insecurity among crop farming households. Ahmed et al. (2015) stated that there may be increase in the level of food insecurity because of reduced production and revenue triggered by inadequate farming experience. Number of extension visits contributed significantly to farm revenue at the 50th quantile. This result supports various findings in the literature. For example, Anang et al. (2020) reported that agricultural extension had a statistically significant influence on farm income in Northern Ghana.

Cooperative membership had a direct and significant connection with farm revenue at the 25th and 50th quantiles but indirect and significant influence on HFIAS at the 25th quantile. This shows that members of cooperative society(ies) would have higher revenue by about 11.96% (v_i = [exp(0.113)-1]) and 25.23% (v_i = [exp(0.225)-1]) at the 25th and 50th quantile, respectively. However, members of cooperative society(ies) would have lower HFIAS (higher level of food security) by around 124.57% (v_i = [exp(0.809)-1]) at the 25th quantile. Similar result was gotten by Kabunga et al. (2014) where cooperative membership was observed to have positively influenced farm income.

Credit constraints variable positively and significantly influenced farm revenue at 75th quantile while the same variable negatively and significantly influenced HFIAS at 50th quantile. The implication of this is that non-credit constrained crop farming households realized higher farm income than credit constrained crop farming households by about 65.04% (v_i = [exp(0.501)-1]) at the 75th quantile, while the HFIAS reduced (that is, reduced level of food insecurity) by around 29.30% (v_i = [exp(0.257)-1]) among non-credit constrained crop farming households at the 50th quantile. Shahzad and Abdulai (2020) reported similar result which states that credit constrained farmers had higher HFIAS (that is, increase in level of food insecurity) than their non-credit constrained counterparts. Non-farm income had a direct and significant effect on farm revenue at the 50th and 75th quantile, while it had a negative and significant influence on HFIAS at the 50th quantile. This implies that crop farmers who have non-farm income realized more farm revenue by about 40.92% (v_i = [exp(0.343)-1]) at the 50th and about 162.74% (v_i = [exp(0.966)-1]) at the 75th quantile. Crop farmers with non-farm income had lower HFIAS by about 45.93% (v_i = [exp(0.378)-1]) at the 50th quantile. The probable reason for the association between non-farm income and HFIAS could be the income effect of participating in non-farm activities which can raise farmers' income that helps in improving household food security (Twumasi et al. (2021). This result establishes the finding of Abdullah et al. (2019).

Conclusion

This study analysed the impact of ICTs use on agroforestry technologies' adoption with the use of ETPR model which accounts for the likely selection bias owing to the unobservables related to ICTs use. Also, UQR model was used to examine the heterogenous impact of ICTs use and agroforestry technologies' adoption on farmers' welfare (farm revenue and HFIAS). The results indicated that the use of ICTs improved the adoption of agroforestry technologies that facilitate friendly environment. Specifically, ICTs users adopted agroforestry technologies more than non-users in 1.744 times on the average. The ATT and ATE results indicated that ICTs use promotes adoption of agroforestry technologies in the study area. Also, ICTs use and agroforestry technologies' adoption statistically and heterogeneously influenced farm revenue and HFIAS. Precisely, ICTs use had positive and significant association with farm revenue at the 25th and 75th quantiles with the topmost influence of ICTs use on farm revenue occurring at the lowest quantile. There is an inverse relationship between ICTs use and HFIAS at the 50th quantiles, suggesting that use of ICTs by the crop farmers would improve their food security status since reduced HFIAS implies better food security status. Adoption of agroforestry technologies positively and significantly influenced farm revenue at the 25th quantile, indicating that agroforestry technologies positively contribute to farm revenue. Household food insecurity access scale (HFIAS) is negatively influenced by adoption of agroforestry technologies at the 25th and 75th quantiles with the uppermost effect of agroforestry technologies' adoption on HFIAS at the 25th quantile.

Therefore, it is suggested that policies that promote crop farmers' access to ICTs should be the priority of policy makers who are interested in the welfare of crop farmers and increased farmers' level of agroforestry technologies' adoption. This is important since ICTs use improved the agroforestry technologies' adoption, farm revenue and food security status of the crop farmers. Also, policy measures aimed at encouraging the adoption of agroforestry technologies should be the top agenda of government and other stakeholders who are conscious of friendly environment and crop farmers' welfare since adoption of agroforestry technologies improved farm revenue and food security status among farmers. Having seen that cooperative membership significantly contributed to agroforestry technologies' adoption, farm revenue and food security, cooperative societies, as a matter of policy, should be included in the government's and other stakeholders' efforts to promote agroforestry technologies adoption and other welfare related programmes. Credit conditions of crop farmers should be improved through availability of single-digit-interest credit facilities that will enable them to use ICTs and adopt agroforestry technologies. This is necessary because ICTs use and agroforestry technologies require certain level of financial investments and credit constraints variable significantly influenced the use of ICTs adoption of agroforestry technologies. Years of education variable positively contributed to ICTs use, agroforestry technologies' adoption and welfare of crop farmers in the study area. Therefore, investment in education (formal or informal) should form part of the policy measures meant to promote ICTs use, adoption of agroforestry technologies, farm revenue and food security status of crop farmers. Now that the results from this study are interesting, further studies should focus on the impact of each of the agroforestry technologies on farmers' welfare in order to avoid loss of information on the roles of each of the technologies in farmers' welfare improvement.

Corresponding authors:
Lawrence Olusola Oparinde, Ph.D.
Department of Agricultural and Resource Economics. The Federal University of Technology Akure, P.M.B. 704, Akure, Nigeria
Phone: +2348062317878, Email: saintlawrence8@yahoo.com; looparinde@futa.edu.ng

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Appendix

	ICTs use	Agroforestry technologies' adoption
	0.2659 (0.000)	(0.0176) (0.1521)

Notes: Figures in brackets are the p-values
Source: Author's estimations based on data from survey 2022

Appendix 1: Pearson correlation test results for the validity of the instrumental variable.

Volume XV Number 4, 2023

The Climate Effect on Colombian Coffee Prices and Quantities Based on Risk Analysis and the Hedging Strategy in Discrete Setting Approach

Javier Pantoja-Robayo[1], David Rodriguez-Guevara[2]

[1] Business School, EAFIT University, Medellín, Colombia

[2] Department of Finance, Faculty of Economic and Administrative Sciences, Instituto Tecnológico Metropolitano, Medellín, Colombia

Abstract

This paper provides a risk-hedging strategy for coffee markets including climate impact in the context of Colombian Coffee producers, companies, regulators, and policymakers. From the intermediaries' perspective, we present a hedging price and quantity risks using financial instruments based on price and weather variables (El Niño and La Niña phenomena). The coffee price and quantities produced are mitigated by the inclusion of climatic variables in two ways: first, through analysing the changes observed in the forward curve against spot price measuring the deterministic effect, known in this market as the forward risk premium. Second, including the weather index in the hedge structure on price and quantity in the coffee market improves the agent's result; this latter aims to improve the hedging claim's performance due to the link between demanded volume and weather-linked index. An experiment shows the strategy profit over the best-performing claim price derived only and without hedging.

Keywords

Weather index, Coffee market, hedging strategy, forward risk premium.

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Introduction

Coffee-producing countries such as Brazil, Vietnam, Colombia, Indonesia, Ethiopia, Honduras, and India centralize trade through federation-like entities in coordination with producer associations (often cooperatives) and futures contracts with Intercontinental Exchange, Inc. (ICE). The fluctuations of prices and quantities for the producers, in contrast to the agreements signed with the federations, establish a risk exposure due to the differences between the international price and the local price, as well as quantities produced and quantities contracted; these distortions financially impact everyone: producers, cooperatives and federations.

The first coffee bean futures market began trading in 1882 (the Coffee Exchange of New York or CECNY). Intercontinental Exchange, Inc. acquired NYBOT in 2007 and changed its name to ICE Futures USA (Jenkins and Barbosa, 2020). This market represents a standard trade coffee quality quoted price is not necessarily the same delivery price at the value traded between buyers and sellers. The price differential reflects the physical market conditions and the quality of the coffee (Federación Nacional de Cafeteros de Colombia, 2020). Three factors explain the coffee price, the C-contract or international price of washed Arabica coffee; the quality differential and the TRM rate and the price differential between buyers and sellers.

Analysing the Colombian coffee price allows us to predict the commodity portfolio using exogenous variables. Studies such as Pham et al. (2019), Martins et al. (2015) and Paes (2010) found the direct effect of climate on coffee prices. The current coffee market (2019-2023) has presented high volatility levels due to the excessive rains, changes in sunlight and soil conditions in Brazil, lowering the market price, and lack of labour in Central America, increasing the price due to the lack of production. Regarding the C contract, there were peaks in December, March, and September. The dollar showed volatility due to the world economic dynamics showing values above 4000 COP, and oil futures showed adverse effects (Federación Nacional de Cafeteros de Colombia, 2020). By 2021, the market's increased interest in Colombian coffee because of the devaluation of the Colombian peso (COP) made this commodity more attractive on the New York Stock Exchange. Even so, the world coffee market had an increase of 7.2% produced from 2020 to 2021. (Increase by 10.2% between 2016 and 2021) (Federación Nacional de Cafeteros, 2021a).

The coffee price and quantities produced are mitigated by the inclusion of climatic variables in two ways: first, through the analysis of the changes observed in the forward curve (future prices at different terms) against spot price (Ravi et al., 2022), measuring the deterministic effect, known in this market as the forward risk premium. Second, the inclusion of weather indices in the structuring of hedging on price and quantity in the coffee market improves the result for the agent; This latter aims to enhance the hedging claim's performance due to the link between demanded volume and weather-linked index (Hazell, 2000).

Results show the inclusion of weather variables improves the hedging claim's performance due to the link between demanded volume and the weather-linked index. An experiment shows the gain of the proposed strategy over the best-performing claim derived on price only and without hedging.

Coffee studies and climate in commodities

The coffee quantities and prices are analysed in the following studies. Cárcamo and Franco (2012) initially stated supply and demand drive coffee prices. Johnson (1957) proclaimed the existence of global inventory (from several producing countries) to avoid volatile price effects. Volume risk is more important than product market risk. Uncertainty about stocks and production expectations generates volatility Rodríguez and Melgarejo (2020) found in their study the stochastic elements influenced by exogenous variables are fundamental in the price analysis. Pham et al. (2019) complement coffee as a climate-sensitive perennial commodity.

With these considerations, current studies on coffee risk hedges incorporate price and weather. Pham et al. (2019) and (Barrios et al., 2022) studied coffee prices; they found climate changes in the asset price, such as a drop in yields and an increase in pests and diseases, or positive effects, such as an increase in the harvesting niche and pollination services. Martins et al. (2015) complement climate hits on the productivity and quality of coffee are related to atypical events (El Niño and La Niña phenomena), generating flawed crops.

Läderach et al. (2017) quantified the impact of progressive climate change on higher-quality coffee, minimising risk production, showing four climate effects with adaptation effects for low altitudes and long-term adaptation for high altitude crops. Tucker et al. (2010) used risk perception on farmers associated with the high risk of climate effects on seed adaptations. However, farmers associated with high-risk events were less likely to make specific adaptations

In studies focused on mathematical or econometric models, Álvarez et al. (2019) analysed the climate as an uncertainty variable on bananas price using Vector Autoregressive (VAR) models, finding the correlation between the price, the asset, and the Chicago Mercantile Exchange climate index. Paes (2010) and Pokorná & Smutka (2010) used linear models to identify weather impacts on the price of coffee in two moments; he found out the rainy season positively affects plant growth and increases grain numbers, and the dry season affects the production in the quantity and quality of the bean. The study predicts events three to six months in advance.

Garcia (2003) used a neural network and ARIMA model to identify price behaviour, showing better results in Variance Error Neural Network in 22% compared to the ARIMA model. Nhung et al. (2020) sought to hedge Vietnamese coffee risk using a Vector Error Correction Model (VECM); they found hedging ratios and the optimal number of each futures contract short-term hedging tools. Makonnen et al. (2021) used quantile regression to identify the temperature impact on futures returns on soybean, corn, cotton and coffee under extreme bear and bull market conditions. Vijayakumar (2022) examined a vector correction model with long-run cointegration in the US dollar index and crude oil on coffee. He discovered the ICO price changes, Arabica coffee futures, crude oil and the US dollar index led to a long-run change in coffee prices.

Materials and methods

Coffee spot price expectations

Riaño (1997) and Pantoja (2012) shows at maturity time T, whoever bought at contract price at time t_o, will have to pay a value Ft_{oT}. In return, the commodity valued at the spot price is P_l Whoever sells the contract in a short position will have a net profit equal to and opposite in sign to the buyer. Formula (1) shows the accurate market price of the commodity.

$$P_t = P_l - Ft_{oT} \quad (1)$$

To measure the forward risk premium (FRP) is the difference between the expected spot price and the contract price. An FRP_{tT} positive value shows a contract price (2) below the expected exchange price (Chen and Ryan, 2023), and the selling agent pays the contract. An FRP_{tT} negative value indicates the price contract is higher than the exchange expectation, and the demand agent pays the hedge (Bessembinder and Lemmon, 2007).

$$FRP_{tT} = E(P_l) - F_{tT} \quad (2)$$

External effects analysis - structural change

Longstaff and Wang (2004) did the Bai-Perron test using structural change time series breakpoints for evidence of significant phenomena showing the number of structural breaks or information restrictions for each m-partition $(T_1, \ldots T_m)$, minimizing the sum-squared residuals $S_T(T_1, \ldots T_m)$ and obtaining the optimal regressions (3).

$$\sum_{i=1}^{m+1} \sum_{t=T_{i-1}+1}^{T_i} [y_t - x_t'\beta - z_t'\delta_i]^2 \quad (3)$$

Greene (2008) and Cermák et al. (2017) recommends using four complementary tests: Chow, CUSUM, OLS-CUSUM and Rec-CUSUM for reading changes in time series. In the first test, Chow (1960) measured the structural change in time series, comparing two regression slopes and proving if they were statistically equal. According to (4) where SSE_R fit the original model $m = 1$, SSE_{NR} as the sum of the SSE of the break models $m = 2, 3$. Then F_{chow} statistic value is greater than the $F_{theoretical}$ evidence of structural change.

$$Y_t = \alpha^m + \varepsilon_t^m + \sum_{t=1}^{n} \beta_k^m X_{tk};$$

$$m = \{1,2,3\};\ F_{chow} = \frac{\frac{SSE_R - SSE_{NR}}{k}}{\frac{SSE_{NR}}{n-2k}} \quad (4)$$

The second test, OLS - CUSUM (Ordinary Least Square CUSUM), explains the stability of coefficients (β) in a recursive multiple linear regression model, based on a sequence of sums of squares, under the null hypothesis of coefficient constancy (5) are recursively linear models $s = k + 1, k + 2, \ldots, n$, where $\varepsilon_t^{(s)}$ is the residuals obtained recursively and measured with standard Brownian process variance. When the residuals exceed the theoretical boundary, there is a structural change.

$$\varepsilon_t^s = Y_t^s - \alpha^s - \sum_{s=k+1}^{n} \beta_k^s X_{tk}^s;$$

$$B^{(n)} = \frac{1}{\hat{\sigma}\sqrt{n}} \sum_{t=1}^{zn} \hat{\varepsilon}_t^{(n)};\ 0 \le z \le 1 \quad (5)$$

The third test is Residuals Rec-CUSUM test also applies residual recursion process (6). w_r is a standardised residual series based on each recursive path's scalar variance-covariance matrix root. It starts from w_r, where w_t are the standardised summation of w_r. Stablished by the minimum confidence ($k \pm a\sqrt{(n-k)}$) and maximum confidence ($n \pm 3a\sqrt{(n-k)}$), whose test analysis is the same as OLS – CUSUM.

$$w_r = \frac{\hat{\varepsilon_t}}{\sqrt{1 + x_t'(X_{t-1}'X_{t-1})^{-1}x_t}} \sim N(0, \sigma_\mu^2);$$

$$w_t = \sum_{r=k+1}^{t} \frac{w_r}{\sigma_\mu};\ \sigma_\mu = \frac{SSE}{n-k};\ E(w_r) = 0;\ \alpha = 0.05 \quad (6)$$

Static risk coverage via quadratic optimisation

Oum and Oren (2009) used the price function (7), where the price given the produced asset quantity is equivalent to the local price f_{tT}, P_l is the asset spot price, and q is asset demand. The procedure can involve an external weather variable of the risk hedge. Pantoja and Vera (2020) set spot price at time T, x_w is a function of weather at time T and total profit Y.

$$y(P_l, q) = (f_{tT} - P_l)q \quad (7)$$

The objective of the function is to maximize the mean-variance process for profit hedging at time T (8). It maximizes the expected utility under the constraint cost of making financial portfolios with contingent rights $x_p(p)$ y $x_w(w)$ are equal to zero.

$$Y(P_l, q, x(P_l), x(w)) = y(P_l, q) + x(P_l) + x_w(w);$$
$$x(f_{tT})\ (P_l)\ x_w(w) \qquad (8)$$

Pantoja and Vera (2020) proposes a restricted continuous solution for portfolios in (9). For this purpose. 1) The independent solution case, where weather is independent of price and production factors (10); and 2) The general solution case, where the set of weather on prices and quantities correlations (11).

$$\max_{x(p),z(\iota)} E(U\left(y(P_l, q, x(P_l), x(w)\right)];$$
$$s.t\ E^{\phi}[x(P_l)] = 0, E^{\phi}[x(w)] = 0 \qquad (9)$$

$$x_{P_l} = \begin{bmatrix} \widehat{M_{pP_lP_l}} \\ \phi_{P_l}^T \end{bmatrix}^{-1} \begin{bmatrix} \widehat{c_{P_l}} + \frac{1}{2a}(\hat{\psi}_{P_l} - \hat{\phi}_{P_l}) \\ 0 \end{bmatrix};$$
$$x_w = \begin{bmatrix} \widehat{M_{ww}} \\ \phi_w^T \end{bmatrix}^{-1} \begin{bmatrix} \widehat{c_w} + \frac{1}{2a}(\hat{\psi}_w - \hat{\phi}_w) \\ 0 \end{bmatrix} \qquad (10)$$

$$\begin{bmatrix} x_{P_l} \\ x_w \end{bmatrix} = \begin{bmatrix} \widehat{M} \\ B \end{bmatrix}^{-1} \begin{bmatrix} \hat{c} + \frac{1}{2a}(\hat{d} - \hat{b}) \\ 0 \end{bmatrix};$$
$$\lambda_{P_l} = \lambda_w = 1 \qquad (11)$$

Results and discussion

For hedging, we use Colombian coffee international prices and Spot prices from Bloomberg and National Weather Service – National Oceanic and Atmospheric Administration. Table 1 provides information on the local price of coffee, the market price, coffee production and a climatic variable using the ONI 3.4. The database uses monthly information from April 2016 to January 2023, making 83 observations. The local price series and the coffee market price series present a variation of 41.8 and 32.25 USD cents with rightward skewness behaviour; Jarque Bera indicates both series are statistically not normally distributed. The coffee production series shows a higher level of deviation, suggesting seasonal volatility; according to Jarque Bera, the coffee quantity presents normal distribution. Regarding the climate series, the ONI 3.4 works with the average values of ocean temperature showing normal distribution according to the Jarque Bera test.

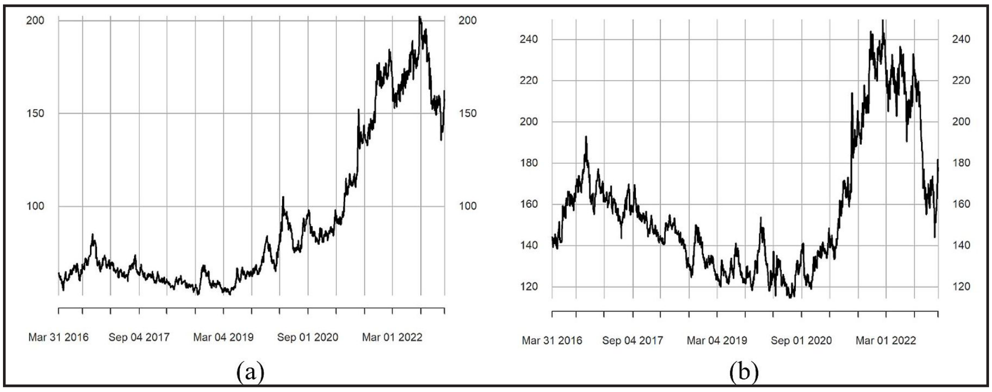
Figure 1 shows the series of Spot prices (local prices) of Colombian coffee and the series of coffee market prices; in both series, until 2020, the coffee price was stable, but compared to the market price, the spot price is below market values, showing speculation effects in production and avoiding the criterion of excessive volatility (Tröster and Gunter, 2022).

Figure 2 shows the development of (2). The process shows forward contracts are negative (the forward price is higher than the expected local price for the coffee future) in time series, showing two moments of lower fall of the FRP are appreciated, in the middle of 2016 and at the beginning of 2022.

Variable	Local Coffee Price (P_l)	Coffee Market (F_{tT})	Production (q)	ONI 3.4 (w)
Min	52.18	114.35	616	25.28
Median	70.74	150.25	1089.5	26.82
Mean	92.27	157.97	1121.68	26.79
Max	202.34	249.65	1743	28.72
Standard Dev	41.8	32.25	214.94	0.9
Variance Coefficient	0.45	0.2	0.19	0.03
Jarque Bera	368.81	275.3	4.29	4.65
P-value Jarque Bera	0	0	0.12	0.1

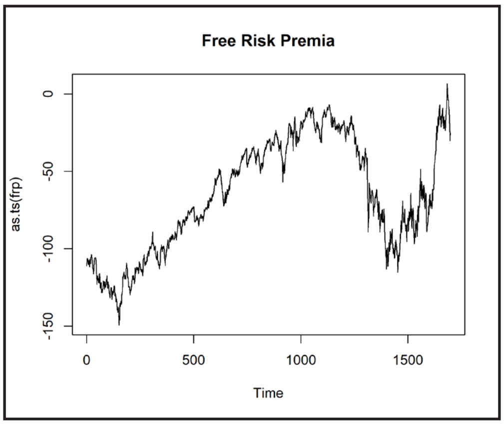
Source: own elaboration based on data from Bloomberg (2023)

Table 1: Colombian coffee market database and ONI 3.4.



Source: own elaboration based on data from Bloomberg (2023).

Figure 1: Coffee local price (left) and Coffee market price (right) from 2016 to 2023.



Source: own elaboration based on data from Bloomberg (2023)

Figure 2: Forward risk premium in the coffee market.

Structural change analysis

Table 2 shows the results of structural change tests of models (3-5) applied in Figure 2; the tests show structural change processes statistically verifiable through P-values; the 0% value shows an alternative hypothesis identifying structural change setting in the times series on FRP.

Test	Statistic	P-value
Chow	4648.1	0%
OLS CUSUM	10.047	0%
Recursive CUSUM	5.6376	0%

Source: own elaboration based on data from Bloomberg (2023)

Table 2: Statistical tests for structural change.

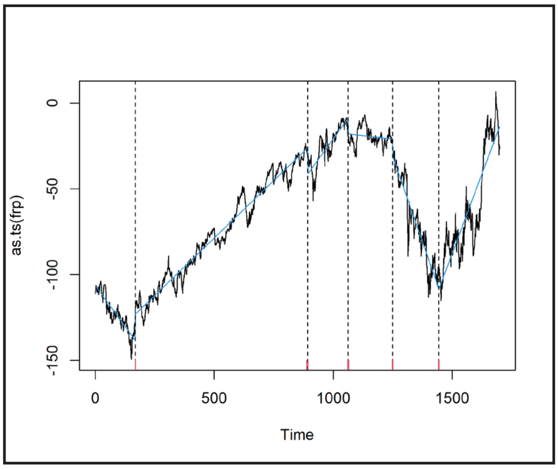
Applying Bai Perron structural change (6), we identify six climatic breakpoints between 2016 and 2022. In 2016 the FRP structure was affected by a weak Niña phenomenon. From 2016 to 2019, two climatic phenomena increased the value of the FRP until they approached zero risk values. Between the final 2019 and the middle of 2020, no climatic event affected the local prices, and between 2020 and 2023 La Niña Phenomena were relevant for the local prices.

Table 3 and Figure 3 shows the climate breakpoints identified by the FRP in (2). In 2016, climate conditions increased world coffee production in Central America, Brazil, and Colombia. The explanation obeys Brazil's price expectation was lower due to a reduction in rainfall in the southern region of Minas Gerais and an increase in temperature impacting production. In addition, speculation about Vietnamese coffee production in the fall of 2017/18 (Federación Nacional de Cafeteros de Colombia, 2016).

Breaks	(Intercept)	Trend	Phenomenon
1/4/2016 – 1/12/2016	-106.295	-0.189	La Niña weak
2/12/2016 – 30/10/2019	-145.585	0.134	La Niña – El Niño weak
31/10/2019 – 24/07/2020	-212.491	0.192	No event
27/07/2020 – 22/4/2021	0.277	-0.017	La Niña moderated
23/4/2021 – 27/01/2022	466.797	-0.398	La Niña moderated
28/01/2022 – 2/2/2023	-643.855	0.371	La Niña moderated

Source: own elaboration based on data from Bloomberg (2023)

Table 3: Breakpoints for climate events in the Forward Risk Premium.
(Null and CCM, 2023).



Source: own elaboration based on data from Bloomberg (2023)

Figure 3: Structural change processes of the FRP series under Bai and Perron (1998) methodology.

For the second period on record, the coffee price fell to 135cUSD/lb due to the expectations and weather rectification of the Brazilian crop and a positive coffee production level for Colombia, Honduras, and Peru. In 2017/18, the coffee price decreased for market supply by selling mild coffees and considerable inventory from importing countries. In 2018, the arabica coffee price recorded a systematic fall (29% between January and December 2018) caused by a downward trend influenced by the depreciation of the Real currency (R$) and the increase in Brazilian export estimates. Political and social factors and speculative Bolsonaro's political victory in 2018-19 accelerated the price decline (Federación Nacional de Cafeteros, 2017,2018). This event occurred until July 2020 as a market lag of the high volatility in the New York quotation. The effect of the exchange rate COP/USD and the fall in economic dynamics increased the devaluation effect in Colombia.

In the last (sixth period), the risk premium shows that there is a change in agents' expectations, having values of the forward contracts below the Spot prices determined by the international coffee market, modifying the C contracts by the expectations of lower production due to world health conditions and adverse weather quality (Federación Nacional de Cafeteros, 2020, 2021b).

Hedging model with discrete quadratic optimisation

The static risk coverage (10) and (11) shows two results. The independent case shows the hedging without the correlation between the price of coffee production and the weather index; and the second is the general case considers the correlations between local prices, quantities, and weather index.

Independent case

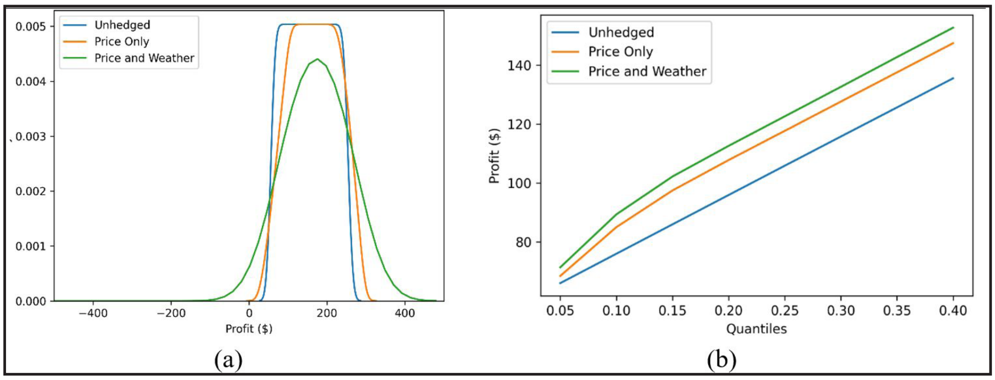
For a discrete solution in an independent case, Table 4 shows the parameters the distributions operate in (10). The correlation levels between price and quantity are inverse expected in market terms. Concerning the correlation between coffee quantities and climate can be explained by extreme climate phenomena where high levels of rainfall or drought alter the coffee quantities.

Table 5 shows the distribution parameters function and the measurement of coffee prices; the correlation factors between prices, quantities and the weather factor are negative, explaining the price will increase if coffee production is lower.

ψ:	$log(P_l) \sim N(2.07, 0.14^2)$	$q \sim N(1038.34, 218.85^2)$	$w \sim N(26.38, 0.78^2)$
	$Cor(log(P_l),q) = -0.35$	$Cor(w,q) = -0.34$	$Cor(w, log(P_l)) = 0$
ϕ:	$log(P_l) \sim N(1.92, 0.17^2)$	$w \sim N(26.78, 0.89^2)$	$Cor(w, log(P_l)) = 0$

Source: own calculations based on data from Bloomberg (2023)

Table 4: Fitting parameters for the optimisation of the independent case.



Source: own elaboration based on data from Bloomberg (2023)

Figure 4: Distribution of profits in the independence case for different strategies: no hedging, price only and price plus weather. (a): profit density distribution, (b): profit quantiles.

%	No hedge	Price only	Price and Weather
5	66.055	68.491	71.414
10	76.021	85.034	89.369
15	85.982	97.469	102.202
20	95.93	107.776	112.594
25	105.862	117.672	122.597
30	115.758	127.598	132.603
35	125.621	137.503	142.687
40	135.502	147.397	152.663

Source: own elaboration based on data from Bloomberg (2023)

Table 5. Profits in the independent case for coffee price hedging.

The weather effect affects production when it is extreme, explaining the conditions of the last three years of the series. Figure 4(a) shows the density distribution of profits, which due to the characteristics of contracts with expectations with forward contracts above local prices, the application of weather identifies risk effects on profits making the series more concentrated. Figure 4(b) shows the improvement of the agent's utility function when price and weather hedging is applied, obtaining better profits in using a forward contract. including the payoffs resulting of the hedging claim.

General case

Table 6 shows the relationship between spot prices and weather is inversely proportional. When the weather has extreme effects, like warm months from March to June (El Niño phenomenon), prices have low market expectations, and for the La Niña phenomenon, the price increased due to a shortage of rainfall.

Table 7 and Figure 5 show the direct correlation between price and weather, such as suitable options in the strategy reflecting higher levels of portfolio utility.

Applying the general case adds the correlation between local price and weather; in the independent case, this value is zero. In the general case, the local price and weather relationship is negative; the hedge portfolio has a similar effect to the independent case; generating this hedge gives better gains than strictly analysing price, weather, and no hedge, with the best result being the price and weather application of hedging (Table 7).

ψ:	$\log(P_l) \sim N(2.07, 0.14^2)$	$q \sim N(1038.34, 218.85^2)$	$w \sim N(26.38, 0.78^2)$
	$Cor(\log(P_l),q) = -0.35$	$Cor(w,q) = -0.34$	$Cor(w, \log(P_l)) = -0.30$
ϕ:	$\log(P_l) \sim N(1.92, 0.17^2)$	$w \sim N(26.78, 0.89^2)$	$Cor(w, \log(P_l)) = -0.46$

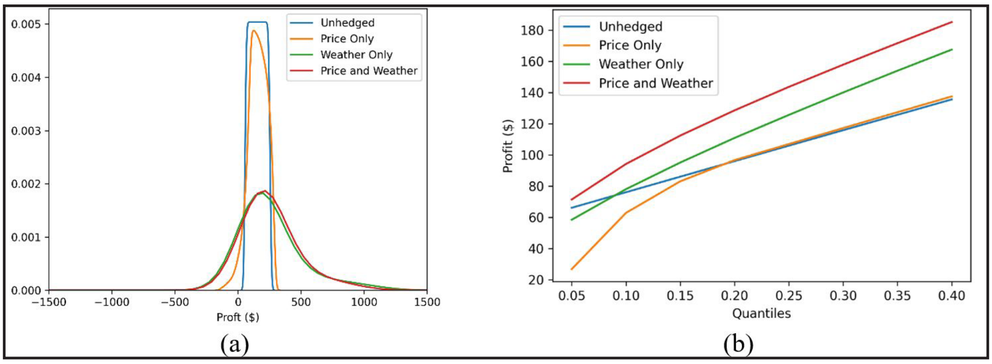
Source: own calculations based on data from Bloomberg (2023)

Table 6: Fitting parameters for the general case optimisation.

%	Price only	No hedge	Weather Only	Price and Weather
5	26.724	66.055	58.38	71.347
10	62.777	76.021	77.989	94.135
15	83.005	85.982	95.054	112.326
20	96.593	95.93	110.812	128.483
25	106.865	105.862	125.562	143.525
30	117.119	115.758	139.947	157.747
35	127.275	125.621	153.87	171.518
40	137.402	135.502	167.417	185.085

Source: own elaboration based on data from Bloomberg (2023)

Table 7: Profits in the general case for coffee price hedging.



Source: own elaboration based on data from Bloomberg (2023)

Figure 5: Distribution of profits in the general case for different strategies: No hedging, price only, weather only, and price and weather. (a): profit density distribution, (b): profit quantiles.

Conclusion

The study measures the climate effect (Oceanic Niño Index) on the price of coffee in Colombia through two methodologies; i) the structural change on forward risk premium (FRP) and ii) risk hedging through a discrete optimisation with the climate effect as an exogenous variable explains the price and production of the asset between April 2016 and January 2023.

For the development process, first, we identify the Forward Risk Premium with the Spot Price (Local Coffee Price) and the market price; the result of FRP shows a derivative behaviour above the market price until 2020 passing this year, the market expectations change leading higher prices than the agreed futures. Studying the price behaviour, we use structural change tests to identify five moments of change in the series, allowing us to understand the strong dependence of the climatic variable on market expectations; both the market reports and the climatic moments identified coincide with the spot prices changes when a climate phenomenon (Niño or Niña) also changes.

Using the last information, we apply as a climate variable by the ONI index (Oceanic Niño Index 3.4) in a discrete quadratic optimisation hedging portfolio, the results show the correlations of price, quantities, and climate are inverse, the strict relationship with price and climate (independent case), as the relationship between ONI, local price, and quantity (general case) has better profit results when including the design rather than not.

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Corresponding author:
David Rodriguez Guevara
Department of Finance, Faculty of Economic and Administrative Sciences
Instituto Tecnológico Metropolitano, Calle 54a # 30-01 of.1 L405, Medellín, Colombia
Phone: +573104347629, E-mail: davidrodriguez@itm.edu.co

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Adapting Agriculture: Policy Implications of the Rise of Resistant Seeds in Farmers' Climate Change Strategy

Dáša Ščurková , Marianna Marčanová

Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Slovakia

Abstract

This paper explores farmers' perceptions of climate change and their preferred adaptive and mitigatory strategies within Slovakia's Nitra region, aiming to devise recommendations for climate change-oriented agricultural policies. Our methodology incorporates an analysis of perspectives gathered from a regional survey using the Analytical Hierarchy Process (AHP) and SuperDecisions software, complemented by a risk-attitude assessment using the modified Multiple Price Lists (MPL) method. A subsequent heterogeneity analysis correlates these preferences with respondents' socio-economic status and risk attitudes. Our findings underscore the use of improved, resilient seeds as a favored adaptation measure and reveal a correlation between farmers' socio-economic attributes and their climate change strategy preferences. Based on this, we propose inclusive, micro-level agricultural policies that prioritize the unique climatic needs of the Nitra region and strongly consider the priority viewpoints of farmers within this region, aiming to promote sustainable agriculture under changing climatic conditions.

Keywords

Preferences, climate change, adaptation, mitigation, support policy, AHP, GMO.

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Introduction

The agricultural sector is a very distinctive area of the national economy, characterized by significant barriers to entry such as the need for substantial initial capital and seasonality, which among other things, results in irregular and sporadic income for agricultural enterprises (Mukaila, 2022). However, agriculture is increasingly associated with landscape maintenance, rural development, and environmental protection. Agricultural production impacts the improvement of the rural population's living standards and mitigates the effects of urbanization and a changing climate (Adger et al., 2009). Pretty et al. emphasizes the critical role of sustainable agriculture in improving the livelihood of rural populations and mitigating the impact of environmental changes (Pretty et al., 2018). Agricultural support is dependent on state support policies, which are subject to various internal and external influences. Therefore, agricultural policy is becoming increasingly important. For an agricultural enterprise, state support is a significant factor that affects many aspects of its operations (Brooks, 2014).

Another crucial factor exerting a considerable impact on agriculture is climate change. More intense rainfall and higher temperatures are projected for Europe due to climate change (Berg et al., 2013). Changes in temperature and precipitation, as well as weather and climate extremes in Europe, are already influencing crop yields and livestock productivity (EEA Report, 2019; Scherrer et al., 2016). Weather and climate conditions also affect the availability of water needed for irrigation, livestock watering, processing agricultural products, and transportation and storage conditions. Climate change can also cause significant shifts in what and where European farmers can produce (Nelson et al., 2014). The extent of climate change impacts will depend on various factors such as geographic area, socio-economic development, changes in agroecosystems, and the adaptability of a given region (Ciscar et al., 2018; Raza et al., 2019). Agriculture itself also has a significant environmental impact, particularly through the release of greenhouse gases and pollutants that contaminate the air and soil (Lynch, 2021). Climate change directly and indirectly affects agricultural production and the agroecosystems upon which farmers rely.

In the future, these already observed impacts of climate change are expected to deepen (Peltonen - Sainio et al., 2011).

Agriculture thus influences the landscape not only as an area that ensures food production but also values that are not subject to production and trade, such as biodiversity, cultural and aesthetic value of the landscape, and a quality of environment. The role of the state is to ensure and support agriculture so that its sole objective is not just the production of sufficient quantities of quality food for the population but also to maintain the landscape, develop rural areas, and the currently much-needed environmental protection. Therefore, future measures in agriculture should focus on those that bring comprehensive benefits in terms of economy, food security, adaptation and mitigation of the impacts of climate change, biodiversity support, and environmental protection. As per the findings of Torres et al. (2020), future agricultural policies addressing climate change need to align with farmers' preferences and behaviors, be inclusive, and consider farm and farmer typologies at the micro-level.

In this context, the objective of our research was to determine the relative importance of various climate change adaptation and mitigation actions connected to agricultural activities in a Nitra region in Slovakia. This information is intended to help policymakers focus on prioritized solutions that enhance the sustainability of agricultural systems (Firley, 2023). Additionally, we analyzed the relationship between farmers' preference structures, their risk attitudes, and their socioeconomic characteristics and propose inclusive agricultural policies that prioritize the unique climatic needs of the Nitra region and strongly consider the priority viewpoints of farmers.

Materials and methods

Given the objective of the study, we decided to divide our research into multiple sections. We conducted a thorough analysis of the study region from both a climatic and agricultural perspective, highlighting the development of climate change and agricultural aspects within Nitra region. Through a comprehensive review of relevant literature and an analysis of the region's climatic and agricultural features, we were also able to identify appropriate adaptive and mitigating measures. We also focused on an analysis of farmers' socio-economic characteristic and preferences for possible implementation of adaptation and mitigation measures aimed at climate change. We conducted an analysis of heterogeneity, linking farmers' preferences for measures against climate change to their expressed risk attitudes related to their farming activities and socio-economic characteristics. In the final stage, we formulated recommendations in the area of support agricultural policy under the conditions of climate change that take into account our research findings.

Data for our research was collected mainly through a survey representing a sample of 47 farmers from the Nitra region (Figure 1).

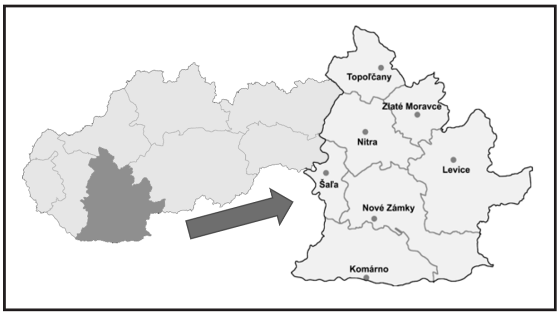

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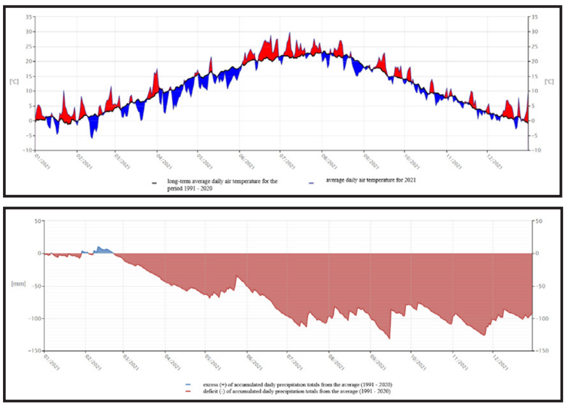
Figure 1: Study area location.

Respondents were approached based on a list and contacts of more than 120 agricultural entities provided by the Agricultural Paying Agency of Slovakia, which is a budgetary organization involved in financial relations with the budget of the Ministry of Agriculture and Rural Development of the Slovak Republic. Data collection took place in a structured format, adapted to the specifics of the surveyed subjects. Farmers filled out the questionnaire from December 2022 to April 2023. In case of ambiguities and additional questions from respondents about the survey questions, a structured interview was conducted with the respective respondent to obtain the requested information. The questionnaire contained 25 questions and was divided into 4 blocks according to the types of information collected. The survey was divided into the following sections: 1) Characteristics of the farmer and the farm (respondent's persona, legal entity - type of the farm, production); 2) Socio-economic status of farmers (land, education and investments, insurance, subsidies); 3) Environmental attitudes and opinions of farmers, and their preferences for climate change adaptation and mitigation measures. 4) Farmers' attitude towards risk. Each farmer needed approximately 50 minutes to answer the questions, and the survey was conducted in accordance with confidentiality rules and principles of personal data protection for each participant. Moreover, each participant was informed about the survey's purpose.

The Nitra region is one of the eight autonomous regions of Slovakia. With its area of 6,343.7 km², the Nitra region occupies 12.9% of the territory of the Slovak Republic. According to the Statistical Office of the Slovak Republic, the region manages the largest area of agricultural land among all the regions of Slovakia. The total land fund of the region is 643,318 hectares. Of this, agricultural land comprises 469 thousand hectares, representing 74% of the total area of the region in terms of percentage evaluation (Statistics Office of the Slovak Republic, 2021). This region has long been one of the most significant agricultural producers. The most common are crops such as wheat, barley, corn for grain, edible peas, technical sugar beet, oilseed rape, sunflower for seed, and it is the largest producer of cereals, oilseeds, legumes for grain and grapes in Slovakia. In the Nitra region, compared to other regions, plant production is dominant. Némethová and Feszterová (2019) study found that crop production was more profitable than animal production in Nitra region, especially in the case of cereals and oilseeds. There are also cultural and historical reasons for the emphasis on plant production (Izakovičová et al., 2022).

Data show temperature and rainfall changes over the past few decades (Figure 2).



Source: Slovak Hydrometeorological Institute, 2021

Figure 2: Average daily temperature (◦C) and excess and deficit of accumulated amount of Average daily temperature (◦C) and excess and deficit of accumulated amount of precipitation (mm) (2021) amount of precipitation (mm).

This is suggested by meteorological data for the last 30 years (1991-2021), which show an upward trend in the average annual temperature and a downward trend in the annual average amount of precipitation (mm). The NUTS3 region, which includes Nitra, recorded an average annual temperature increase of +2.72 °C between the 60s and the period 2009-2018. This places it first among the NUTS3 regions in Slovakia where the temperature has risen the most.

The Analytical Hierarchy Process (AHP) was used to identify farmers' preferences and estimate the relative importance (i.e. priorities) of various adaptation and mitigation measures. The AHP method is a multi-criteria analytical tool developed by Saaty (2001) in the late 1970s. It is frequently utilized in agricultural research, particularly in analyzing farmers' attitudes and setting priorities in their decision-making, resolving agricultural and environmental problems, and analyzing marketing issues related to consumer preferences (Kallas and Gil, 2012, Ndamani and Watanabe, 2017, Aslam et al., 2018). The AHP method includes 3 main phases: 1. modelling, 2. evaluation, and 3. priority setting and synthesis.

Phase 1. Modelling - In this phase, we carried out activities: a) identification and definition of the problem and b) structuring the decision-making model in the form of a hierarchy.

Ad a. Identification and Definition of the Problem - From the study of the given issue, we found that currently there is a lack of information and data indicating the preferences of farmers in Slovakia regarding adaptation and mitigation measures in the area of climate change, as a normative framework for creating public policies related to agricultural production under climate change conditions. Globally, farmers are incorporating a range of strategies that include, but are not limited to, improved crop and livestock management practices, increased use of drought-resistant crop varieties, precision farming techniques, agroforestry, and conservation agriculture (Lal, 2015). Enhanced crop and livestock management strategies involve adjusting planting dates, altering the mix of crops and livestock species, and improving irrigation efficiency (Havlík et al., 2014). In many parts of the world, precision agriculture, which uses technology to optimize returns on inputs while preserving resources, is becoming more prevalent (Zhang et al.,2002). Another widely recognized measure is the use of drought-resistant crop varieties, which has become increasingly important as many regions experience more frequent and severe droughts (Howden et al., 2007). Conservation agriculture, including practices such as cover cropping and no-till farming, can improve soil health and water retention, reduce erosion, and sequester carbon, making it an effective mitigation and adaptation strategy (Powlson et al., 2014). Lastly, agroforestry systems can enhance resilience to climate change by improving soil quality, biodiversity, and carbon sequestration (Mbow et al. 2014).

When choosing the measures from which our survey subsequently proceeded, it was necessary to consider the constraints and specifics associated with the analyzed Nitra region. The identified measures (Figure 3), based on which the hierarchical analysis was carried out, were organized into two main groups. Measures implemented to strengthen resilience to climate change at multiple levels were defined as adaptation measures, and measures aimed at reducing greenhouse gas emissions from agriculture were defined as climate change mitigation measures (Mussetta et al., 2017). Based on a broad variety of adaptation and mitigation strategies, we chose those that, given the current scientific research, we believed to be the most appropriate for the chosen area.

A1 - Changing crop production - Some crops may adapt better to these changing conditions, requiring fewer resources (Challinor et al., 2014). Crop selection must consider factors such as soil, water, and market demand (Lobell et al., 2008). Research indicates certain crops like maize, wheat, and rice can withstand climate variations (Zhao et al., 2017).

A2 - Enhanced and resistant seeds/varieties - Embracing genetically enhanced and resistant crop varieties can significantly increase yield (Tester and Langridge, 2010). For instance, studies indicate hybrid corn seeds with advanced pest and disease resistance can drastically enhance yields (Castiglioni et al., 2008). Similarly, wheat varieties engineered for drought resistance have shown increased yields and superior grain quality (Trnka et al., 2011). The use of genetically modified (GM) corn with built-in pest resistance can not only improve yield but also reduce pesticide usage (Qaim and Zilberman, 2003).

A3 - Adapting the planting calendar - A study demonstrated that advanced sowing generally leads to better wheat, barley, and oats yields, though optimal dates can vary per crop and locale (Semenov and Stratonovitch, 2015). Therefore, strategic sowing schedules are suggested to maximize yield and offset risks associated with climate change (Challinor et al., 2014).

A4 - Investing in irrigation infrastructure- Careful investments in irrigation infrastructure can enhance environmental and agricultural outcomes. Modern irrigation technology can lower water use while boosting productivity (Fereres and Soriano, 2007). Khan et al.'s research corroborates this, highlighting increased agricultural productivity and profitability, alongside reduced soil erosion (Khan et al., 2009).

M1 - The restriction of tilling the soil - Limiting soil tillage, a practice known as reduced or no-till farming, can enhance soil structure, improve water permeability, and reduce soil erosion, contributing to better retention of soil moisture (Lal, 2004). This approach can also sequester carbon, helping to lessen greenhouse gas emissions (Montgomery, 2007). Additionally, reduced tillage can lower energy consumption, boosting agricultural efficiency (Pimentel et al., 2005).

M2 - Organic farming – Organic farming can improve soil quality, yielding better crop outputs and lower costs over time (Seufert, Ramankutty and Foley, 2012). Moreover, comparing farming systems, found organic farming had lower greenhouse gas emissions, less soil erosion, and improved soil quality compared to conventional farming, suggesting the former's superior environmental sustainability (Mondelaers et al., 2009). Organic farming's sustainable potential lies in minimizing synthetic inputs and fostering ecological processes.

M3 - Use of renewable energy - Leveraging renewable energy in agriculture, such as solar and wind, can lead to reduced energy costs, increased energy self-reliance, and diminished greenhouse gas emissions (Kumar et al., 2013). Renewable sources, along with biogas production, can considerably reduce emissions and improve energy self-sufficiency, provided supportive policies and financial mechanisms are in place (Edenhofer et al., 2013).

CLUSTER 1 — *Addressing climate change through adaptation and mitigation measures*	
Adaptation Measures	*Mitigation Measures*
- Changing crop production (A1)	- The restriction of tilling the soil (M1)
- Enhanced and resistant seeds/varieties (A2)	- Organic farming (M2)
- Adapting the planting calendar (A3)	- Use of renewable energy (M3)
- Investing in irrigation infrastructure (A4)	- Using new, less polluting, and energy-efficient machinery (M4)
CLUSTER 2	CLUSTER 3

Source: Own processing

Figure 3: Identified adaptation and mitigation measures.

M4 - Using new, less polluting, and energy-efficient machinery - Modernizing farm machinery for greater energy efficiency and reduced emissions can lead to several benefits, such as cost savings, improved air quality, and a lower carbon footprint. Ogle et al. (2005) in their study suggests that changes in agricultural management, including the use of modernized machinery, can improve energy efficiency and thereby reduce greenhouse gas emissions. Moreover, adopting precision agriculture technologies, like GPS-guided tractors and drones, can decrease fuel and fertilizer use, and greenhouse gas emissions while improving crop yields and reducing production costs, thereby enhancing farmers' profitability (Griffin et al., 2004).

Ad b. The Structure of the Decision Model in the Form of a Hierarchy - The chosen hierarchical model (Figure 3) captures the identified measures based on what is most accepted according to the preferences of farmers. In our model we had two levels. Cluster 1 (adaptation vs. mitigation) was located in the first level and cluster 2 (adaptation measures) and cluster 3 (mitigation measures) in the second level.

Phase 2 - Decision making - Respondents made decisions using pairwise comparisons of all elements at each level of the cluster (Figure 3) using Saaty's proposed scale (Scale from 1 - Both measures are equally important to 9 - The preferred measure is substantially more important than the others), based on which we later estimated the relative importance of alternative measures. For a cluster 1, only one pairwise comparison is applied [n·(n-1)/2 = 2·(2−1)/2 = 1] to adaptation and mitigation measures. For each of the clusters at the lower level according to the dimension n = 4 (4 alternative actions), 6 pairwise comparisons were used [n·(n-1)/2 = 4·(4−1)/2 = 6], where each alternative in the hierarchy was compared with the remaining alternatives within its cluster at the same level, depending on the satisfaction it provides to the respondent (farmers). Pairwise comparisons were collected in our survey.

Phase 3 - Priority setting and synthesis - This phase includes: a) synthesis to identify the best alternative and b) examination and validation of the decision, which correspond to the last two activities of the hierarchical analysis process, through which we estimated priorities (i.e. relative importance).

Ad a. Synthesis to Identify the Most Preferred Criteria - In this part of the model, joint prioritization of all sub-criteria proposed in the model was carried out to select the one that solves the given problem; up to this point, we had to make all comparisons between the elements of each cluster for each farmer (k), from which we obtained the corresponding Saaty matrices ($\hat{A}_k$), through which the local weights of the identified elements $\widehat{w}_{iK}$ were obtained according to the preferences of each farmer using the Row Geometric Mean Method (RGMM) (Kallas and Gil, 2012). The estimate of priorities $\widehat{w}_{iK}$ as realized using the Super Decisions software designed to implement the AHP methodology. All judgments ($\hat{a}_{ijk}$) obtained from pairwise comparison led to the construction of a Saaty matrix for farmer k ($\hat{A}_k$) with dimensions (n x n = 4×4). Example of a Saaty matrix:

$$\hat{A}_k = \begin{bmatrix} a_{1.1k} & a_{1.2k} & a_{1.3k} & a_{1.4k} \\ a_{2.1k} & a_{2.2k} & a_{2.3k} & a_{2.4k} \\ a_{3.1k} & a_{3.2k} & a_{3.3k} & a_{3.4k} \\ a_{4.1k} & a_{4.2k} & a_{4.3k} & a_{4.4k} \end{bmatrix}$$

Based on the Saaty matrix, we estimated the relative importance (i.e. weights or priorities) of different actions using RGMM:

$$\widehat{w}_{ik} = \sqrt[n]{\prod_{i=1}^{i=n} \hat{a}_{ijk}} \quad (1)$$

The previously estimated values are normalized to one

$$\sum_{i=1}^{j=n} \widehat{w}_{ik} = 1 \quad (2)$$

Ad b. Examination and validation of the decision

In the verification phase, it is important to note that for each generated matrix, the consistency ratio (CR) of farmers' responses was calculated according to the corresponding mathematical expressions:

$$CR = CI/RI \quad (3)$$

Where *CI* is the consistency index obtained as:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

Where n is the number of alternatives and λ_max is the maximum value of the components of the vector obtained as:

$$\lambda_{max} = \Sigma_i \Sigma_j \hat{a}_{ijk} \widehat{w}_{ik} \quad (5)$$

RI is a random index, which was obtained by multiple random extraction of the Saaty matrix of size n x n (Table 1). A CR value lower than 10% indicates satisfactory consistency for pairwise comparisons (Siraj et al., 2015).

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Own processing based on Saaty (1994)

Table 1: RI index.

The level of risk posture is related to human behaviour, which is specific to each individual with decision-making authority. Individuals prefer options that provide greater utility based on their risk preferences (Brick et al., 2012). **The MPL method** or "lotteries" is used in the agricultural sector based on the expected utility theory u(x) and risk preference strength v(x) with a "real equivalent" used to measure risk attitudes (Pennings and Garcia, 2001). The MPL method allows identification of levels of tolerance or aversion to risk through a set of questions posed to decision-making individuals - in our case, farmers. We examined 8 scenarios with different lottery pairs, where the respondent chose one option (Option A or Option B). The degree of risk aversion is based on the number of safe answers (Option A) chosen by the respondent. A respondent who is risk-tolerant chose the safe option (Option A) only for the first and second scenario. A farmer who is neutral towards risk chose option A for the first to fourth scenario and option B for the remaining scenarios (Scenarios 5 to 8). A farmer with risk aversion chose option A for scenarios 1 to 7 and a farmer with extreme risk aversion chose option A for all 8 scenarios. In the given model, the safe option (Option A) corresponds to a 100% probability of success and the risk option (Option B) corresponds to a 50% probability of achieving success and a 50% probability of failure (based on a coin toss). The value of success provided by Option A gradually decreases.

Hypotheses analyzed

H1: The estimated preferences of farmers regarding adaptive measures and climate change adaptation measures (AHP method) were influenced by declared risk attitudes (MPL lotteries).

H2: The estimated preferences of farmers regarding adaptive measures and climate change adaptation measures (AHP method) were influenced by the socio-economic characteristics of the farm.

The above hypotheses were analyzed using the Kruskal-Wallis test. Which is non-parametric test used to determine whether there are significant differences between multiple groups based on a single dependent variable (Kruskal and Wallis, 1952). To test the chosen hypotheses, we therefore performed a separate Kruskal-Wallis test for each of the eight dependent variables, comparing multiple dependent groups (8 preferences) based on respondents' declared independent variables (risk attitudes and socio-economic variables). This allowed us to determine if there were any statistically significant differences between the groups in terms of their preferences for the selected measures, and whether these differences were influenced by their declared independent variables.

The test statistic for the Kruskal-Wallis test was calculated as follows:

$$Q = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{T_i^2}{n_i} - 3(n+1) \qquad (6)$$

- n is the total sample size in all groups
- n_i is the sample size for group i
- T_i is the sum of ranks for group i

The test statistic follows a X^2-distribution with degrees of freedom equal to the number of groups minus one (k-1), where k is the number of groups being compared. The p-value was then calculated from the X^2-distribution using the degrees of freedom and the calculated test statistic. If the p-value is less than the chosen significance level (set at 0.05), we reject the null hypothesis and conclude that there is a significant difference between the groups being compared.

Results and discussion

We utilized the AHP to identify farmer preferences and estimate the relative importance (i.e., priorities) of various adaptation and mitigation measures. Weights (i.e., relative importance) were estimated at the local (i.e., for each cluster from local weights) and global level (i.e., for the level of hierarchy from global weights). Based on the measure the respondent preferred, we identified the value of the relative importance of each measure. Table 2 shows the values of relative importance of specific adaptation and mitigation measures.

Cluster 1	
Adaptive measures	0.61
Mitigation measures	0.39
Cluster 2	
Adaptive measures	Value of relative importance
Investments to improve irrigation infrastructure	0.14
Changing production	0.18
Adapting the sowing calendar	0.29
Enhanced and resistant seeds/varieties	0.4
Cluster 3	
Mitigation measures	Value of relative importance
Organic farming	0.11
Limitation of soil tillage (Zero tillage management)	0.35
Use of renewable energy	0.24
Use of less polluting and energy-efficient machinery	0.3

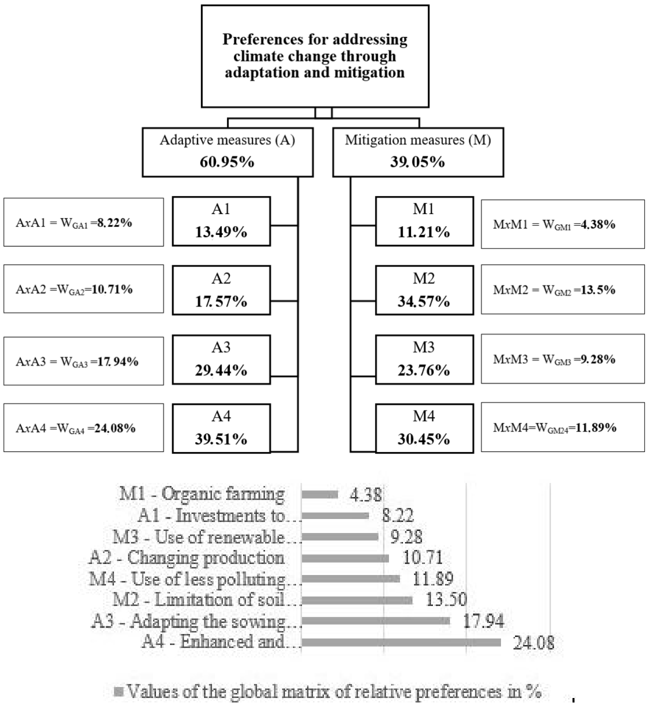
Source: Own processing

Table 2: Values of the matrix of relative importance of individual adaptation and mitigation measures AHP method.

The weights of relative importance of preferences in the matrix for adaptation measures reached a value of 0.60947, which, rounded to two decimal places, represents a preference level of 60.95%, and the preference value for mitigation measures 0.39053, which represents 39.05%. The estimated weights show that adaptation measures, as a whole, were considered more important and preferred by farmers. In the calculation of relative importance of preferences, we verified the consistency ratio within each cluster, according to the chosen methodology. The consistency value for pairwise comparisons of adaptation measures reached a value of 0.06827, which represents 6.82%. The consistency value is satisfactory, as it is less than 10%.

At the next level of our hierarchy, in cluster 2, the weights of relative importance of preferences for adaptation measures in the matrix reached the highest value for measure A4 - Use of new, improved, and resistant seeds, with a value of 0.39508, or 39.51%. The highest preference for this measure indicates that farmers see significant potential in enhancing crop resilience through genetic improvements. The second most preferred measure was A3 - Adapting the sowing calendar (29.44%). Farmers considered A2 - Changing production the third most advantageous measure among adaptation measures, this measure reached a preference value of 17.57%. The measure with the lowest preference value in cluster two was A1 - Investments to improve irrigation infrastructure (13.49%). This could suggest that farmers might perceive the cost of improving irrigation infrastructure as prohibitive, particularly for small-scale or financially constrained operations. Improvements to irrigation systems can involve significant capital expenditure, ongoing maintenance costs, and possibly higher water usage costs. The consistency value for pairwise comparisons of adaptation measures reached a value of 0.06827, which represents 6.82%. The consistency value is satisfactory as it is less than 10%.

In cluster 3, the most preferred mitigation measure was M2 - Limitation of soil tillage (Zero tillage management), with a relative preference value of 34.57%. This suggests farmers acknowledge the role of conservation agriculture in both preserving soil health and reducing carbon emissions. The use of less polluting and energy-efficient machinery – M4 being the second most preferred (30.45%) signals an interest in reducing the carbon footprint of farming operations. However, the lower preference values for the M2- use of renewable energy (23.76%) and M1- organic farming (11.21%) might indicate perceived barriers such as cost, lack of access to technology, or the need for substantial operational changes. The consistency value for pairwise comparisons of mitigation measures reached a value of 0.0975, which represents 9.75% and is also satisfactory.



Source: Own processing

Figure 4: Preferences for addressing climate change through adaptation and mitigation.

From the preference weights of adaptation and mitigation measures as a whole, we identified the value of global relative preferences for adaptation and mitigation measures based on individual farmer preferences. The use of new, improved, and resilient seeds, as a type of adaptation measure, is the most preferred measure among respondents (24.08%). Saad et al. (2022) in his research also recognizes the importance of genetic improvements for developing crops that can adapt to changing environmental conditions. The second most favored measure was the adjustment of the sowing calendar, garnering a preference of 17.94%. Limiting soil tillage, which serves as a mitigation measure, was the third most preferred strategy among our respondents with a 13.5% preference. Lal (2004), a prominent soil scientist, details how practices such as zero tillage can help sequester carbon in soils, which is an important strategy for climate change mitigation. The use of new, less polluting, and energy-efficient machines was the fourth most preferred measure in our study, aligning with a 11.89% preference. This supports findings from similar study made in Mexico from Torres et al. (2020) that suggests public policy should promote the use of less polluting and more efficient agricultural machinery because farmers preferred this measure and thus the positive results in context of climate change could be further intensified. This was followed by a change in production (10.71%), the use of renewable energy (9.28%), and investments in improving irrigation infrastructure with a global preference value of 8.22%. Organic farming was the least preferred option with a preference value of 4.38%, as shown in Figure 4.

The MPL results regarding the stated risk attitudes show that the majority of respondents have risk aversion, rounding to whole numbers, up to 53% of surveyed farmers. 36% of respondents have extreme risk aversion, 11% are neutral, and no respondent chose the risky option for the first two scenarios, so 0% of respondents are risk-tolerant.

All chosen hypotheses were tested using the Kruskal-Wallis test.

H1: Farmers' preferences for adaptation and mitigation measures are influenced by their declared risk attitudes.

The level of risk tolerance and respondent preferences regarding climate change adaptation and mitigation measures were subjected to analysis, based on which we found that risk attitudes and farmer preferences for adaptation and mitigation measures are not clearly related. The analysis performed did not reveal any significant relationship between preferences for adaptation and mitigation measures and the level of risk tolerance.

H2: Farmers' preferences for adaptation and mitigation measures are influenced by the socio-economic characteristics of the farm.

Various socio-economic characteristics and respondent preferences regarding climate change adaptation and mitigation measures were subjected to Kruskal-Wallis test analysis for the purpose of finding a correlation between individual socio-economic factors and preferences for measures. Specifically, we examined 3 factors, namely the level of agricultural education achieved, the type of legal entity, and the last examined factor was the existence of agricultural insurance.

Our analysis reveals a significant correlation between the level of education of respondents and their preferences for adaptation and mitigation measures in farming. Further, we discovered a significant relationship between the type of legal entity and farmers' preferences for adaptation and mitigation measures. Contrastingly, the analysis did not indicate a significant correlation between a farm's insurance status and preferences for adaptive and mitigation measures.

The finding that the most preferred adaptation measure among farmers is the use of new, improved, and resilient seeds is also in line with the results of other studies, which also found that crop breeding and genetic improvements are considered by relevant parties to be key strategies for adapting to climate change in agriculture. Mohd Saad et al. (2022) emphasizes the need for future crop improvement efforts to rely on integrated genomic strategies. They highlight the need to develop future crops that are highly resilient and adaptable to changing environments for maintaining global food security. Pourkheirandish et al. (2020) discusses the importance of development of climate change resilient crops, how advancements in genomics can transform plant breeding, and how such technology can help overcome the challenges posed by climate change.

In Europe's agricultural sector, the role of Genetically Modified Organisms (GMOs) remains a contentious issue, yet one that cannot be dismissed in light of the growing demand for climate-resilient farming practices. As highlighted by our study, the utilization of new, improved, and resilient seed varieties has been marked as a preferential adaptation strategy by farmers. Such approaches often involve genetically enhanced crops designed to resist drought, pests, and other environmental stressors, which are anticipated to increase under climate change scenarios. GMOs in this context may present a strategic tool to tackle these challenges and contribute to sustainable agriculture. The Nitra region, located in the southwestern part of Slovakia, is characterized by its fertile soil and a variety of crops such as wheat, barley, and sunflower, along with maize. Given the projected impacts of climate change, such as increased temperatures, altered precipitation patterns, and potentially more frequent extreme weather events, certain GMO crops might be beneficial for the region. Genetically modified (GM) crop that could potentially be suitable is GM maize. Maize is an essential crop for the region, and drought-resistant varieties of this crop could be advantageous in the face of climate change. According to the European Commission (2010), and others (Kvakkestad et al. 2003). Wheat is a staple crop in the Nitra region, and drought-tolerant GM wheat could potentially offer a useful adaptation strategy. Transgenic wheat varieties are being developed with enhanced tolerance to drought (Begcy and Dresselhaus, 2019). Given that water scarcity may become a critical issue due to climate change, such innovations could prove beneficial. Another important crop in the Nitra region is sunflower. GM sunflower varieties are being studied and developed, some with increased resistance to pests, others with enhanced drought resistance (Kiani, 2007). However, it is important to remember that the use of GMO crops must align with the strict regulatory guidelines imposed by the European Union and introducing GMOs into the environment also comes with potential environmental implications, such as impacts on biodiversity, are a primary concern (Hilbeck et al., 2015). Furthermore, socioeconomic implications such as potential inequality among farmers, with smaller farmers disadvantaged due to the high costs of GM seeds, is another significant issue (Stone and Glover, 2017).

Therefore, any introduction of GMOs in Slovakia - and European agriculture in general - should be carefully considered. Not only should the potential benefits regarding resilience to climate change be examined, but also the potential environmental, health, and socio-economic impacts.

We emphasize the importance of understanding the specific needs and constraints of farmers and adapting policies and interventions to meet these needs. Preference results may reflect insufficient awareness or understanding among farmers of the benefits of certain measures (e.g., irrigation infrastructure and organic farming) or the perception that their implementation is more challenging or costly than other measures.

The positive outcomes of our analysis suggest a connection between the level of agricultural education achieved and respondents' preferences for various adaptation and mitigation measures. This correlation could be due to the fact that individuals with a higher level of agricultural education may better understand the range of available adaptation and mitigation measures, along with their potential benefits and drawbacks. A respondent with a higher level of agricultural education is more likely to understand the potential benefits of selected measures and other sustainable farming practices, and therefore, is more likely to support measures that promote these practices. Another factor examined was the type of legal entity. This can be because the type of legal entity can be associated with differences in decision-making processes, priorities, and the availability of resources among different agricultural actors.

Over the years, the Common Agricultural Policy (CAP) has increasingly focused on environmental and climate protection. The new CAP for 2023 - 2027 sets adaptation in the agricultural sector as one of the main goals. Adapting to climate change has been elevated to a goal that needs to be addressed through strategic plans that member states had to develop. Slovakia's Strategic Plan for implementing the CAP for the period 2023-2027 also includes specific measures to support adaptation and mitigation in response to climate change. The plan recognizes the importance of climate change and its impacts on the agricultural sector and outlines specific measures to address this issue, such as: (1) Promoting the use of climate-friendly agricultural practices, such as conservation tillage and agroforestry, to improve soil health, water management, and biodiversity. (2) Supporting the development and use of precision farming technologies to reduce inputs and increase efficiency. (3) Supporting the implementation of agri-environmental measures that promote the protection and improvement of ecosystems and biodiversity. (4) Providing financial support for investments in agricultural enterprise infrastructure and equipment that enhance the resilience of agricultural systems to climate change, such as water management systems and renewable energy technologies. (5) Supporting the development of local food systems, which can help reduce the carbon footprint of food production and distribution by reducing the need for long-distance transportation.

In our recommendations, we focused on the most preferred measure and also took into account the results of our analysis, which indicate the existence of a correlation between the socio-economic characteristics of the respondent/farm and the degree of preference for adaptation and mitigation measures. Given these findings, we believe it is necessary to consider these specifics when selecting an appropriate policy measure and to influence the level of education and information of farmers. Equally important is considering the type of legal entity of the recipient. It is crucial to note that our survey, focusing on farmers in the Nitra region, was not representative of the entire Nitra region due to the sample size of respondents included in the study. Therefore, we must be aware of potential biases when interpreting the results. Nonetheless, the findings are valuable and useful for policymakers. As part of the AHP verification phase, we found it essential to test the consistency ratio of respondents' answers, and we subsequently included only those respondents in our study whose answers were satisfactory. Despite the results of the study not being generalizable to a larger population, they still hold significant informative value for the subjects included in the study.

Policymakers can incentivize climate-resilient seeds usage via subsidies, tax reliefs, or grants. However, alternative measures like education may be considered alongside to mitigate potential market distortions or disincentives for innovation. Arslan et al. warn that subsidies can lead to inefficiencies and can disincentivize innovation. In their study, they highlight the role of education in ensuring that subsidies lead to sustainable and efficient outcomes (Arslan et al., 2014). Offering education and training programs to farmers promotes the adoption of improved seed varieties is crucial. Workshops, conferences, and accessible resources enhance understanding and knowledge on seed selection, planting, crop management, and storage techniques, reducing post-harvest losses (Kibwika et. al., 2009). Educational initiatives can empower farmers with knowledge on sustainable practices, but financial incentives may be necessary to incite change (Prokopy et al., 2008).

The educational program should focus on seed education and be coupled with financial incentives. Success is context-dependent and ensuring wide access can be challenging. Technology, community collaborations, and direct farmer engagement can help extend education resources to remote areas. We advise focusing on education about resilient seeds, planting techniques, and crop management. We suggest implementing this measure alongside financial incentives, ensuring broad farmer access. Success depends on multiple factors, including context and current circumstances. The use of technologies like online courses, mobile apps, and video conferences can extend education resources to remote farmers. Collaborating with local communities in developing training programs ensures contextual relevance. We endorse a multifaceted approach involving technology, community programs, and direct farmer cooperation, to facilitate education and training access under diverse conditions.

Investing in research and development to create new seed varieties is also recommended. The development and use of these seeds should be accompanied by relevant regulations and safety assessments to minimize potential risks and ensure they promote fair and sustainable development. We recommend regionally-focused research to identify and create the most suitable seeds for specific climatic conditions.

Therefore, as a whole, the policy maker should prioritize policies and programs that encourage the adoption of climate-smart agricultural practices, while also providing farmers with informational support and financial protection against risks associated with climate change and the uncertainty of implementing a new measure.

Conclusion

This study advances the existing body of knowledge, offering crucial insights for policymakers who are seeking to refine support mechanisms for agricultural production in ways that align more closely with the needs and preferences of farmers. This alignment could potentially amplify the efficacy of such policies in promoting general welfare. Furthermore, it may guide public support towards prioritizing initiatives that foster the growth of more sustainable agricultural practices, both at the regional and national levels.

To combat the effects of climate change on agriculture, it's vital to implement mitigation and adaptation measures that resonate with farmers' interests and preferences. We focused on Nitra Region, one of the most productive agricultural areas, as our study region. Our findings show that the use of new, improved, and resistant seeds as an adaptation measure is the most preferred among respondents. Generally, farmers tend to favor adaptation measures over mitigation measures, as the benefits of the former are perceived to be more immediate.

Analysis of our hypotheses showed no significant relationship between risk attitudes and preferences for adaptation and mitigation measures, leading to the rejection of hypothesis H1. Our findings are in line with those of Jianjun et al. (2015), who used MPL and also found an unclear relation between risk attitudes and preferences for climate change adaptation and mitigation. Individuals who are averse to risk are usually inclined towards taking actions that prevent or protect against possible damages (Weber et al., 2002). Our study revealed that the majority of farmers in the region under investigation display a significant aversion to risk. This suggests a heightened readiness on their part to implement actions geared towards diminishing the impact of climate change, whether through adaptation or mitigation strategies. However, further analysis clearly showed that preferences were related to other socio-economic variables, specifically, the level of agricultural education of the respondent and the type of legal entity of the agricultural enterprise. There's a substantial body of research suggesting similar results that socio-economic factors, including level of education and type of agricultural enterprise, can significantly influence farmers' adaptation and mitigation strategies in response to climate change. Arbuckle et al. (2015) found that farmers with higher levels of education were more likely to acknowledge and respond to climate change, and were more willing to implement both adaptation and mitigation measures. Research also explores how different types of farming enterprises have different vulnerabilities and hence responses to climate change, based on their available resources, institutional frameworks, and social networks (O'Brien et al., 2007). Niles et al. (2013) also suggest that farmers' characteristics including their level of education and the type of their farm can influence their perception of climate policy risks and consequently their response in terms of adaptation and mitigation measures.

In conclusion, our research emphasizes the importance of understanding and addressing the preferences and needs of farmers in policy development. The success of climate change adaptation and mitigation in the agricultural sector heavily relies on well-established, flexible policies that are grounded in quality scientific research, consider various economic, social, and environmental factors, and are adapted to specific regional needs and circumstances.

Corresponding author:
Ing. Marianna Marčanová
Faculty of Economics and Management, Slovak University of Agriculture in Nitra
Trieda A. Hlinku 2, 949 76 Nitra, Slovakia
Phone: +421 907 213 402, E-mail: xmarcanova@uniag.sk

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Agriculture Data Platform – Institutional Data Repository – Selected Aspects

Michal Stočes, Jiří Vaněk, Jan Jarolímek, Vojtěch Novák, Jan Masner, Pavel Šimek, Eva Kánská, Martin Havránek, Karel Kubata, Vladimir Voral

Department of Information Technologies, Faculty of Economics and Management, Czech University of Life Sciences Prague, Czech Republic

Abstract

This paper presents selected aspects of a data platform to store agricultural data. It analyses the key user and system requirements for the data platform. The presented aspects were identified through a literature review, interviews and discussions with selected data experts and researchers and future users of the platform. The following issues of the data platform are discussed in the paper: architecture, data types, data source types, metadata, disciplinary interfaces, data sharing, data reusability, Open Science, FAIR data principles, and further data processing options. Part of the knowledge from this article was used in the design and implementation of the Institutional Data Repository called Data Management Platform (DaMP.) CZU (Czech University of Life Sciences Prague) (OPENAI, 2023).

Keywords

Data models, data modelling, metadata, data sharing, open science, FAIR data principles, data platform, agriculture data, life sciences, institutional data repositories, data process, DOI, FAIR data.

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Introduction

With the advent of new technologies, it is possible to share data easily and at a reasonable cost over the Internet around the world. The sharing of data in machine-readable formats was kick-started by the Open Data initiative (Stočes et al., 2018) (Marešová et al., 2019), which primarily aimed at publishing public sector data. The current trend is the concept of Open Science. The idea that scientific research should be free for all was popularised by Robert King Merton in the early 1940s. Data produced by research should be freely shared for the common good. (Merton et al., 1942) Open science has the potential to make the scientific process more transparent, inclusive and democratic and is increasingly recognised as a critical accelerator for achieving the Sustainable Development Goals and a true game changer in bridging gaps in science, technology and innovation and fulfilling the human right to science (Tzanova, 2020), (UNESCO, 2013).

The data is stored and made available through so-called data repositories. The current trend is to link national, thematic and other repositories using metadata catalogues so that data can be retrieved from one place (Thoegersen and Borlund, 2022). The issue of data sharing and repository creation, either at the national or scientific society level, is one of the European Commission's research and innovation strategies. This strategy is presented under the term European Open Science Cloud (EOSC) (Burgelman, 2021). In the Czech Republic, this issue is addressed by the project: the project for the creation of a modernised national large research e-infrastructure e-INFRA CZ, which is formed by a consortium of organisations CESNET, CERIT-SC and IT4Innovations.

In order to increase the reusability of scientific data, it is essential that the data is appropriately described with metadata and standardised. The FAIR Principles initiative addresses this issue. In 2016, "The FAIR Guiding Principles for Scientific Data Management and stewardship" was published in the journal Scientific Data (Wilkinson et al., 2016). The authors intended to provide guidelines for improving the discoverability, accessibility, interoperability, and reuse of digital assets. The principles emphasise machine action (i.e., the ability of computational systems to find, access, interoperate, and reuse data with little or no human intervention) as people increasingly rely on computational support to work with data due to the increase in the volume complexity, and speed of data creation. This methodological toolkit presents how to publish data based on fifteen principles in four groups: Findability (to be Findable), Accessibility (to be Accessible), Interoperability (to be Interoperable) and Reusability (to be Reusable). The FAIR principles are also reflected by science and research funders such as Horizon Europe, TAČR and others (Prodan et al., 2022).

The advent of innovative techniques and technologies to acquire data in the field of biology has brought the problem of how to effectively handle the acquired data. Communities have started to emerge in different scientific disciplines to create standards, regulations and ontologies for data handling. An example is the MIAPPE community (Papoutsoglou et al., 2020), which addresses the issue of data standards designed to harmonise data from plant phenotyping experiments. Other initiatives are addressing the issue of how to share data efficiently further. Examples include The Breeding API (BrAPI) project (Selby et al., 2019), an ontology-driven information system designed for plant phenotyping PHIS or the open-source ISA framework.

ISA's open-source framework and tools help to manage an increasingly diverse set of biological, environmental and biomedical experiments that use a single technology or combination of technologies. Built on the "Investigation" (project context), "Study" (unit of research), and "Assay" (analytical measurements) data models and serialisations (tabular, JSON, and RDF), the ISA framework helps you provide detailed descriptions of experimental metadata (i.e., sample characteristics, technologies and measurement types, relationships between samples and data) so that the resulting data and discoveries are reproducible and reusable (Sansone et al., 2012).

In Europe, the non-governmental ELIXIR (David et al., 2020) is the umbrella for activities dealing with bioscience data. ELIXIR brings together biological data resources, which include databases, software tools, training materials, cloud storage and supercomputers. The ELIXIR structure aims to coordinate these resources to form a single infrastructure. This infrastructure makes it easier for scientists to find and share data, exchange expertise, and agree on best practices. Ultimately, it will help them to gain new insights into how living organisms work.

Materials and methods

Building data repositories in organisations working with data reflects the current state of development in data management. Correct data management without tools to store and catalogue data is almost impossible. This paper presents selected aspects of data platforms. The article's authors are actively involved in developing the CZU institutional repository called the Data Management Platform CZU (Czech University of Life Sciences) (DaMP.) In the following sections, selected aspects and requirements for a data platform used to store scientific and research data from the field of agriculture in general from the Life Sciences will be presented.

The procedure for the development of this paper was as follows. The selected aspects presented were developed based on a thorough literature search of current knowledge in the field of data storage and sharing. In the second step, extensive interviews were conducted with scientific lawyers in the field of data sciences. The results were then complemented by interviews with future platform users - life scientists.

The scientific community perceives the need to manage data in a way that enables its reuse. The problem is the theoretical requirements arising from FAIR principles on the one hand and theoretical models and standards based on disciplinary needs on the other. According to a survey (Godem et al., 2022), 46% of biologists do not know how to organise data to reuse it. The object of the project application is to fill the identified research and technology gap, using data from the field of agricultural research and rural development as an example, e.g. crop production, hydrology, economics, etc. Based on the findings, general conclusions valid for other scientific fields will be formulated.

Results and discussion

The current state of data management

In discussions with members of the different scientific teams, it became apparent that there is a notable diversity in the approaches each group employs for data storage. The variations in data storage methods are quite substantial, ranging from the conventional use of USB flash drives to the utilisation of cloud drives and even the implementation of advanced and intricate storage systems. Each team has adopted a unique strategy tailored to their specific needs and preferences, showcasing the diverse landscape of data storage practices within the scientific community.

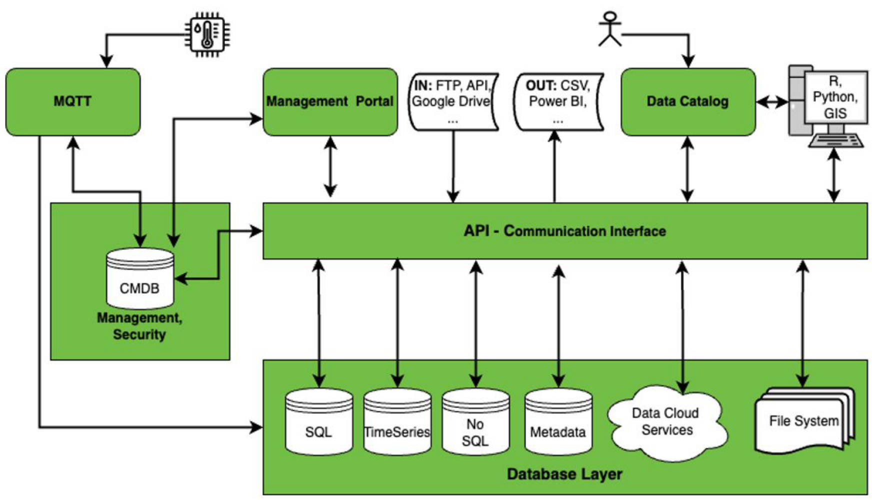
The following main issues were identified:

- Insufficient or non-existent backup procedures were identified as a prevalent issue during discussions with scientific team members. This vulnerability could potentially lead to data loss, highlighting the critical need for robust backup mechanisms.
- Another challenge raised was the inadequate description of data and the time-consuming nature of data retrieval processes. The lack of comprehensive data documentation could hinder efficient data management and retrieval, posing a significant obstacle to research progress.
- Regarding data protection, concerns were expressed about suboptimal measures in place, exposing valuable data to potential risks. Strengthening data protection protocols emerged as a priority to safeguard against unauthorised access or loss of sensitive information.
- Additionally, the difficulty encountered in sharing data with other scientific teams emerged as a noteworthy concern. The existing barriers to seamless data exchange underscored the importance of fostering improved collaboration and interoperability between research groups.

System architecture design

In the analysis of the system architecture, two key requirements were identified and defined: scalability and modularity. Scalability became a priority in view of future growth and increasing demands on the system. This requirement requires the system to scale efficiently and handle increased loads without loss of performance. The second important requirement is modularity, which emphasises a structured and hierarchical approach to system design. A modular architecture allows the separation of functionalities into separate and independent components, making it easier to maintain, extend and update the system. This feature also contributes to the system's overall flexibility, allowing adaptation to changes in requirements and technological environment. Meeting these two requirements together in architectural design is key to creating a robust and sustainable system capable of responding to current and future needs.

The main functional modules of the data platform were defined as data catalogues used for access to data. Database layer used to store heterogeneous data. Which are available through a single API (application programming interface) module. The management portal with the CMDB (Configuration management database) field controls data access through the catalogue and the interface, describing and configuring data sources and describing data collections with metadata. The MQQT broker is an entry point for messages sent by sensors and IoT devices. The modules and data flows of the proposed solution are presented in Figure 1.



Source: author

Figure 1: Data platform - modules and data flow.

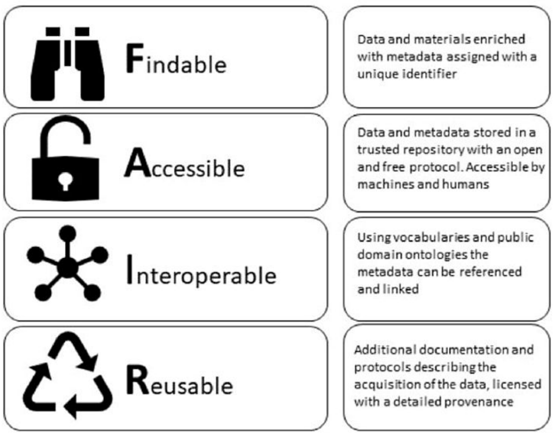
Data sharing

Based on a survey of users (data owners), a key need emerged to enable effective information sharing between different scientific teams. This requirement reflects the urgent interest in creating a mechanism to facilitate seamless data exchange between teams, thereby promoting mutual collaboration and synergy in research.

Given the diversity of scientific projects and the specialisms of the different teams, it proved crucial to ensure that the system allows flexible and secure sharing of data resources. In this way, scientific groups could enrich each other's knowledge and results, ultimately contributing to synergetic progress in scientific research.

Moreover, the emphasis on this need also reflects the importance of communication interfaces and standards that would allow interoperability between the different data systems used by the different teams. This would ensure that data sharing takes place efficiently and without loss of information value, although individual teams may work with various data formats and structures.

In response to the identified need for efficient data sharing between scientific teams, a solution was proposed that uses the principles of Findable, Accessible, Interoperable and Reusable (FAIR). This approach provides a framework for ensuring data findability, accessibility, interoperability, and reusability. Implementing FAIR principles ensures that data are systematically structured and described to make them easily locatable, accessible, and compatible with different systems. (Figure 2)



Source: Kalendralis at al.

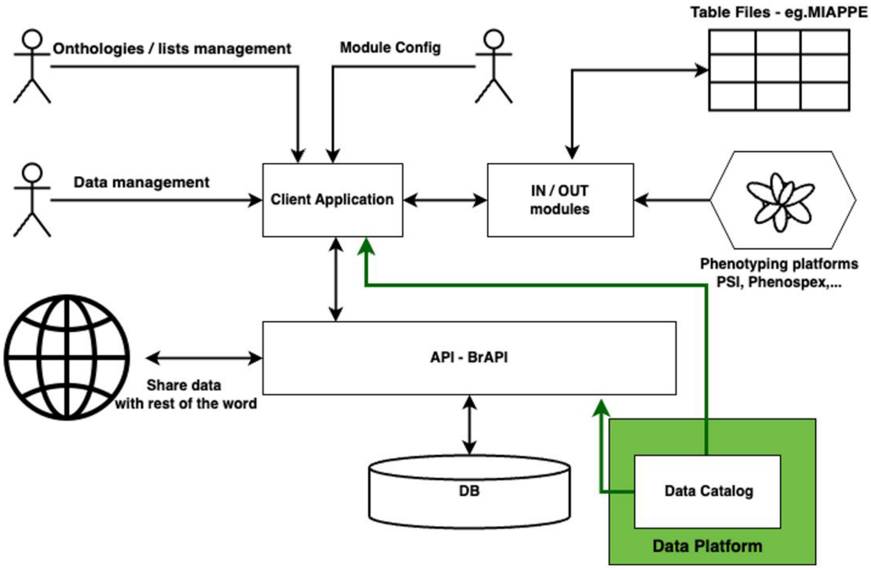
Figure 2: Schematic representation and description of the FAIR data principles..

Another key element of this solution is the use of a Digital Object Identifier (DOI), which is a standardised identifier that uniquely identifies a digital object, in this case, data. The DOI provides a unique and persistent reference to the data, increasing its citability and continued availability. This combination of FAIR principles and the DOI identifier thus strengthens the integrity, reliability and sustainability of data-sharing processes between scientific teams.

Standards for data harmonisation

Scientific information data harmonisation tools and frameworks are key in addressing several important data management challenges. One of the main challenges is the diversity of data formats and structures, which can complicate interoperability and information exchange between different scientific projects. These frameworks facilitate standardisation, providing a unified approach to defining schemas and metadata, eliminating differences and facilitating compatibility between different datasets. Another major problem that these tools address is the lack of a unified approach to data description and metadata. Metadata standards help to create a consistent and structured description of data, which simplifies the processes of finding, interpreting and managing information. This increases the transparency of scientific data and facilitates knowledge sharing among scientific communities. These frameworks and tools support a systematic and consistent approach to scientific data management, contributing to more efficient information exchange, reliable data analysis and overall higher-quality scientific research. The area of plant phenotyping was selected for further analyses in the area of data harmonization. Based on the analysis of the issue and interviews with plant scientists to further evaluate the MIAPPE and BrAPI data harmonisation guidelines and standards.

The following figure shows the connection scheme of the BrAPI module to the data platform modules (Figure 3).



Source: author

Figure 3: Diagram of a possible connection between the data platform and BrAPI.

Conclusion

The following requirements for the Data Platform can be defined from the results. As the data is acquired, it will be stored. This will create the so-called Row data, and then the processed data will be stored. This implies that the Data Platform "does not need to understand the data".

The platform development should be based on pilots' different data sources with data of different natures. The core data types from the agricultural domain are:

- Location data - GIS data
- Sensor data - time series
- Tabular data - e.g. csv format
- Data stored in the field interface
- Photographs, video recordings

Key types of data sources include

- IoT - data from IoT sensor networks
- REST-based interfaces
- Cloud-based file systems - primarily for initialising data retrieval.

The system for describing data with metadata needs to be made generic so that it is extensible and mappable to different data consumers in the future. The form of the metadata itself must allow the use of different data formats such as XML (Extensible Markup Language), JSON (JavaScript Object Notation) or YAML (Ain't Markup Language).

Other aspects, such as platform security, data backup and archiving, and API access to data, will be addressed in follow-up studies.

The aspects discussed in this article are mainly focused on scientific data from the field of agriculture - generally life sciences. However, similar principles can be implemented when analysing the requirements for a data platform for agricultural enterprises.

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Corresponding author:
Ing. Michal Stočes, Ph.D.
Department of Information Technologies, Faculty of Economics and Management
Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Prague - Suchdol, Czech Republic
E-mail: stoces@pef.czu.cz

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Digital Transformation of Agricultural Extension in Indonesia: A Comprehensive Analysis

Suswadi, Norbertus Citra Irawan

Agribusiness Department, Agriculture Faculty, Tunas Pembangunan University, Surakarta, Indonesia

Abstract

Digital transformation in the field of agricultural extension is quite essential for agriculture in the future. The problem is that not all extension workers understand the use of cyber extension. The research objective is to explore the relationship between individual motivation (IM), social capital (SC), digital extension adoption (CEA), knowledge sharing (KS), and agricultural extension performance (EP) in Indonesia. The research method used was explanatory, with purposive location selection and a population focused on agricultural extension workers. Sampling was carried out using quota techniques. Data analysis in this study used Structural Equation Modeling with Partial Least Squares (SEM-PLS). More specifically, IM and SC act as construct variables, while CEA and KS not only act as construct variables but also as mediators. Agricultural Extension (EP) performance is measured as a latent variable. The research results reveal that all construct variables, namely IM, SC, CEA, and KS, positively and significantly influence the EP. These findings demonstrate the importance of these factors in supporting digital transformation in agricultural extension in Indonesia and can provide valuable guidance for decision-makers and practitioners in efforts to increase the effectiveness of agricultural extension using digital technology.

Keywords

EU, Russian Federation, foreign trade, invasion, restrictive measures, sanctions.

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Introduction

Digitalization has changed agricultural extension communication and information services. To learn more about agriculture, extension workers must use digital tools. In terms of how to inform farmers effectively and efficiently about agriculture, digital consultation presents similar challenges. Next, extension workers cannot find reliable knowledge and information about the extension materials that farmers need to solve their farming problems. Extension workers cannot give farmers accurate information and make consulting services ineffective due to a lack of digital skills. Modern technology and media such as social media, mobile applications, and internet platforms can help farmers get the latest and most up-to-date information about farming and improve their skills. Extension workers must adapt to a quickly changing environment and learn digital skills to support farmers. Through the Ministry of Agriculture, the Indonesian government has implemented an agricultural information system by utilizing information and communication technology (ICT) to deal with one of the problems of disseminating agricultural information in the digital era. The Indonesian cyber extension (http://cybex.pertanian.go.id/) is an agricultural extension information system through internet media built to support the provision of extension materials and agricultural information for extension workers in facilitating the learning process of agribusiness extension workers, farmers, and entrepreneurs (Sabir et al., 2019).

Motivational and social capital problems may prevent Indonesian extension workers from adopting agricultural cyber extension technology (Pratiwi and Suzuki, 2017). The perceived usefulness, ease of use, and attitude of extension workers may significantly affect their willingness to adopt the technology (Saadé and Bahli, 2005). They may not adopt the technology if they are unsatisfied with it or find it helpful (Bermejo-Caja et al., 2019). Cyber extension technology adoption among extension workers may also be influenced by their social capital, which includes their network of contacts, their level of trust with one another, and the degree to which they share common beliefs and values (Delilah Roque et al., 2020). They may not adopt the technology if they lack peer trust or strong network ties (Freeman & Qin, 2020). Different norms and values between individuals who have accepted the technology and those who have not may also constrain adoption (Takahashi et al., 2020).

The motivation of extension workers is low, and they tend to be unwilling to adopt cyber agriculture extension (CE) technology, including a) Not having sufficient knowledge to operate the technology (Utami et al., 2019), b) Lack of motivation and support from local authorities (Norton and Alwang, 2020), c) Extension workers feel that they will not get good benefits from adopting the technology (Agussabti et al., 2022), d) Extension workers may not have enough money to adopt new technologies (Listiana et al., 2020), e) Extension workers may not receive sufficient assistance to understand and operate new technologies (Takahashi et al., 2020), f) Extension workers may have many other tasks to complete so they do not have sufficient time to adopt technologies cyber extensions (Kulikova, 2021).

There may be several obstacles in the way of extension workers in Indonesia adopting agricultural cyber extension technologies (Madonna et al., 2022). Cyber extension adoption depends on utilization, integration into work procedures, and technology proficiency (Cimini et al., 2020). Extension workers may not use the technology to its total capacity if they do not use it often or integrate it into their work routines (Steinke et al., 2021). Extension workers' knowledge-sharing frequency, quality, and reach may influence their performance (Wang et al., 2021). It may not improve extension performance if the information is given infrequently, inadequately, or to a small audience (Chandra-Mouli and Akwara, 2020). Thus, improving Indonesian extension workers' performance may require addressing these cyber extension adoptions and knowledge-sharing issues (Wijaya et al., 2019).

This article aims to find the nexus between individual motivation (IM), social capital (SC), cyber extension adoption (CEA), knowledge sharing (KS), and extension workers' performance (EP) as part of the digital transformation of agricultural extension in Indonesia through cyber extension.

Materials and methods

The basic research method used is explanatory, which is research that tests a theory or hypothesis. Explanatory research is chosen because the aim is to test theories or hypotheses, obtain information about things that are not yet known, gain a broad understanding of the topic, and produce new insights about phenomena. This method allows researchers to test existing hypotheses, obtain initial data, understand in depth the phenomenon being studied, and make a significant contribution to the development of knowledge about a topic.

The determination of research locations was purposive, namely in three provinces in Indonesia, which are food crop production centers, especially rice, and have implemented sustainable organic rice cultivation. Then, in each province, one regency was selected as the research location. The regency areas included Karawang (West Java Province), Sragen (Central Java Province), and Ngawi (East Java Province). This study uses five variables and 15 indicators described in Table 1.

The population in this study were field extension workers in the three selected regencies. Researchers have determined the number of samples in this study using quota sampling techniques with each regency of 50 people so that the total number of respondents was 150. The quota sampling method was chosen because it is easy to implement and manage, is suitable for research with time constraints, allows control of specific characteristics in the sample, can reduce research costs, and does not require absolute representativeness but rather the determination of cases or individuals based on specific reasons. The sampling technique in each regency uses simple random sampling.

Responses from respondents were arranged using a Likert scale where the values were 5 (strongly agree), 4 (agree), 3 (neutral), 2 (disagree), and 1 (strongly disagree). The use of the Likert scale was chosen because it is easy for respondents to understand, the data is easy to analyze and produces quantitative data, it can measure the level of intensity and variation in respondents' responses, and it is flexible to use in various types of questions and research topics.

The collected data were then analyzed using Structural Equation Modeling-Partial Least Square (SEM-PLS). Structural Equation Modeling-Partial Least Square (SEM-PLS) is a multivariate statistical analysis method that allows estimating complex cause-and-effect relationships in path models with latent variables. SEM-PLS uses a component

No	Variables and indicators		Explanations
1	*Individual Motivation (IM)*		
	IM1	Perceived usefulness	A belief that CE will work more efficiently and effectively (Ramayah and Lo, 2007)
	IM2	Perceived ease of use	Using CE is simple (Caffaro et al., 2020)
	IM3	Attitude towards techno-logy	Willingness to use CE technology, then understanding of its potential benefits and risks or related to an overall comfort level with its use (Tanveer et al., 2021)
2	*Social Capital (SC)*		
	SC1	Network ties	The extension worker's connections to other colleagues, farmers, and technology experts who can support the adoption and utilization of CE (Colussi et al., 2022)
	SC2	Trust	The extension worker's trust in their network and technology can impact their willingness to use CE (Fabregas et al., 2019)
	SC3	Shared norms and values	The extension workers and their networks promote integrity, respect for diversity, and lifelong learning, as well as quality client service, collaboration with other professions, and sustainable agricultural methods (Ertiaei et al., 2022)
3	*CE Adoption (CEA)*		
	CEA1	Usage behavior	They search for relevant content, participate in online forums and discussion boards, create and exchange files, and participate in virtual meetings to acquire information, share knowledge, and cooperate with other professionals (Bermejo-Caja et al., 2019)
	CEA2	Integration into work processes	The degree to which CE has been integrated into the extension worker's regular work processes and activities (Mapiye et al., 2021)
	CEA3	Level of proficiency	The level of skill and expertise the extension worker has in using CE can impact the effectiveness of their use of the technology (Maulu et al., 2021)
4	*Knowledge Sharing (KS)*		
	KS1	Frequency of sharing	The frequency at which extension workers share information, resources, and experiences related to the use of CE (Joshi and Dhaliwal, 2019)
	KS2	Quality of sharing	The extent to which the information and resources shared are relevant, accurate, and valuable to others in the network (Nayal et al., 2022)
	KS3	Reach of sharing	The extent to which the information and resources shared by extension workers are widely disseminated and used by others in the network, including other extension workers and farmers (Ortiz-Crespo et al., 2021)
5	*Extension Worker's Performance (EP)*		
	EP1	Efficiency	The time and effort needed to execute extension worker tasks and how cyber extension reduces these demands (Dharmawan et al., 2021)
	EP2	Effectiveness	The extension worker's ability to share information and resources with farmers and its effect on farmer knowledge and practices (Ayisi Nyar-ko and Kozári, 2021)
	EP3	Job satisfaction	How cyber extension affects extension worker job satisfaction (Listiana et al., 2019)

Source: Author

Table 1: Variables, indicators, and explanations.

approach that is different from the covariance-based approach in structural equation modeling, especially suitable for data that is not normally distributed and small sample sizes. It consists of a measurement model and a structural model and can be applied in various scientific disciplines. The software used in this research is SmartPLS.

The choice of IM and SC construct variables in research on the performance of extension workers using cyber extension mediated by CEA and KS has fundamental reasons. Individual Motivation helps understand the instructor's level of motivation in using technology such as cyber extension, while Social Capital reveals the influence of social interaction and social support on the use of this technology. The performance of extension workers is measured in terms of their effectiveness and efficiency in using cyber extension. Mediating variables such as CEA and KS help explain how individual motivation and social capital contribute

Direct Effect		Indirect Effect	
H1:	IM affects the CEA	H6:	IM affects the KS through CEA
H2:	SC affects the CEA	H7:	SC affects the KS through CEA
H3:	CEA affects the KS	H8:	IM affects the EP through CEA
H4:	CEA affects the EP	H9:	SC affects the EP through CEA
H5:	KS affects the EP	H10:	CEA affects the EP through KS
		H11:	IM affects the EP through CEA and KS
		H12:	SC affects the EP through CEA and KS

Source: Author

Table 2. The hypotheses.

to extension workers' performance through technology adoption and knowledge sharing. This mediation provides a more holistic understanding of the factors that influence extension workers' performance in adopting and utilizing cyber extensions.

Results and discussion

The relationship between individual motivation, social capital, cyber extension adoption, knowledge sharing, and extension performance can be analyzed using path analysis and partial least square (PLS) modeling output. PLS is a statistical method that can be used to examine the relationship between multiple variables (Purwanto and Sudargini, 2021) (Figure 1).

Path analysis will examine the relationships between individual motivation, social capital, cyber extension adoption, knowledge sharing, and extension performance. We were also determining how each variable affects the others. The output of the PLS model can then be used to estimate the strength and direction of these relationships and to identify the critical drivers of adopting and effectively using cyber extension by agricultural extension workers. The results of path analysis show the strength and direction of the relationship between IM, SC, CEA, KS, and EP variables. The results of all paths show positive numbers, meaning all relationships between IM, SC, CEA, KS, and EP, so the variables are positively related (Table 3). This relationship means positive feedback between the variables, where higher levels of one variable contribute to a higher level of the other and vice versa. This relationship can help support the extensive use and implementation of effective cyber extension by agricultural extension workers. It can lead to improved performance in using technology to support their work.

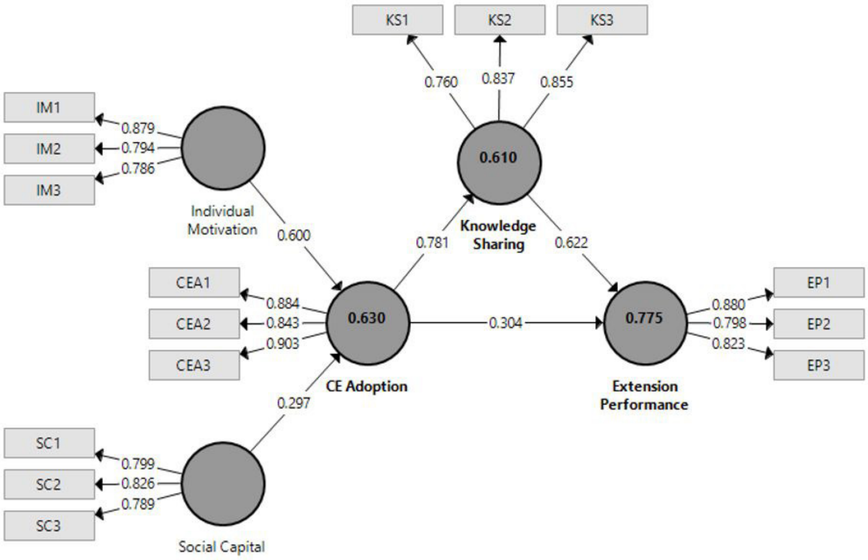
The construct's reliability, validity, and model accuracy must be tested to confirm the relationship between individual motivation, social capital, cyber extension adoption, knowledge sharing, and extension performance. Reliability can be verified by analyzing the consistency of the construct's results across time. At the same time, validity can be tested by comparing the results of the construct with existing theories and studies. Cross-validation, bootstrapping, and machine-learning algorithms can help researchers assess model accuracy. Interviews and surveys can be used to evaluate the construct's results. From the results of cross-loading, CA, rho_A, CR, AVE, and R Square, it is found that the relationship between these variables is quite strong (Table 4).

1. Individual motivation affects the agricultural cyber extension adoption

Based on Table 4, individual motivation elements like perceived usefulness, perceived ease of use, and attitude toward technology affect agricultural cyber extension adoption. Perceived usefulness means believing technology will improve job performance and make work easier. Agricultural cyber extensions can be used more if seen as beneficial. Perceived ease of use means technology is easy to use. Increased adoption of agricultural cyber extensions can also result from increased perceived ease of usage. Attitude toward technology is a person's overall positive or negative feelings toward technology. A positive attitude toward technology can boost the possibility of adopting agricultural cyber extensions.

2. Social capital affects the agricultural cyber extension adoption

Based on Table 4, social capital variables with indicators like network ties, trust, shared norms, and values affect agricultural cyber extension adoption. Network ties are people's connections and relationships with each other. An extensive social network can help disseminate information about emerging technology, such as cyber extensions for agriculture. Trust is the idea



Source: Author

Figure 1: Path model of the relationship between IM, SC, CEA, KS, and EP.

Var.	Ind.	Cross Loading					CA	rho_A	CR	AVE	R^2
		IM	SC	CEA	KS	EP					
IM	IM1	**0.879**	0.345	0.599	0.647	0.632	**0.756**	**0.755**	**0.861**	**0.673**	-
	IM2	**0.794**	0.354	0.633	0.570	0.665					
	IM3	**0.786**	0.544	0.612	0.681	0.546					
SC	SC1	0.395	**0.799**	0.401	0.424	0.438	**0.732**	**0.738**	**0.846**	**0.648**	-
	SC2	0.403	**0.826**	0.472	0.471	0.503					
	SC3	0.417	**0.789**	0.552	0.528	0.567					
CEA	CEA1	0.650	0.671	**0.884**	0.610	0.634	**0.850**	**0.850**	**0.909**	**0.769**	**0.630**
	CEA2	0.756	0.354	**0.843**	0.700	0.703					
	CEA3	0.569	0.563	**0.903**	0.739	0.736					
KS	KS1	0.559	0.525	0.598	**0.760**	0.565	**0.753**	**0.765**	**0.858**	**0.670**	**0.610**
	KS2	0.769	0.492	0.608	**0.837**	0.772					
	KS3	0.565	0.461	0.707	**0.855**	0.754					
EP	EP1	0.629	0.383	0.542	0.724	**0.880**	**0.781**	**0.781**	**0.873**	**0.696**	**0.775**
	EP2	0.581	0.696	0.788	0.740	**0.798**					
	EP3	0.671	0.480	0.623	0.677	**0.823**					

Test Type / Value	Value	Description
Cross-loading	If ≥ 0.7	Constructs have high validity and reliability
Cronbach's Alpha (CA)	If ≥ 0.7	Higher levels of coherence and consistency among items within a construct
rho_A	If ≥ 0.7	The construct accurately measures the latent construct, so it is reliable
Composite Reliability (CR)	If ≥ 0.7	The construct's items accurately and reliably measure the latent construct
Average Variance Extracted (AVE)	If ≥ 0.5	Observed variables measure latent constructs reliably and effectively
R Square	If ≥ 0.6	The independent variables effectively explain the variance in the dependent variable.

Source: Data processing

Table 3: Reliability and construct validity tests of IM, SC, CEA, KS, and EP variables.

that other people are reliable and can be counted on. People who trust each other may be more willing to share information and work together on adopting agricultural cyber extensions. In this context, "shared norms and values" are related to group members' accepted standards of behavior

Variable	Original Sample (O)	T Statistics	P Values	Sig.
Direct effect				
IM → CEA	0.600	7.387	**0.000**	***
SC → CEA	0.297	3.155	**0.002**	***
CEA → KS	0.781	27.986	**0.000**	***
CEA → EP	0.304	3.709	**0.000**	***
KS → EP	0.622	8.686	**0.000**	***
Indirect effect				
IM → CEA → KS	0.469	6.781	**0.000**	***
SC → CEA → KS	0.232	3.170	**0.002**	***
IM → CEA → EP	0.183	4.189	**0.000**	***
SC → CEA → EP	0.090	1.874	**0.062**	*
CEA → KS → EP	0.486	8.782	**0.000**	***
IM → CEA → KS → EP	0.292	4.759	**0.000**	***
SC → CEA → KS → EP	0.144	3.506	**0.000**	***

Note: Significance level: ***= 99%; **= 95%; *= 90%; ns = not significant
Source: Data processing output

Table 4. The direct-indirect effect path coefficient and hypothesis testing.

and attitudes. If everyone agrees on how important it is to use new technologies, like agricultural cyber extensions, that may make it more likely for them to be used.

3. Agricultural cyber extension adoption affects the knowledge-sharing

Table 4 shows how extension workers use and integrate cyber extension into their work can significantly affect how often, well, and widely they share knowledge. A high level of skill in cyber extension can lead to more efficient and effective information sharing, improving extension performance. Suppose cyber extensions are not popular. In that case, information exchange may be infrequent, low-quality, and reach only a tiny fraction of the community, which may reduce extension worker efficiency. Usage behavior, integration into work processes, and proficiency level can impact knowledge sharing among agricultural extension agents in Indonesia. Frequent sharing of information and best practices can increase awareness and understanding of the technology among individuals, leading to increased usage behavior and integration into work processes. As individuals adopt and become proficient in using technology, they can share their knowledge and experiences with others, leading to increased awareness, understanding, and adoption of technology in the broader network.

4. Agricultural cyber extension adoption affects the extension performance

Table 4 shows that agricultural extension workers' performance in Indonesia will likely affect their use of agricultural cyber extensions. How extension workers use these technologies, how well they fit into their work processes, and how well they know how to use them can improve their efficiency, effectiveness, and job satisfaction. For example, if they are better at using technology, they may be able to do their jobs more quickly. If they are better at integrating technology into their work, they may be able to do their jobs more effectively. Individuals proficient and confident in using technology are more likely to experience higher levels of job satisfaction, as they can perform their work more effectively and efficiently. Usage behavior, integration into work processes, and proficiency level can impact extension performance, including efficiency, effectiveness, and job satisfaction of agricultural extension agents in Indonesia. By adopting technology and increasing their proficiency, individuals can improve their efficiency, effectiveness, and job satisfaction, ultimately leading to a more prosperous and impactful extension program.

5. Knowledge sharing affects the extension performance

Based on Table 4, knowledge sharing, including frequency of sharing, quality of sharing, and reach of sharing, can impact extension performance, including efficiency, effectiveness, and job satisfaction of agricultural extension workers in Indonesia. Frequent sharing of information and best practices can increase awareness and understanding of essential concepts and strategies, leading to improved efficiency and effectiveness in extension work. High-quality knowledge sharing, with clear and concise information, can also increase an individual's confidence and ability to perform their work effectively. Extension work may be more efficient and effective if more people see and comprehend crucial information and tactics. Knowledge sharing provides high-quality information and best practices, which boosts workplace satisfaction and confidence. Sharing information and best practices improves efficiency, effectiveness, and work satisfaction, making extension programs more successful and influential.

6. Individual motivation affects knowledge sharing through agricultural cyber extension adoption

Based on Table 4, perceived usefulness, ease of use, and technological attitude can influence an individual's willingness and propensity to utilize and adopt cyber extensions in their work processes. This process can affect the frequency, quality, and reach of knowledge sharing between extension workers and other partners in the agricultural sector. The more motivated an extension worker is to use and adopt cyber extensions, the more likely they will share the knowledge they gain from using the technology with others in their network. Individuals becoming more proficient and integrating technology into their work processes may develop a more positive attitude towards technology, leading to improved extension performance. This convenience can make it easier for people to work together and share information, improving the extension worker's overall efficiency, effectiveness, and job satisfaction.

7. Social capital affects knowledge sharing through agricultural cyber extension adoption

Based on Table 4, "social capital" describes the strengths and opportunities that come from people's connections to and interactions with others. Social capital can play a role in influencing whether extension workers adopt and make use of agricultural cyber extensions. For example, strong network ties, a high level of trust, and shared norms and values can create a supportive environment that encourages the sharing of information and knowledge. Strong community networks and trust may help people adopt and use technology. People are more inclined to adopt technology if their community accepts and values it. On the other hand, insufficient social capital can make sharing knowledge harder to adopt and use agricultural cyber extensions effectively.

8. Individual motivation affects the extension performance through agricultural cyber extension adoption

Based on Table 4, an extension worker's decision to use agricultural cyber extensions can be affected by how helpful the technology is and how easy they think it is to use. Their productivity, effectiveness, and happiness on the job may all improve due to adopting this practice. For example, suppose an extension worker thinks a specific agricultural cyber extension is valuable and easy to use. In that case, they may be more likely to adopt and use it in their work. Technology users who have a positive attitude and see it as valuable and easy to use are more likely to adopt and employ it at work, improving productivity, effectiveness, and job satisfaction. Although intrinsic motivation is significant in determining extension success, other elements, such as technological expertise and how well it fits into existing work procedures, can also play a role. As people grow more adept and integrate technology into their work processes, they may become more positive towards technology, improving extension performance. After this integration, their work may become more efficient and effective, resulting in increased job satisfaction.

9. Social capital affects the extension performance through agricultural cyber extension adoption

Based on Table 4, social capital, which comprises network ties, trust, and shared norms and values, can significantly impact how extension workers in Indonesia adopt and use agricultural cyber extensions. Extension workers with more social capital may have more chances to get access to and make good use of these technologies. They may also be more likely to have a network of people who support them and can help them get through any problems they have with these technologies. Also, the network's shared norms and values can help build a culture of sharing knowledge and working together, making the extension workers more efficient and effective. Strong community relationships and trust may help people adapt and use technology, improving efficiency, effectiveness, and job satisfaction.

On the other hand, if social capital is low, it may be hard for extension workers to access and use these technologies, and it may be hard for them to share their knowledge, making them less efficient and effective. As people grow more skilled and integrate technology into their profession, they may create stronger network links and trust with others, increasing extension performance. Finally, social capital's impact on extension performance through agricultural cyber extensions depends on the situation and the social capital network's strengths and weaknesses.

10. Agricultural cyber extension affects the extension performance through knowledge sharing

Based on Table 4, when extension workers adopt agricultural cyber extension technology, they can access a broader range of information, resources, and tools to enhance their knowledge and skills. This increased knowledge can then be shared with farmers and other stakeholders through knowledge-sharing platforms like the agricultural cyber extension. Such platforms allow people in the agricultural industry to easily exchange ideas and practices and access information that can help increase agricultural productivity. Not only that, but they also provide resources accessed by extension workers to help farmers with everyday tasks, such as information, solutions, new techniques, and more. By exchanging data and information, these platforms used by extension workers can help farmers make better decisions, increase efficiency, and ultimately increase the profitability of their operations.

Through knowledge sharing, extension workers can improve the efficiency and effectiveness of their work, leading to better extension performance. For example, they can use the knowledge they have gained to design and deliver more targeted and relevant extension programs, leading to increased agricultural practices and technology adoption by farmers. This process can result in improved agricultural productivity, profitability, and sustainability, critical indicators of extension performance.

11. Individual motivation affects the extension performance through agricultural cyber extension adoption and knowledge sharing

Based on Table 4, the adoption of agricultural cyber extension can be influenced by several factors, including individual motivation, which can directly affect extension performance through usage behavior, integration into work procedures, and level of expertise with the technology. There is a correlation between the amount to which extension workers accept technology, how they feel about its effectiveness, and how easy they find it to use. Agricultural cyber extension, including usage behavior, integration into work processes, and proficiency level, can impact knowledge-sharing frequency, quality, and reach, impacting extension performance. Additionally, having a positive attitude about technology can motivate extension workers to become more competent in using the technology, which can contribute to improved overall performance. Individual motivation can also benefit extension performance by increasing the frequency, quality, and scope of information sharing among extension workers. Individuals who adopt and utilize technology may be more likely to engage in knowledge-sharing activities, leading to improved efficiency, effectiveness, and job satisfaction.

Technology can boost productivity, effectiveness, and job satisfaction if extension workers view it as valuable, easy to use, and have a good attitude toward it. As people grow more adept and incorporate technology into their work processes, they may regard it as more useful and easier to use, increasing motivation and extension performance. Technology can increase knowledge-sharing frequency, quality, and reach, improving efficiency, effectiveness, and job satisfaction.

12. Social capital affects the extension performance through agricultural cyber extension adoption and knowledge sharing

Based on Table 4, social capital can affect how effective those workers are at their jobs because of its effect on the use of agricultural cyber extensions and the spread of knowledge among extension workers. Strong network ties and high levels of trust within a community of extension workers might make it easier for information to be disseminated and exchanged, which can lead to an increase in the use of agricultural cyber extensions. Strong network relationships and trust can stimulate technology adoption and use, improving efficiency, effectiveness, and job satisfaction. Extension performance can increase if workers access more tools and resources more efficiently. However, the degree to which social capital influences extension performance may vary depending on factors such as the nature of the social capital in question (bonding, bridging, or linking) and the accessibility of other resources and technology. As people grow more adept and integrate technology into their work processes, they may build deeper network ties and trust with others in the extended community, improving extension performance. Technology can increase knowledge-sharing frequency, quality, and reach, improving efficiency, effectiveness, and job satisfaction. Frequent, high-quality social capital can improve knowledge sharing, efficiency, effectiveness, and job satisfaction.

Conclusion

In Indonesia, the success of agriculture extension workers is affected by various factors, including the workers' motivation and social capital levels, the adoption of cyber-based agricultural extension, and the sharing of relevant knowledge. There is a complex relation between individual motivation, social capital, adoption of agriculture cyber extension, sharing of knowledge, and performance of agriculture extension workers. Individual motivation and social capital are essential factors in adopting cyber agriculture extensions and their effects on agriculture extension workers in Indonesia. The adoption and utilization of agriculture cyber extensions can be affected by a person's level of motivation, such as the desire to improve skills and knowledge. Higher degrees of motivation were associated with better performance among agriculture extension workers; these workers were more likely to adopt cyber agriculture extension and contribute to knowledge sharing. Individuals with high levels of motivation are more likely to use cyber extensions and share their knowledge more actively, which can improve the performance of extension workers.

In the same way, the level of social capital, or the networks and trust between people, can also affect how these technologies are adopted and used. Substantial social capital, seen in network ties, trust, and shared norms and values, can also make it easier for people to use cyber extensions and share knowledge more often, better, and further. Also, social capital positively affected agriculture extension workers' performance. The consequences of this action are because those with higher levels of social capital were more likely to teach other farmers and use cyber agriculture extension.

Agriculture extension worker performance was linked to agriculture cyber extension and knowledge sharing. Those who used agriculture cyber extension and shared their knowledge were likelier to do well than those who did not. Adopting cyber agriculture extensions can significantly affect how people share information and how well extension workers do their jobs. When extension workers have access to and know how to use these technologies, they can share information with others in their network more efficiently and effectively. Improvements in productivity, output, and employee satisfaction can be attributed to these alterations for the extension workers. So, we can say that individual motivation, social capital, adoption of agriculture cyber extension, and sharing of knowledge are all linked to the performance of agriculture extension workers in Indonesia.

Research recommendation focuses on social capital because it is crucial to improving agricultural cyber extensions, information exchange, and agricultural extension worker performance in Indonesia. Social capital, or the resources and advantages of social networks, has been shown to boost the adoption of new technology and extension services. Extension workers can share information and build social capital by networking. This relationship can create a supportive workplace, motivating and engaging workers. Training programs for agricultural extension workers should focus on networks and social relationships to enhance social capital benefits. This relationship makes it easier for workers to work together, share information, and use new technology and best practices. By sharing information and the best ways to do things, Extension staff can learn about new technology and how to use it. This relationship fosters trust, a friendly environment, and employee engagement. By stressing social capital in agricultural extension and encouraging knowledge and resource sharing, Indonesian extension workers can adopt agricultural cyber extensions and perform better.

Future research based on individual motivation, social capital, agriculture cyber extension adoption, knowledge sharing, and agriculture extension worker performance in Indonesia, with an emphasis on social capital, includes: a) Studying how social capital, education, experience, and technology skills affect the adoption and usage of agricultural cyber extensions, b) Investigating social capital's role in agricultural innovation and extension worker performance, c) Investigating social capital's long-term impact on agricultural cyber extensions, and d) Assessing social capital-building and agricultural cyber extension strategies and programs. These opportunities for future research can give valuable information about the relationship between social capital, the adoption of agricultural cyber extensions, the sharing of knowledge, and the performance of extension workers. Research candidates can also help design policies and programs based on evidence to help Indonesian extension workers adopt and use agricultural cyber extensions.

Corresponding author:
Suswadi
Agribusiness Department, Agriculture Faculty, Tunas Pembangunan University
Surakarta Jalan Balekambang Lor No 1 Manahan Banjarsari 57139, Indonesia
E-mail: suswadi@lecture.utp.ac.id

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